



ANTICOAGULANT RESISTANCE IN THE NORWAY RAT AND GUIDELINES FOR THE MANAGEMENT OF RESISTANT RAT INFESTATIONS IN THE UK

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1. Background, history and development of resistance

The introduction of the anticoagulant rodenticides and their use.

The development of the anticoagulant rodenticides in the early 1950s revolutionised rodent control. Up to this point the limitations of the acute rodenticides had made it virtually impossible to achieve a complete clearance of a rodent population and repeated applications of acute rodenticides to rapidly recovering and “bait shy” rodent populations were required. The “chronic” anticoagulant rodenticides revolutionised rodent control and, for the first time, complete control of target rodent populations was possible and practical.

The main reason why the anticoagulants work so much better than the alternative acute rodenticides is that they are slow-acting. Minimum time to death is two to three days, with average times to death being four to eight days. In some cases death may not occur for 14 days. This enables the rodents to keep feeding on the anticoagulant rodenticide baits until a lethal dose has been consumed. If other aspects of the rodenticide treatment have been conducted correctly, then

100% mortality can be achieved. The essential elements of a chronic rodenticide treatment are to ensure not only that the baits are placed

correctly, as would be a requirement for any rodenticide treatment, but that the rodents in an infestation are able to feed on the anticoagulant baits on a daily basis, possibly for several weeks, even though the daily consumption of bait may be very low. This is termed “surplus” or “saturation” baiting. It is essential that the baits are visited and replaced frequently, daily if necessary.



The first of the anticoagulants to appear on the market in the early 1950s was warfarin. Within a few years additional anticoagulants were available in the UK, including diphacinone, coumatetralyl and chlorophacinone. These are now collectively known as the “first-generation anticoagulants”. They all have broadly similar levels of toxicity to the commensal rodents, although there is some variation between them in their toxicity to other species.



Produced by the Rodenticide Resistance Action Group

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You can find out more about RRAG at www.bpca.org.uk/RRAG.

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Development of anticoagulant resistance

early anticoagulants was not maintained. Resistance not only to warfarin but to all the first-generation compounds was detected in the UK in some Norway rat and house mouse populations by the late 1950s and early 1960s.

The first documented case of anticoagulant resistance was identified in 1958 during a routine field trial of diphacinone on a pig farm in central Scotland. Following an initial knockdown, the survivors were not controlled after a 30-day exposure to diphacinone and a subsequent baiting of 18 days using warfarin. Laboratory feeding tests carried out in Scotland, and at the MAFF laboratories in Tolworth, gave a survival rate of almost 90%. The infestation was eliminated by April 1959 but by September 1961 the farm was again reported to be heavily infested with rats. During this period tests were carried out at many sites where resistance was suspected or reported but in almost all cases the reason for lack of control was found to be poor technique. By 1962 resistance had been confirmed by field trial and laboratory tests at seven sites within an area of 200 square kilometres. Following the warfarin treatments, survivors were eradicated using the acute rodenticides, zinc phosphide; arsenious oxide and ANTU, or by trapping. Although subsequent checks after six to nine months identified a low level of rat activity, this was thought to be as a result of animals surviving the treatment rather than reinfestation. These acute rodenticides are no longer available and, while it is unlikely that this level of commitment would be practicable today, it did demonstrate the benefit of good control in the management of resistant rats.

In 1960, resistance was identified in the Anglo/Welsh border area based around Welshpool and Shrewsbury. In an attempt to curb the spread of the outbreak, a cordon sanitaire using acute poisons was set up. This was relatively unsuccessful and was abandoned in 1966. Detailed monitoring of this Welsh

“The first documented case of anticoagulant resistance was identified in 1958 during a routine field trial of diphacinone on a pig farm in central Scotland.”

resistance showed that it spread radially at about 4.8 km per year. Subsequently, resistance was identified in the Kent/Sussex border areas of southern England and then in Hampshire. Although Norway rat resistance to the first-generation anticoagulants was found first in the United Kingdom, it was subsequently identified in many other industrial countries. Whilst resistance may be present in some areas this does not mean that it is present in all areas.

The development of resistance encouraged the search for more potent anticoagulants that could be used to control the resistant populations. In the early 1970s, difenacoum was marketed and effectiveness against resistant populations of both Norway rats and house mice was claimed. At about the same time, bromadiolone was developed with similar claims.

Resistance to the second-generation anticoagulants.

Difenacoum and bromadiolone were called “second-generation anticoagulants”. Both however required application using the saturation or surplus baiting techniques discussed earlier. Within a few years of the arrival of difenacoum and bromadiolone on the market, populations of Norway rats resistant to either difenacoum or bromadiolone, or both, were being identified, particularly in central southern

England. Subsequently, individual sites with resistance to either difenacoum and/or bromadiolone were identified during the 1980s and 1990s in a number of areas including East Anglia, Yorkshire and Lincolnshire.

The development of the more potent second-generation anticoagulants, brodifacoum and flocoumafen, provided the opportunity to use an alternative baiting strategy. The new strategy has been termed “pulsed” baiting. In practice this

simply means that the higher toxicity of these compounds allows some flexibility with the bait application regime. Visits to replace baits may be made less frequently, perhaps at weekly intervals, and the quantity of bait placed can be reduced. The increased toxicity of the later anticoagulants may result in faster control. However the minimum time to death and average time to death of individual rats remains the same as for the first-generation anticoagulants. The time taken to control the typical Norway rat infestation with these compounds is about 14-28 days.

The increased toxicity of brodifacoum and flocoumafen brought with it a perceived increased risk to non-target species and, until recently, these two active substances could only be applied indoors, virtually precluding their use against rats in resistance management. A third potent second-generation compound, difethialone, has also been developed and introduced, and was similarly restricted to indoor use.

2. Definitions of resistance

The following general definition of anticoagulant resistance was proposed in 1994 by Dr John Greaves and is now widely used:

“Anticoagulant resistance is a major loss of efficacy in practical conditions where the anticoagulant has been applied correctly, the loss of efficacy being due to the presence of a strain of rodent with a heritable and commensurably reduced sensitivity to the anticoagulant.”

Some other terms are also used in relation to the resistance phenomenon:

Resistance factors – the factor by which the dose of rodenticide required for a susceptible rodent population must be multiplied to achieve the same effect in a resistant rodent population.

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Technical resistance – this term is used in cases where resistance tests identify resistance but where resistance factors are low and the resistance has no observable practical effect.

Practical resistance – this term is used in cases where resistance tests identify resistance and resistance factors are sufficiently high so that an acceptable level of control is unlikely to be achieved.

Metabolic resistance – this is a form of resistance not conferred by a mutation in the VKORC1 gene (see table 1). Instead modified enzymes permit animals that possess this resistance to break-down and/or eliminate anticoagulants from the body more quickly and efficiently than normal.

3. General resistance strategy. Integrated Pest Management

The control of rat populations should never rely upon the use of chemical control measures alone. It is essential that an integrated pest management (IPM) programme is implemented. When dealing with resistant rat populations it is more important than ever that such procedures are followed.

In addition to the use of chemical control measures, an IPM programme against a resistant population of rats will utilise the following:

- Trapping
- Environmental and habitat management (restriction of access to food, water and harbourage)
- Proofing, exclusion and restriction of movement.

Further reference to the use of these procedures may be found in a variety of publications (see Further Reading).



4. DNA testing for anticoagulant resistance

General

Until relatively recently, deciding whether a rat was resistant to anticoagulants or not depended on catching it alive and using one of several expensive and time-consuming laboratory tests. Needless to say these tests were not much used as they were largely impractical for routine resistance monitoring. But recently researchers in Germany led by Dr Hans-Joachim Pelz made a critical break-through. They identified which part of the genetic code of rats and mice carried the DNA sequence, or gene, which alters when rodents become resistant to anticoagulants. The gene they discovered affects the enzyme vitamin K epoxide reductase, a crucial enzyme in the vitamin K cycle and the one blocked by all anticoagulant rodenticides. The gene was given the name VKORC1 and the sequence of chemicals (nucleotides) used in its construction was decoded.

Knowing the gene's DNA sequence, it became possible for the first time to look for changes, or mutations, which resulted in anticoagulant resistance in rodents. Pelz, and his many co-workers, went on to study the amino-acid sequence of the VKORC1 gene from Norway rat and house mouse resistance areas in Germany, France, Denmark and the UK. In a bench-mark paper published in 2005 in the journal *Genetics* they showed there were many different mutations of the gene. A fascinating pattern began to emerge. Anticoagulant resistance in Norway rats had evolved many times over the years, with different mutations in different places. But occasionally the same mutation was found in rats from different countries indicating either that the same mutation emerged several times or that the rat populations developed from the same original stock.

Often, much-heralded scientific advances offer little practical benefit to pest control technicians. But few have not found a troublesome rodent

infestation and wondered whether anticoagulant resistance was the cause. In the past, wondering was usually as far as it got as resistance testing was so expensive and took far too long. Scientists in the UK now have the capacity to conduct routine DNA anticoagulant resistance assays. These scientists include Dr Colin Prescott (University of Reading), a member of RRAG, and his co-workers who provide resistance monitoring and mapping information. To be able to say if the rodent is resistant or not, these tests require only the tip of the tail, which can be sent in the post. A sensible sample size would be 10 – 20 tails. So the common question "have I got resistance?" can now be answered. This new DNA technology holds great promise. Not only will it enable more effective rodent control in problem areas, but it will allow us to make more effective use of existing anticoagulants.

Collection of tissue sample for DNA extraction

Before collecting samples for DNA analysis it is advisable to contact the laboratory to which the samples will be sent to obtain instructions about rat trapping and sample collection. The following paragraphs provide outline guidance. The tissue sample to be collected will be the 2cm tip of the rat tail. The samples should be collected from Norway rats that have been dead for less than 24 hours. When possible the tail tip should be immediately transferred into clean small plastic or glass collection tubes that contain a small volume of alcohol (surgical spirit). The sample tubes should then be stored in a freezer (at -21°C) as quickly as possible, and no longer than 4 hours after collection.

If these arrangements are not possible the tail tip may be sent as rapidly as possible to the laboratory dry in a sealed polythene bag. Successful DNA extraction and sequencing may be somewhat less likely in these circumstances but useful information may be obtained.

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Care should be taken to clean instruments that are used to take the tail sample before and after each collection, to ensure that there is no cross-contamination of DNA between samples. This could involve thorough cleaning with a tissue drenched with surgical spirit. Surgical spirit is available from all chemists, and contains ethanol to which a small amount of methanol has been added to render it unfit to drink. It is used to sterilize surfaces and to cleanse skin abrasions and sores.

Interpretation of DNA sequencing results

The information obtained from the DNA analysis of rodents requires careful interpretation. The following paragraphs provide information that will support better understanding of analytical results and allowed reasoned decisions to be made about actions to be taken at sites where resistance is discovered.

Homozygous and heterozygous

The genetic code of all advanced animals is made up of two sets of genes, one obtained from the mother and one from the father. If the two genes carried by an individual for a particular characteristic, such as susceptibility to anticoagulants, are the same, the individual is said to be

“homozygous”. If the genes are different, the individual is said to be heterozygous. If the genes are different then the actual characteristic possessed by the individual will depend on which of the two genes is dominant. Heterozygous resistant animals may be somewhat less resistant than those that are homozygous.

Incidence of resistance

The actual degree of resistance shown by rodent populations will depend on the type and frequency of the resistance gene in the population. If DNA tests show that a population has a high proportion of animals carrying the resistance gene (i.e. a high incidence), and a high proportion of those are homozygous resistant animals, then we might expect that the resisted compound(s) will be largely ineffective against that population. Conversely, if the resistance gene is very rare in the population, and those animals that carry it are mainly heterozygous, the resisted compound(s) would be largely effective. However, when resisted compounds are used against populations where a resistance gene is present, even at a low incidence, the animals carrying the resistance gene have a selective advantage. Those animals will

be more likely to survive and breed, while the susceptible animals will die. Consequently, the incidence of resistance in the population will increase until, eventually, control problems may occur.

Norway rat resistance strains were formerly named after the areas in which they were first found. However, we now know that these strains are much more widespread and old names, such as Welsh and Scottish resistance, are no longer useful. They will now be named using the abbreviated form of the genetic mutation (Table 1). Only those five resistance strains known in rats to exert a significant detrimental effect on the efficacy of rodent control operations will be discussed further here in detail. For more detailed information about where resistance mutations can be found visit the RRAG web-site at: bpca.org.uk/rrag. However, please note that the apparent absence of resistance from any area may be due to a lack of samples from the area in question and may not indicate that all animals in the area are susceptible.

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Table 1.

VKORC1 mutations in Norway rats (NR) in UK.

Major resistance mutations with known practical consequences shown in bold.

Mutation.	Abbreviations.	Where present.
Leucine128Glutamine	L128Q†	Scotland, parts of NW and NE England
Tyrosine139Serine	Y139S†	Anglo-Welsh border
Leucine120Glutamine	L120Q†	Hampshire, Berkshire and elsewhere
Tyrosine139Cysteine	Y139C†	Gloucestershire, Norfolk, Lincoln-shire, Yorkshire, SW Scotland, Anglo-Welsh border and elsewhere
Tyrosine139Phenylalanine	Y139F†	Kent, Sussex and elsewhere
Argenine33Proline	N33P‡	Nottinghamshire
Phenylalanin63Cysteine	F63C*	Cambridge/Essex
Tyrosine39Asparagine	Y39N*	Cambridge/Essex
Alanine26Threonine	A26T#	Cambridge/Essex
† Known either from field experiments and/or field experience to have a significant practical effect on antico-agulant efficacy. ‡ Known from laboratory experiments to confer warfarin resistance. * Shown in laboratory experiments to have a significant impact on protein function. # Unlikely to confer any significant degree of resistance.		

5. Managing rats carrying the main resistance mutations

L128Q (formerly “Scottish resistance”)

This mutation is the one found at the site of the first occurrence of anticoagulant resistance in Scotland. It has subsequently been found in rats from the North-west of England and from Yorkshire. It was also present in a sample of rats taken for DNA resistance testing in France. The gene is known to confer strong practical resistance to warfarin and diphacinone. Coumatetralyl may still retain some effectiveness against rats that carry it although efficacy is somewhat impaired. Second-generation anticoagulants are normally fully effective against this strain.

Y139S (formerly “Welsh” resistance)

Resistance was found in a large focus on the Anglo-Welsh border centred on the town of Welshpool soon after

the original discovery in Scotland. Welsh resistant rats are now known to carry the Y139S mutation. To date this mutation has only ever been found in the original focus, although the extent of its spread is now unknown. However, it is likely to be present over much of the Anglo-Welsh border, especially around the towns of Welshpool, Oswestry and Shrewsbury, and to have spread eastwards into the West Midlands.

Welsh resistant rats have very high resistance factors to the first-generation anticoagulants and these compounds are virtually ineffective against them. Before the second-generation compounds were introduced, coumatetralyl had some limited effect against Welsh resistance but is not now recommended for use at this focus. The second-generation compounds are effective against Welsh resistant rats. However, bromadiolone is likely to be the least effective compound and is probably best avoided.

Y139C (formerly “Gloucestershire” resistance)

The resistance in rats which has been present for decades in Denmark and North-west Germany is caused by this resistance mutation. Recently, DNA testing in the UK has discovered rats from the counties of Gloucestershire, Yorkshire, Lincolnshire, Norfolk and elsewhere that carry this mutation. The occurrence of this resistance mutation has been recently recorded on the Anglo-Welsh border in the area previously thought to contain only the Y139S resistance mutation. The resistance in Gloucestershire is long-standing, although not much researched, and therefore this type of resistance in the UK had been called “Gloucestershire” resistance. Y139C mutation has probably been elsewhere in the UK undetected for many years. Few trials have been conducted in the UK against this strain and most of

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what we know about it comes from trials in Denmark and Germany. This mutation confers strong practical resistance against the first-generation anticoagulants. However, field trials of coumatetralyl conducted in Germany against populations containing some Y139C rats resulted in a degree of success, but not full population control. This strain shows some resistance to the second-generation anticoagulants, particularly where populations contain a high percentage of resistant animals and homozygous animals are frequent. The efficacy of bromadiolone particularly is poor against animals carrying this mutation and, although difenacoum is generally more effective, complete infestation elimination may be difficult even with that compound.

Although products containing either bromadiolone or difenacoum may be effective in Y139C areas under some circumstances their continued use will lead to the spread of resistance and increases in its severity. Therefore populations of Norway rats carrying this mutation are best treated with products containing brodifacoum, difethialone and flocoumafen, where permitted by product labels. [Recent field trials in Germany showed that the former compound is fully effective against these rats.]

L120Q (formerly “Hampshire” and “Berkshire” resistance)

A third major resistance focus discovered in the UK was in Hampshire, with some farms over the border in south Berkshire also having this resistance. It was known in early research papers as “difenacoum resistance” but the strain shows resistance to other compounds as well. Resistant rats from this focus carry the mutation L120Q. The term “Hampshire resistance” was commonly used when referring to this strain in order to make it clear that rats there are not only resistant to difenacoum. However, the strain is now widely referred to as L120Q.

This resistance focus has been the cause of considerable discussion for some time because research work provided inconsistent results. In particular, the significant degree of resistance seen in early field trials was not supported by laboratory studies, which showed quite low resistance factors among Hampshire rats, for both difenacoum and bromadiolone. It was later postulated that a reluctance to take poisoned baits, which was sometimes very pronounced in the area, exacerbated the resistance problem and this has since been confirmed. Practical experience in the Hampshire focus has shown that bromadiolone may be more effective than difenacoum in this area.

Some time after the initial discovery of “Hampshire resistance”, rat infestations were identified in north-west Berkshire that were even more resistant to difenacoum and bromadiolone. In the laboratory, some of these rats were found to survive a seven-day feed on low-strength brodifacoum bait (5ppm or 0.0005% - a tenth of field strength), and these individuals were said to possess “low-grade brodifacoum resistance”. However, as full strength brodifacoum baits are usually fully effective against these animals, this low level of resistance is “technical resistance” and not “practical resistance”.

Subsequent field trials against a rat infestation in an area northwest of the town of Newbury, showed for the first time that there was full-scale “practical resistance” to the second-generation anticoagulant bromadiolone, with a high likelihood that difenacoum was also fully resisted. The type of resistance in this area became known as “Berkshire resistance”. A difficulty in interpreting the results of resistance tests of rats from this area is that both Hampshire and Berkshire resistant rats carry the same mutation (L120Q). The genetics of this situation remains in question, although it has been shown by research conducted in France that Berkshire resistance is conferred by the presence

of the L120Q mutation, as well as an additional level of resistance provided by enhanced clearance of the rodenticides by special enzymes (metabolic resistance).

What can we say with confidence about the use of rodenticides in this area? Firstly, resistance is such that the first-generation anticoagulants are broadly ineffective. Secondly, that bromadiolone is more likely to be effective than difenacoum in some parts of this resistance focus. However, there is growing practical experience that, in some parts of the focus it is very likely that both bromadiolone and difenacoum are largely ineffective. A recent, carefully-monitored practical treatment has shown that brodifacoum is fully effective against L120Q rats. Previous treatment records at the site, showing the complete failure of difenacoum and bromadiolone baits, suggest that the resistance there was of the Berkshire type.

L120Q rats are now to be found across much of central-southern England. There are also populations with this mutation in apparently isolated pockets elsewhere in the country. All infestations present in areas that contain L120Q rats should only be treated with products containing the compounds brodifacoum, difethialone or flocoumafen, where permitted by product labels.

Y139F (formerly “Kent” resistance)

Anticoagulant resistance was found in Kent in 1968 and surveys conducted between then and 1972 found resistant rats across a substantial part of west Kent and eastern Sussex, from the Thames estuary to the south coast. Little was heard subsequently from this focus until a recent report of the failure of rodent control on animal-rearing facilities in the centre of the resistance area identified earlier. DNA analysis of rats taken from the site revealed the mutation Y139F for the first time in the UK. This is one of the most common resistance mutations found in France

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and it also occurs in Belgium. Limited published information is available on the level of resistance to anticoagulants conferred by this mutation, and none is available from the UK, but published reports from the continent suggest that bromadiolone is less effective than difenacoum against this strain. Indeed, the former was the active substance which was found to have failed in the recent (2009) reports from Kent.

Y139F rats are now to be found across much of south-eastern England. There are also populations with this mutation in apparently isolated pockets elsewhere in the country. The occurrence of this resistance mutation has been recently recorded on the Anglo-Welsh border in the area previously thought to contain only the Y139S resistance mutation. Although products containing either bromadiolone or difenacoum may be effective in Y139F areas under some circumstances their continued use will lead to the spread of resistance and increases in its severity. Therefore, infestations present in areas that contain Y139F rats are best treated with products containing the compounds brodifacoum, difethialone or flocoumafen, where permitted by product labels.



Other mutations and “hybrid resistance”

Recent surveys of resistance mutations carried out at the University of Reading have found for the first time some Norway rats that possess two different resistance mutations. This phenomenon has been termed “hybrid resistance”. This has been found across the UK and resistant rats have been found which carry the following hybrid combinations: L120Q/Y139C (Dorset, East Sussex and Greater Manchester), L120Q/L128Q (Midlothian), Y139S/L128Q (Merseyside) and Y139C/L128Q (Greater Manchester, East and West Yorkshire, County Durham). These hybrids have been found in areas where known and once separate foci of resistance, involving single mutations, have coalesced and interbred. Up to now our knowledge of the practical effects of resistance, such as that given in this document in previous sections, has relied on laboratory and field studies of Norway rats carrying only a single mutation.

The consequence of hybrid resistance for rodent pest management in the UK is currently unknown. So far rats have only been found that are heterozygous for each of two mutations. It seems unlikely that the degree of anticoagulant resistance that they possess would be greater than that found in a Norway rat that is homozygous for the severe L120Q mutation. So far, no rats have been found that are homozygous for more than one resistance mutation. Some resistance mutations result in higher dietary requirements for vitamin K, more so in homozygous animals than in those that are heterozygous, presumably because they have a detrimental effect on the action of the vitamin K epoxide reductase enzyme. It seems possible that hybrid resistance may not be viable with certain severe SNP hybrid combinations, such as L120Q and Y139F, because they will prevent vitamin K epoxide reductase from functioning properly. This may explain why we have not yet found hybrid resistance with these SNPs in south east England, although Norway rats that are homozygous for them are common and

foci are in close proximity.

6. Alternative active substances

6.1 Cholecalciferol

Rodenticide baits containing the active substance cholecalciferol are an alternative to anticoagulants for the control of Norway rat infestations. This substance, otherwise known as vitamin D3, exerts a rodenticidal effect by disrupting calcium metabolism when consumed by rodents in baits that nominally contain 0.075% of the active substance. These baits are authorised for use in UK by professionals (i.e. those able to prove competence according to the requirements of the Rodenticide Stewardship Regime, see: <https://www.thinkwildlife.org/training-certification/>) and can be applied both indoors and outdoors around buildings (i.e. in and around buildings), and can be used for permanent baiting, Risk mitigation measures to be used to prevent the exposure of non-target animals during applications of cholecalciferol are similar to those used for anticoagulants. However, those more familiar with anticoagulants may find that baiting programmes follow a different course when cholecalciferol is used due to the onset of the ‘stop feed’ effect, which results in less bait being consumed during treatments. As with all biocides, it is essential that product labels are read carefully and their instructions are followed.

6.2 Aluminium phosphide

Several pellet formulations containing aluminium phosphide are authorised in the UK for the control of Norway rats by burrow fumigation. Pellets are introduced into rat burrows and phosphine gas is evolved on contact with ground moisture. All aspects of the purchase, transport, storage, use and disposal of formulations based on aluminium phosphide are controlled by a stewardship programme, the Register of Accredited Metallic Phosphides Standards (RAMPS), which should be consulted when considering the use of these products (see: <https://basis-reg.co.uk/scheme-ramps>).

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6.3 Hydrogen cyanide

Hydrogen cyanide is also authorised for use in the UK against Norway rats by application as a fumigant in empty structures by professional technicians. Methods of application and risk mitigation measures to protect those making the application, bystanders, non-target animals and the environment are highly specialised and technically challenging. This control measure can therefore be applied only by companies that have specially trained and certificated technicians and appropriate equipment.

6.4 Advantages of alternative active substances

The use of these active substances, which are alternatives to anticoagulants, carry the very important benefit that they do not select for the anticoagulant resistance genetic trait because they act with similar effectiveness against both susceptible and resistance Norway rats. Therefore their use, within a wider integrated strategy for the control of Norway rats, will serve either to remove or severely to limit resistant rat infestations and to prevent the spread of anticoagulant resistance.

7. Further advice about dealing with anticoagulant resistant populations

For more detailed information about where Norway rat resistance mutations can be found in the UK visit the RRAG web-site at: bpca.org.uk/rrag. However, please note that the apparent absence of resistance from any area shown on resistance maps may be due to a lack of information from the area in question rather than the fact that resistance is not present.

If you have submitted rat tails for DNA analysis and the result is obtained that rats you are treating carry a resistance gene, what should you do next? Useful guidelines about the most effective anticoagulants in different parts of the UK are provided in the preceding

sections of this document and these are summarised in Table 2. You may also wish to contact the UK Rodenticide Resistance Action Group directly. This can be done either through the website (<http://www.pesticides.gov.uk/rags.asp?id=702>) or through the British Pest Control Association and National Pest Technicians Association.

Generally, first-generation anticoagulants should be used where practitioners can be reasonably confident that no anticoagulant resistance exists, for example where DNA testing shows that rats are fully susceptible. The use of products containing bromadiolone and difenacoum may be effective in controlling anticoagulant resistant rats across much of the UK. However, the resistance mutations Y139C (formerly Gloucestershire resistance), L120Q (formerly Hampshire/Berkshire resistance) and Y139F (formerly Kent resistance) confer levels of resistance to either bromadiolone or difenacoum, or both, such that treatments using them may be ineffective. If practical applications of both difenacoum and bromadiolone have been found to be unsuccessful against rats carrying these mutations, then no further applications of these compounds should be carried out. Further applications of ineffective anticoagulants will exacerbate resistance at the site and constitute an unnecessary and unacceptable risk to non-target animals.

If populations resistant to bromadiolone and difenacoum are in and around buildings they should be treated with products containing brodifacoum, difethialone or flocoumafen. If resistant populations are in open areas, and not associated with buildings and other man-made structures, then alternative control measures such as trapping, gassing and habitat modification to reduce the rodent carrying capacity of the site should be attempted.

Recently some manufacturers have introduced products that contain lower concentrations of the active ingredients

than have been used in the past. These so-called “low-strength baits” are available both to the general public and to professional pest control practitioners and have the advantage that they are not classified “toxic to reproduction”. In use scenarios where this classification is not a significant factor, formulations containing the highest available concentration of an active substance should always be used in resistance areas, in particular where the severe forms of resistance conferred by the Y139C, Y139F and L120Q mutations occur. The use of full-strength baits will ensure that treatments are conducted quickly and efficiently, and the risk of treatment failure will not increase the severity of resistance and promote its spread.

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Table 2.

The different anticoagulant active substances and their effectiveness against the resistance mutations found in rats in the UK. A red box means that the active substance should not be used against that strain and a green box means that it may be used with a reasonable expectation of a successful outcome. Some treatments may be effective using bromadiolone and/or difenacoum against resistant rats carrying the Y139S, Y139C and Y139F mutations, although complete eradication may not be achieved and these active substances are probably best avoided (amber box).

Active substance	Resistance mutation and where found				
	L128Q Scotland, Yorkshire, Lancashire	Y139S Anglo-Welsh border	Y139C Gloucester- shire, Norfolk, Lincolnshire, Yorkshire, SW Scotland	L120Q Hampshire, Berkshire and elsewhere	Y139F Kent, Sussex and, elsewhere
Leucine128Glutamine					
Warfarin					
Coumatetralyl					
Difenacoum					
Bromadiolone					
Brodifacoum					
Difethialone					
Flocoumafen					

Further reading

1. CRRU UK. 2015. CRRU UK Code of best practice – Best practice and guidance for Rodent Control and the safe use of rodenticides. Campaign for Responsible Rodenticide Use, UK. March 2015. 24 pp. <http://www.thinkwildlife.org/crru-code/>. Feb. 17, 2017. Available at: <https://www.thinkwildlife.org/about-crru-uk/>.
2. Rodenticide Resistance Action Committee of CropLife International. RRAC Resistance Guide. Available at: <http://rrac.info/>.
3. Buckle, A., Jones, C. and Prescott, C. (2020). Anticoagulant resistance in rats and mice in the UK - Summary report with new data for 2019-20. Report from the Campaign for Responsible Rodenticide Use (CRRU) UK for the Government Oversight Group. Vertebrate Pests Unit, The University of Reading. 19 pp. Available at: <https://www.thinkwildlife.org/downloads/>.

Authorship

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Produced by the Rodenticide Resistance Action Group

This Guideline has been produced by the Rodenticide Resistance Action Group of the UK, with assistance from Killgerm Chemicals Ltd., to provide a summary of the information we now have available on anticoagulant resistance in house mice and to promote the effective use of anticoagulants, and alternative methods of control, against this ubiquitous and very troublesome pest.

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You can find out more about RRAG at www.bpca.org.uk/RRAG.

ANTICOAGULANT RESISTANCE IN THE NORWAY RAT AND GUIDELINES FOR THE MANAGEMENT OF RESISTANT RAT INFESTATIONS IN THE UK

Appendix

Rodenticide Resistance Action Group: Classification of Active Substances for Resistance Management

The use of ONLY effective active substances against resistant infestations of house mice and Norway rats has important benefits:

- (1) Rodent infestations are controlled quickly and efficiently.
- (2) The spread and increases in severity of resistance are prevented.
- (3) Unnecessary and often high emissions to the environment of rodenticide active substance are avoided.

The classification of rodenticide active substances that are authorised in the UK given below will help users to decide which active substances to use when they encounter resistant rodent infestations.

Group		Sub-Group		Compounds	Recommended uses
1	Anticoagulants	A	FGAR	warfarin, coumatetralyl	For use against Norway rats when there is no resistance to anticoagulants.
		B	SGAR	bromadiolone, difenacoum	For use against Norway rats when there is no resistance to anticoagulants, and against rats carrying mutations (L128Q and Y139S).
		C	SGAR	brodifacoum, difethialone, flocoumafen	For use against house mice, and all strains of resistant rats (L128Q, Y139S, L120Q, Y139C, Y139F).
2	Calciferols	-	-	cholecalciferol	Recommended against house mice, and all strains of rats.
3	Narcotics	-	-	alphachloralose	Recommended for control of all strains of house mouse.
4	Gases	-	-	carbon dioxide, aluminium phosphide, hydrogen cyanide	Specific applications by trained professionals only. Species restrictions may apply.

FGAR - first-generation anticoagulant rodenticide; SGAR - second-generation anticoagulant rodenticide

General guidance:

- Always know the name of the active substance you are using and follow the instructions on the product label.
- The use of full-strength baits (i.e. containing 50 ppm if it is a Group 1B and 1C active ingredient) will ensure that treatments are conducted quickly and efficiently, and the risk of partial treatment failure will not increase the severity of resistance and promote its spread.