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Review Article

Modern rodenticides – does the problem boil down only to animal conservation? Review

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Abstract

Environmental pollution by chemicals used in agricultural technology is the biggest problem, but it is impossible to eliminate their use completely. Modern rodenticides occupy a special place. Their use leads to mass death of animals of non-target species, which is confirmed by complex pathomorphological and toxicological studies. The largest but underappreciated problem with modern rodenticides is transmission through food chains. Study of application practice and research results show the existence of a threat to human biological safety.

Keywords: rodenticides; anticoagulants; non-target species; natural systems

Background

Chemicals are the integral part of the modern agricultural industry, which has made it possible to get rid of hunger and food shortages. But the consequences of their expanded use have clearly not been sufficiently studied, which is aggravated by changes in the composition and structure of the seed wedge, which has facilitated the flow of drugs into water bodies.

There are thousands of agrochemical preparations; their choice is dictated by the ratio of prices and mass stereotypes introduced by manufacturers. For proper use, the lists of acceptable ones are updated annually, but this is not enough. It is not customary to indicate chemical names, maximum permissible concentrations of active substances, or their decay periods - manufacturers use commercial names, and users theoretically should look for information in contradictory annotations. The synergism and cumulation of most drugs are not taken into account; their effect on fauna has not been sufficiently studied.

In the struggle to save the harvest, people have long begun to use toxic substances to kill animals which eat grain and crops. We will discuss some of the features of the impact on fauna using the example of recognized toxicants - rodenticides - drugs for killing rodents. The State Catalog (2023) lists 15 names with different numbers of forms, with consumption rates per hole or per hectare. The remaining animals they can influence are called non-targets and include mammals, birds, reptiles, amphibians, fish and, of course, humans.

According to the current tradition, exposure to pure substances through dietary intake is assessed at best, while accumulation is out of sight, as is exposure through inhalation (which can provide intranasal entry into the respiratory system and even the nervous system, bypassing the blood-brain barrier). Until the mid-twentieth century, the most common rodenticides were fast-acting preparations - phosphides (zinc, magnesium, aluminum) - when they are wetted, highly toxic phosphine is released. In the last half century, anticoagulants that interfere with blood clotting have become widespread, 1st generation (warfarins) and 2nd (superwarfarins). They are slow-acting, can accumulate, affect coagulation and the structure of blood vessels, and, unlike phosphides, do not have a pronounced taste or smell. Toxicants differ in the severity of primary (rapid death of the object and disintegration of the drug) and secondary risks (delayed death of the object, while maintaining the toxicity of the drug, the possibility of poisoning when eating a dead animal) (Erofeeva et al., 2021, 2022, 2023).

In recent decades, the list of representatives of non-target species has been expanded by orders of magnitude to include non-herbivores – 2nd order consumers. Their poisoning occurs when toxicants are transferred through food chains, which is not described in the rules and is not taken into account in practice. A comparison of mortality depending on the method of consumption, dose, concentration in baits from different preparations showed that the maximum primary risk in birds and mammals is observed for zinc phosphide. The secondary risk of zinc phosphide is less pronounced (due to rapid degradation), in contrast to superwarfarins. A detailed analysis of the results of using different types of rodenticides was done two decades ago by Erickson and Urban (2004). The study was done - "Potential Risks of Nine Rodenticides to Birds and Non-Target Mammals," commissioned by the US Environmental Protection Agency. Anticoagulants of the 1st and 2nd generation and other drugs were studied, comparing the primary risk (direct consumption) and secondary (eating poisoned prey or carrion). The objects of the study were birds (more than 80 species) and mammals (more than 50 species). The highest primary risk in both birds and mammals was observed for zinc phosphide. The secondary risk when using a rapidly disintegrating drug was less pronounced, in contrast to brodifacoum and difethialone. Differences in primary and secondary risk require a special approach when analyzing the biological effect of rodenticides (Erofeeva et al., 2021, 2022, 2023).

In our country, recorded facts of mass death of animals and birds in fields are confined to periods of above-zero temperatures in autumn and early winter. However, at this time the vegetation does not allow one to notice the carcasses of small animals, so the data is not complete. The necessary route counting - the collection of all carcasses of animals and birds - was done only by the Ministry of Nature of the Krasnodar Territory in 2020. Of the 11 documented (only from publications, not counting personal messages) cases of mass death, route counting was carried out only once. Moreover, toxicological studies are carried out extremely rarely - we know of only two such studies. This is due to the high complexity of analysis and difficulties in timely sample delivery.

The main attention is drawn to the death of animals and birds belonging to the most widespread and/or large and/or Red Book species - cranes, bustards, and sometimes brown hares. The death of small animals is actually not recorded, since their carcasses are difficult to detect; the corpses of small mustelids are almost impossible to see in the grass. To find them is extremely rare, but still possible. Similar is with birds of prey and foxes, but their carcasses are mentioned sometime. However, the death of significantly smaller numbers of 2nd order consumers has been recorded. Their poisoning has been proven.

How could this happen?

Table 1 presents data on the Krasnodar collection 2020. The possibility of poisoning animals when receiving the toxicant orally was compared with when eating grain.

No.	Species	Amount of carcasses	Level of the consumer	Poisoning possibility when eating grain
1	*Columba palumbus*	2998	1	High
2	*Columba oenas*	35	1	High
3	*Lepus europaeus*	5	1	High
4	*Pica pica*	5	1 – 2	Low
5	*Garrulus glandarius*	3	1 – 2	Low
6	***Buteo buteo***	**11**	**2**	**Absent**
7	***Buteo lagopus***	**4**	**2**	**Absent**
8	***Buteo rufinus***	**2**	**2**	**Absent**
9	***Falco tinnunculus***	**2**	**2**	**Absent**
10	***Asio flammeus***	**3**	**2**	**Absent**
11	***Asio otus***	**2**	**2**	**Absent**

Table 1: Possibility of food poisoning of birds and mammals collected in Krasnodar krai, January 24–25, 2020 Data on the collection of carcasses in the places of mass death were presented by the Ministry of Natural Resources and the police of Krasnodar krai (Erofeeva et al., 2023).

The data presented in Table 1 allows us to assert that animals making up half of the list of species (Nos. 6-11) could not obtain the toxicant directly. All of them are consumers of the 2nd order, who do not use grain for food (at autopsy, it was also absent from the crops and stomachs). Consequently, they received toxicants by eating poisoned animals of other trophic levels or by inhaling dust particles or in water. Analysis of registered cases of death of animals and birds suggests that non-target species include not only first-order but also second-order consumers, and poisoning of non-grain-eating birds occurs. The drug is transmitted through food chains.

Species	Bromadiolon mkg/g
Buteo rufinus	0.015
Buteo buteo	0.012
Asio otus	0.047
Vole from the stomach of the owl	0.093
Columba oenas	0.005

Table 2: Results of chemical analysis of samples (Erofeeva et al., 2022). The presence of superwarfarins is determined based on measurements of the mass fraction via reverse phase liquid chromatography with ultraviolet detection and chromatography in isocratic mode of an extract from a sample with a quantitative assessment according to an external standard (Andreev et al., 2019).

The results of chemical analysis established the presence of bromadiolone in bird samples in very low doses (Table 2). But this is enough to cause death. In the vole from the stomach of an owl, the content of the toxicant is also “conditionally low”, but 2-10 times higher than its amount in the tissues of birds (Erofeeva et al., 2022, 2023). According to the literature, the lethal dose of bromadiolone in mammals varies by orders of magnitude: for wild boar it is 3 mg/kg, and for rats 150 mg/kg (Poché et al., 2018). Autopsies (Erofeeva et al., 2023) showed that birds, like brown hares, have macropathological disorders, i.e., partial determination is possible at regional veterinary stations. The composition of violations varies, but there is something in common.

They are localized in

8/8 – circulatory system and hemostasis

8/8 – respiratory system

7/8 – bone and muscle tissues

3/8 – digestive system

2/8 – brain tissue

All presented include the damage to the respiratory system. But the calculation of the lethal dose is made on the basis of intestinal action - i.e. the method of poisoning “by inhalation” is not mentioned.

Modern research approved the presence of rodenticides in animals that do not eat poisoned grain baits. Anticoagulants, predominantly 2nd generation, were found in 68% of 344 raptors and mammals studied in Spain (Poessel et al., 2015). Long-term studies of mustelids for the content of 2nd generation anticoagulant rodenticides were carried out in Denmark (Elmeros et al., 2018). They studied the tissues of animals hit by cars and destroyed while protecting poultry (indoors and within a radius of 25 m from them). It was found that superwarfarins are present in the tissues of 99% of stone martens (Martes foina, n = 71) and 90% of forest polecats (Mustela putorius, n = 69). In Spain, the occurrence of superwarfarins in the tissues of wild animals, 2nd order consumers, is positively correlated with urbanization (Lopez-Perea et al., 2015, 2019), that is, with their use by urban residents and farmers.

In Italy, the presence of anticoagulant rodenticides was studied in the tissues of wolves hunted and found dead for various reasons (Musto et al., 2024). Of the 186 examined, 115 (68%) had traces of one or two anticoagulants, mainly superwarfarins. Of the 115 wolves with proven presence of anticoagulants, only 19 had characteristic macropathological signs of poisoning - coagulopathy. Wolves (or their crossbreeds with dogs, which is not important in this case) are social animals. The death of some animals that received a lethal dose indicates the presence of individuals that survived with the sublethal dose, which is confirmed by the collected material (the presence of superwarfarins in the tissues of animals that died from various causes). A similar situation exists with other predators, terrestrial and flying. A particularly high frequency of toxicants was present in foxes: out of 67, 60 (89.6%) and buzzards, out of 23, 18 (78.3%). Both species are consumers of the 2nd order, which includes humans.

Man occupies a special place. The direct toxic effects of superwarfarins on humans are less pronounced than on dogs (Ruiz-Suárez et al., 2015), which does not exclude accumulation and delayed effects. There is transfer of bromadiolone into human foods - they may be present in milk. In Switzerland, methods for their detection in yogurt cultures are being developed by selecting bacterial cultures that stop growing in the presence of bromadiolone (Hathurusinghe, Ibrahim, 2012; 2016). Poisonings of people have been described many times and on all continents, reports appear systematically. Clinical manifestations of superwarfarin toxicity include hematuria, epistaxis, gingival bleeding, ecchmoysis, hemoptysis, menorrhagia, hemoperitoneum, diffuse alveolar hemorrhage, spontaneous hemothorax, hematemesis, and subarachnoid hemorrhage (Nelson et al., 2006). However, if these symptoms are noted, testing for toxicants is not mandatory.

The clinical symptoms during the hospital stay and the detoxification procedure are described in detail (for example, Zobnin et al., 2013; Voitsekhovsky et al., 2020). A pathological description of brain changes during rodenticide poisoning was made (Ivleva et al., 2017), and a description was given using magnetic resonance imaging (Wang et al., 2017). An analysis of changes in the frequency of use of rodenticides as a poison for suicide in Hubei province showed an increase in the number of cases from 5.6% in 1957–1982 to 19.7% in 1999–2008. Human poisonings from rodenticides account for a significant proportion of the causes of death not only in China but also in Northern India (Liu et al., 2009). Correctly identifying poisoning with anticoagulant rodenticides is complicated by both the lack of easy access to the necessary high-precision equipment and the lack of awareness among physicians about the possibility of poisoning (Chong, Mak, 2019). Voitsekhovsky and co-authors (2020) rightly note that “Diagnosing superwarfarin-induced coagulopathy in a patient is a difficult task, there is not always evidence of contact with a toxic substance, initial clinical manifestations may be nonspecific and it is possible to determine the content of superwarfarin in the blood using high-performance liquid chromatography not in every medical institution".

Rodenticide poisonings have been reported on all continents. The Illinois Poison Center describes a sharp increase in the number of patients with bleeding: all examined had sublethal doses of brodifacoum and/or difenacoum and/or bromadiolone (Devgun et al., 2020). In the Samara and Ulyanovsk regions in 2019, there was a massive (80 identified patients) poisoning with sunflower oil (Galstyan et al., 2020). The oil was done from sunflower seeds treated with rodenticides. Treatment of clinically confirmed cases of poisoning with superwarfarins in the Russian Federation is discussed and recommended from the standpoint of compensation for vitamin K deficiency (Barlamov et al., 2022).

Superwarfarins are considered to be drugs with intestinal action, although they, like warfarins, have a skin-resorptive effect (Ivanitskaya et al., 2011). Recent data indicate the possibility of effects on the central nervous system in the absence of severe hemolytic syndrome (Feinstein et al., 2017; Wang et al., 2017; Zuo et al., 2019), which is consistent with our data. The latter is especially true for humans.

A comparative analysis shows that non-acutely acting modern drugs - anticoagulants, especially the second generation, are much more dangerous in practice. This is due to the ability to accumulate, the duration of elimination, hidden entry and the underestimated possibility of entry through the mucous membranes of the respiratory tract, bypassing the intestinal tract. Moreover, we did not find studies of sublethal doses, although such facts have been described many times. The presence of sublethal doses of superwarfarins is widespread in animals and is completely ignored in humans. Modern medical classification of diseases is based on knowledge of the toxicant. Therefore, poisoning due to the cumulation and synergism of agrochemicals is not directly included in medical statistics, and is considered exclusively as random events.

It is generally accepted that there are natural areas and agrocenoses. Natural ones include forests and steppes, as well as parks; they practically exclude mass chemical treatments, with the exception of targeted regulation of the number of species that carry particularly dangerous infections. In agrocenoses there are no restrictions on chemical treatments; the decision on application is made by agricultural complexes, whose activities are aimed at maximizing production while reducing the cost of the work carried out. However, there are no physical boundaries of agrocenoses and natural areas - animals and birds use all the space, the applied preparations spread far beyond the boundaries of the treatment areas. Improving the quality of technology has led to the transfer of many inconveniences and ravages to arable land. Analysis of changes in the composition of farmland areas in 1990 – 2015. in 67 regions of the Russian Federation showed a widespread increase in crop areas (Lury et al., 2018). These are areas where agrochemicals and rodenticides are introduced. Already at the beginning of the century, in some regions of the Russian Federation, the area of rodenticide treatments more than doubled (Yakovlev et al., 2007), in proportion to the decrease in the share of fields with forage crops. Thus, the catchment areas were deprived of natural filters that at least partially delayed and slowed down the flow of agricultural chemicals into water bodies. This was reinforced by a change in the composition of crops - oilseeds and grains replaced fields of perennial fodder and meadow grazing, which previously created real buffer zones between intensively cultivated fields and water bodies. Was reduced the route of toxicants into water resources. It should be recognized that the impact of agrochemicals on so-called natural territories has enlarged significantly: the increase in the area of crops and modern processing methods have led to a multiple growth of the applied amount of chemicals. The reduction in the area and proportion of natural barriers has led to their increased entry into water bodies and what is considered natural territories. Substances used for chemical treatment are present not only in the products of agrocenoses, but also in wild vegetation, soil and water bodies (Yadav et al., 2015). No part of the human population is completely protected from the influence of agrochemicals that affect the general condition and development of diseases (Thomson, Darwish, 2019).

A study of application practice and research results shows the existence of a threat to biological safety in the area that combines the effects of chemical and biological factors. Is urgently needed systematic interdisciplinary research to develop and implement programs for control and protection from the effects of poisons not only of natural biological systems, but also for the human population.

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