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GENERAL BIOLOGY

Natural Radioresistance as a Criterion of Species (as Exemplified by Large Taxa of the Order Rodentia)

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Natural radioresistance is at the interface between several branches of science, including ecological physiology and animal adaptation and tolerance; it is also closely related to adaptive biodiversity, the least studied aspect of biodiversity, which is now a topical problem. Little is known about the role of differential radioresistance of organisms in maintaining the integral stability of various ecological systems, which explains the interest of ecologists in natural radioresistance. This is now a priority field of research [1], because there are examples of radiation-induced decrease in species diversity and disturbance of interpopulation relationships and community structures [2]. Radioresistance is a fundamental characteristic of the genetic-system reliability, which reflects the ability of these systems to repair DNA damage normally occurring in the course of vital activity [3]. We confirmed that radioresistance is genotypically determined; in our experiments on the contributions of the genetic and environmental components contribute to its formation in rodents [4, 5].

In this study, we analyzed our own data and published data of other researchers on radioresistance of small mammals from the order Rodentia, as well as the dependence of the mammalian radioresistance on their taxonomic position, ecological factors, and biological traits. For this purpose, laboratory colonies of 19 species and intraspecific forms of wild (forest, semidesert, mountain, and synanthropic) and laboratory rodents were collected in the vivarium of the Institute of Plant and Animal Ecology.

We used an IGUR-1 device to irradiate the animals at various doses ones in the autumn–winter period to avoid the seasonal effect on radiosensitivity. The time of animal death was recorded during a month. The average half-lethal dose ($LD_{50/30}$), which is an integral index of radioresistance generally accepted in radiobiology, was calculated by the probit method (Table 1). Published data on $LD_{50/30}$ for other rodent species of both Old and New World [7, 8] were also included into a complex analysis of radioresistance in the order Rodentia.

In total, 51 samples from 22 genera of four families (Sciuridae, Muridae, Cricetidae, and Heteromyidae) were examined, whose specificity can be described by several variables (the material was taken from large sources [9–12]). The variables reflect the main ecological, biological, and systematic traits of the species, can be measured discretely, and can modify radiosensitivity estimated as $LD_{50/30}$. The body size; feeding type; biotopical requirements; the suborder, ecological group, and biological type of the animals according to Vorontsov's classification [11]; diurnal activity; and the area of the species range (in millions of kilometers) served as determinants. The $LD_{50/30}$ of the rodent species served as the dependent variable.

Multiple comparison of the mean $LD_{50/30}$ using Scheffe's *S* method showed that representatives of Sciuridae and Muridae were characterized by the lowest and insignificantly different $LD_{50/30}$ values (6.56 and 7.96 Gy) among the four families studied. Representatives of the families Cricetidae and Heteromyidae showed substantially higher ($p \leq 0.05$) mean $LD_{50/30}$ value (10.13 and 12.23 Gy), which also insignificantly differed from each other.

The results of one-way ANOVA suggest that the family of the rodents influences the level of $LD_{50/30}$ substantially ($p \leq 0.001$). *The variation of the mean half-lethal doses was determined by the family specificity by 42%*:

$$R^2 = SSb/SSw = 126.9 / 301.15 = 0.421.$$

Both ecological and biological determinants of radioresistance were found using the linear step-by-step method of regression analysis [13], which makes it possible to estimate the effect of the partial factorial variables on the dependent variable (the $LD_{50/30}$ response) provided that the remaining variables were fixed. Only 3 out of 11 ecological and biological parameters were significantly correlated with the species-specific $LD_{50/30}$: *body size, feeding type, and biotopical requirements.* They determined 39% of the variation of the half-lethal dose (Table 2).

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Table 1. Natural radioresistance of rodents with various ecological specializations (data obtained by the author)

Species	*n*	$LD_{50/30}$, Gy, $M \pm m$	Place of capturing
Clethrionomys glareolus	95	12.7 ± 0.2	The Southern Urals
Cl. rutilus	56	12.8 ± 0.4	The Southern Urals
Cl. rufocanus*	48	0.3 ± 0.2	The Southern Urals
Alticola argentatus*	61	12.1 ± 0.3	Kyrgyzstan
Microtus arvalis*	27	9.4 ± 0.4	The Middle Urals
M. rossiaemeridionalis	44	9.2 ± 0.47	The Middle Urals
M. gregalis gregalis*	35	9.9 ± 0.3	The Middle Urals
M. gregalis major*	22	10.1 ± 0.3	The Polar Urals
Apodemus (s) uralensis	36	7.0 ± 0.4	The Southern Urals
Ap. sylvaemus tokmak*	36	7.3 ± 0.2	Kazakhstan
Ap. agrarius	57	10.0 ± 0.2	The Middle Urals
Rattus norvegicus	31	10.3 ± 0.7	Iturup Island
Nesokia indica*	33	6.9 ± 0.5	Tajikistan
Phodopus sungorus*	45	11.9 ± 0.3	Mongolia
Ph. campbelli*	81	9.6 ± 0.3	Tuva
Ph. roborovskii*	38	8.9 ± 0.4	Tuva
Meriones meridianus*	92	13.5 ± 0.5	Uzbekistan
M. unguiculatus	30	12.7 ± 0.5	The Trans-Baikal region
Mus musculus	25	0.1 ± 0.5	Tajikistan
Laboratory animals			
BALB/c	101	6.0 ± 0.1	Vivarium of the Institute of Plant and Animal Ecology
CBA	50	9.3 ± 0.2	Vivarium of the Institute of Plant and Animal Ecology
C57Bl/6	47	7.8 ± 0.2	Vivarium of the Institute of Plant and Animal Ecology
BC	61	8.2 ± 0.2	Vivarium of the Institute of Plant and Animal Ecology
Outbred mice	60	7.5 ± 0.3	Vivarium of the Institute of Plant and Animal Ecology
Wistar rats	65	8.8 ± 0.1	Vivarium of the Institute of Plant and Animal Ecology

Note: Species for which the $LD_{50/30}$ was estimated for the first time are indicated with asterisks. The list of species corresponds to the classification given in [6].

The radioresistance was shown to depend on the body size: the $LD_{50/30}$ decreased with an increase in the rodent size. The same is characteristic of not only the order Rodentia, but also the entire class Mammalia. It is known that the lower the animal body weight, the higher the metabolic rate, and the shorter the time of onset of true restoration of blood neutrophils [14]. This is why the mammals in which the temporal parameters of cellular kinetics are higher die sooner because of endogenous infection.

The biotopical requirements of the rodents also influenced the $LD_{50/30}$ significantly. *The species inhabiting dry biotopes had higher* $LD_{50/30}$ *than the species inhabiting moist biotopes.* This is explained by the fact that the animals adapted to permanent exposure to solar radiation are less sensitive to the effect of ionizing radiation, probably, due to cross adaptation.

The $LD_{50/30}$ *was found to depend considerably on the feeding type of rodents and decrease with an increase in the content of proteins in their food.* This dependence can be explained by the specific dynamic effect of proteins, which increases the basal metabolic rate and, hence, modifies radiosensitivity. The data on different radioresistances in closely related species within the same genus confirm the dependence of radioresistance on the feeding type. For example, we studied rough-legged hamsters (genus *Phodopus*) [15] and found that the Roborovsky hamster, which feeds mostly on animal food, was less resistant to radiation than the Campbell's hamster, and especially Djungar hamster, whose food contained a significant proportion of plants. The $LD_{50/30}$ values calculated for these species from the regression equation agreed experimental data.

Thus, the comparative analysis of radioresistances of a series of species made it possible to describe the diversity of this tolerance in various taxa of the order Rodentia. The analysis showed that radioresistance and

Table 2. Results of the linear step-by-step regression analysis of the dependence of $LD_{50/30}$ on the animal size, feeding type, and biotopical requirements

Regression parameter	Estimate of the parameter
The number of estimates obtained, n	51
Free term ($LD_{50/30}$ of small rodents with a carbohydrate feeding type living in dry biotopes), b_0	12.08 64***
Coefficient of $LD_{50/30}$ regression on body size, X_1 (0, small; 1, moderate; 2, large; and 3, very large rodents), b_1	–1.25 0.26***
Coefficient of $LD_{50/30}$ regression on feeding type, X_2 (0, carbohydrate feeding; 1, mixed feeding; 2, a large proportion of animal food), b_2	–1.54 0.47**
Coefficient of $LD_{50/30}$ regression on biotopical requirements, X_3 (0, dry biotopes; 1, moist biotopes), b_3	–1.50 0.60*
Coefficient of determination, R^2	0.392***

Note: Significance levels: * $p \le 0.05$; ** $p \le 0.01$; *** $p \le 0.001$.

radioecological specificity of large taxa, which are fundamental characteristics of the genetic-system reliability, are not homogeneous. The “key” factors, i.e., the main biological and ecological traits of the species were also determined; they account for a total of 40% of variation of the mammalian radioresistance.

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