Inheritance of hair color in sables (Martes zibellina) of breed black sable

S V Beketov¹, K S Karpov², A V Kozlov¹, I A Glebova¹ and I V Lopatkov¹

¹ K. G. Razumovsky Moscow State University of Technologies and Management (the First Cossack University), Moscow, Russia
² Research Institute of fur farming and rabbit breeding named after V. A. Afanasyev

E-mail: mirvar@rambler.ru

Abstract. On the example of a single population of sables of the Pushkin animal farm (Federal state unitary enterprise “Russkiy Sobol”), the heritability of the general coloring of their hairline was studied. In total, puppies of 1,561 female sables of the black sable breed were analyzed with a total score of 4,794 puppies. Based on the results of the study of various color forms of sables, the heritability coefficients \( h^2 \) of the black-brown color form were determined as 0.128; dark brown as 0.108 and chestnut as 0.078, which indicates a high selective sampling for darkening the overall color of the hairline in this population.

1. Introduction

The heritability of a breeding trait \( h^2 \) is one of its most important properties and is defined as the proportion of phenotypic variability in a population due to its genetic variability in relation to a particular qualitative or quantitative trait. In other words, heritability expresses the reliability of the assessment of the phenotype in determining the breeding value of the animal. For this reason, heritability is included in almost every formula associated with breeding methods and the successful solution of many practical problems depends directly on the correct assessment of its level.

The main value of the heritability coefficient is that it makes it possible to establish the degree of reliability of judgments about the breeding value of individuals by their phenotypic characteristics. The success of selection in the desired population change can be predicted only if the degree of correspondence between phenotypic and selection values is known.

However, in domestic animal husbandry and especially in sable breeding, such an important indicator of the selection evaluation of the trait as the heritability coefficient has not received proper distribution and is not fully worked out. This fully applies to the heritability of the hair color of Sables.

Wild sable is characterized by a wide variability of the main color of the hair, in particular, on this basis it has 7 color categories. At the same time, if initially the greatest commercial interest was represented by a particularly dark sable (almost black sable), now its lighter forms are also in demand in the fur market.

In this connection, the development of breeding Sables with a wide range of colors of the General color is one of the promising tasks of Russian fur farming, for which it is necessary to know the variability and inheritance of hair color in this representative of the family of weasels. However, this issue has not been studied enough.
In particular, one of the first studies of color forms of Sables was devoted to the work performed by L. G. Utkin in 1979. In the course of its implementation, the distribution of parental pairs by color was quite conditional, they were divided into dark, medium and light [1].

While according to the score appraisal assessment of hair color in industrial populations of sables five color forms are identified, which allows for a more detailed analysis.

As for the determination of generalized coefficients of inheritance of general hair color of sables, it is possible to mention only the research of S. V. Pavlyuchenko (1981) [2].

Accordingly, the purpose of this research was to establish the heritability levels of the hair color of sables depending on the degree of its darkening with specification for individual color forms of the population under consideration.

2. Materials and research methods
According to the materials “Production and rejection magazines” (analogue of tribal magazines in animal husbandry) for 1991-1996 by the sixth sable brigade of the IV branch of the Pushkin Animal Farm (now Federal state unitary enterprise “Russkiy Sobol” (Moscow Region) created an electronic database including 1561 female sable breeds of black sable breed with a total number of offspring of 4,794 puppies.

The black sable breed is referred to the so-called standard [3], or main [4], it originates directly from wild ancestral forms and is characterized by polygenic inheritance of hair color.

In the course of the research, the calculation of the heritability coefficient was carried out according to the formula $h^2 = \frac{\sigma_x^2}{\sigma^2}$, where $\sigma_x^2$ is the intergroup dispersion, $\sigma^2$ is the general dispersion.

The values of the intergroup dispersion was determined by the formula $\sigma_x^2 = \frac{\sum (x_j - \bar{x}_0)^2 n_j}{\sum n_j}$, where $\bar{x}_j$ is the average value of the series in the group, $\bar{x}_0$ is average value of the total sample, $n_j$ is the number of elements in this j-th group.

The general dispersion is determined by the formula $\sigma^2 = \frac{\sum (x_i - \bar{x}_0)^2 f_i}{\sum f_i}$, where $x_i$ is sample item value, $\bar{x}_0$ is the average value of the series in the group, $f_i$ is individual frequency $x_i$.

An intragroup dispersion ($\sigma_i^2$) is calculated using a similar formula, with the difference that it takes into account the number of elements in a particular group [5-7].

The choice of such a statistical approach to assessing the heritability of the degree of darkening of the overall color of the sable hair of the black sable breed is primarily due to the possibility of intrapopulation differentiation of the analyzed animals depending on the variant of mating of parents belonging to a particular color form, with a total number of puppies in the group of at least 20. At the same time, each specific color type in the offspring was determined as the frequency of its occurrence in a separate litter from 0 to 1.

Primary data were grouped taking into account the main color forms of Sables, identified in the breed black sable and defined as almost black, black-brown, dark brown, chestnut and light brown [8, 9].

Grouping of primary data was carried out taking into account the main painting forms of Sables available in the animal farm, and determined according to the commodity characteristics of sable skins and appraisal assessment of the overall color of the hair.

Data processing was carried out using Microsoft Excel and STATISTICA programs.

3. Research Results
The phenotypic structure of the considered population (descendants) by color forms is presented in table 1.
Table 1. The structure of the population on the phenotype.

| General hair color | number of puppies \((n)\) | % |
|-------------------|--------------------------|---|
| almost black      | 3                        | 0,6*10\(^{-4}\) |
| black-brown       | 212                      | 4,4 |
| dark brown        | 1326                     | 27,7 |
| chestnut          | 2937                     | 61,3 |
| light brown       | 316                      | 6,6 |
| Total             | 4794                     | 100 |

Since the degree of manifestation of the trait is influenced not only by genes, but also by environmental conditions, the value of the dispersion of the trait is determined by how sensitive this genotype is to environmental influences. At the same time, within a group of individuals with a similar genotype, the dispersion will depend only on environmental factors, and the intergroup on genetic ones.

Thus, the intra-group dispersion \((\sigma_i^2)\) reflects a random variation, i.e. a part of the variation occurring under the influence of unaccounted factors and independent of the trait-factor underlying the grouping. While the intergroup variance \((\sigma_x^2)\) characterizes systematic variation, i.e. differences in the magnitude of the studied trait, arising under the influence of the trait-factor (genetic variance).

In turn, the total dispersion \(\sigma^2\) measures the variation of the trait over the whole population and under the influence of all the factors that caused this variation, or is equal to the sum of the average of the intragroup and intergroup dispersions: \(\sigma^2 = \sigma_i^2 + \sigma_x^2\).

Since the average value of intra-group dispersions \((\sigma_i^2)\) is easily calculated by the arithmetic mean formula, the intergroup variance \((\sigma_x^2)\) will be equal to the difference between the total dispersion \((\sigma^2)\) and the average dispersion of the intra-group \((\sigma_i^2)\).

The corresponding results of the analyses are presented in tables 2-4.

Table 2. Frequency of birth of pups sable black- brown hair cover.

| Variants of mating parent forms | sable black-brown hair cover | The average frequency of occurrence \((M\pm Std. err. of Mean)\) | Dispersion \((\sigma_x^2)\) |
|---------------------------------|------------------------------|-------------------------------------------------|-----------------|
| black × black-brown             | 23                           | 0,011±0,0109                                    | 0,0027          |
| black × dark brown              | 85                           | 0,068±0,0188                                    | 0,0300          |
| black × brown                   | 28                           | 0,027±0,0197                                    | 0,0108          |
| black-brown × black-brown       | 123                          | 0,080±0,0145                                    | 0,0258          |
| black-brown × dark brown        | 378                          | 0,047±0,0083                                    | 0,0263          |
| black-brown × brown             | 135                          | 0,058±0,0170                                    | 0,0388          |
| dark brown × black-brown        | 119                          | 0,070±0,0199                                    | 0,0471          |
| dark brown × dark brown         | 448                          | 0,045±0,0076                                    | 0,02558         |
| dark brown × brown              | 175                          | 0,043±0,0136                                    | 0,0324          |
| brown × brown                   | 20                           | 0,025±0,0250                                    | 0,0125          |
| Total                           | 1534                         | 0,051±0,0043                                    | 0,0289*         |

Note* general dispersion \((\sigma^2)\).
Average dispersion – 0,0252
Intergroup dispersion – 0,0037
General dispersion – 0,0289
Heritability coefficient h² = 0,128 or 12,8%.

Table 3. Birth frequency of sable puppies with a dark brown hair cover.

| Variants of mating parent forms | sable dark brown hair cover | The average frequency of occurrence (Mean + Std. err. of Mean) | Dispersion (σ²) |
|---------------------------------|-----------------------------|-------------------------------------------------------------|---------------|
| ♂ × ♀ black × black-brown        | 23                          | 0,337±0,0762                                                | 0,1337        |
| ♂ × dark brown                  | 85                          | 0,289±0,0343                                                | 0,0998        |
| ♂ × brown                       | 28                          | 0,199±0,0539                                                | 0,0813        |
| black-brown × black-brown       | 123                         | 0,311±0,0278                                                | 0,0954        |
| black-brown × dark brown        | 378                         | 0,297±0,0178                                                | 0,1193        |
| black-brown × brown             | 135                         | 0,243±0,0264                                                | 0,0939        |
| dark brown × black-brown        | 119                         | 0,312±0,0298                                                | 0,1056        |
| dark brown × dark brown         | 448                         | 0,309±0,0167                                                | 0,1243        |
| dark brown × brown              | 175                         | 0,232±0,0240                                                | 0,1003        |
| brown × dark brown              | 27                          | 0,148±0,0408                                                | 0,0450        |
| brown × brown                   | 20                          | 0,210±0,0672                                                | 0,0903        |
| Total                           | 1561                        | 0,286±0,0084                                                | 0,1110        |

Note* here and further in Tables 4 - 5 is general dispersion (σ²).

Average dispersion – 0,0990
Intergroup dispersion – 0,012
General dispersion – 0,1110
Heritability coefficient h² = 0,108 or 10,8%.

Table 4. Birth frequency of sable puppies of chestnut hair color.

| Variants of mating parent forms | sable chestnut hair cover | The average frequency of occurrence (Mean + Std. err. of Mean) | Dispersion (σ²) |
|---------------------------------|---------------------------|-------------------------------------------------------------|---------------|
| ♂ × ♀ black × black-brown        | 23                        | 0,598±0,0705                                                | 0,1144        |
| ♂ × dark brown                  | 85                        | 0,576±0,0386                                                | 0,1265        |
| ♂ × brown                       | 28                        | 0,688±0,0619                                                | 0,1074        |
| black-brown × black-brown       | 123                       | 0,550±0,0319                                                | 0,1248        |
| black-brown × dark brown        | 378                       | 0,600±0,0184                                                | 0,1276        |
| black-brown × brown             | 135                       | 0,636±0,0296                                                | 0,1182        |
| dark brown × black-brown        | 119                       | 0,573±0,0323                                                | 0,1241        |
| dark brown × dark brown         | 448                       | 0,588±0,0168                                                | 0,1271        |
### Table 5. Birth frequency of sable puppies of light brown hair color.

| Variants of mating parent forms | n   | The average frequency of occurrence (Mean ± Std. err. of Mean) | Dispersion (σ²) |
|---------------------------------|-----|---------------------------------------------------------------|-----------------|
| ♂×♀                             |     |                                                               |                 |
| black × black-brown             | 23  | 0.054±0.0330                                                 | 0.0251          |
| black × dark brown              | 85  | 0.063±0.0148                                                 | 0.0185          |
| black × brown                   | 28  | 0.086±0.0304                                                 | 0.0258          |
| black-brown × black-brown       | 123 | 0.058±0.0124                                                 | 0.0188          |
| black-brown × dark brown        | 378 | 0.056±0.0073                                                 | 0.0203          |
| black-brown × brown             | 135 | 0.063±0.0133                                                 | 0.0239          |
| dark brown × black-brown        | 119 | 0.045±0.0105                                                 | 0.0131          |
| dark brown × dark brown         | 448 | 0.058±0.0069                                                 | 0.0214          |
| dark brown × brown              | 175 | 0.063±0.0112                                                 | 0.0221          |
| brown × dark brown              | 27  | 0.083±0.0317                                                 | 0.0271          |
| brown × brown                   | 20  | 0.089±0.0381                                                 | 0.0291          |
| Total                           | 1561| 0.059±0.0036                                                 | 0.0207*         |

**Average dispersion** – 0,0223  
**General dispersion** - 0,0207

One can see that according to the results presented in Table 2-4, in such colour forms, both in black-brown and dark brown, and in dark brown, they have the highest value, that the darkest of them (black-brown), \( h^2=0,128 \) and further in the order of possible dimming of colour (dark brown) \( h^2=0,108 \) and (brown) \( h^2=0,078 \). Light brown turned out to be a more general dispersion as in Table 5, which was not possible or we can say that it is close to zero.

Table 6 shows the final values of the dispersion variability and heritability of the hair colour of sables.

### Table 6. Dispersion variability and heritability of different color forms of sables.

| color forms     | general dispersion (\( \sigma^2 \)) | average intergroup dispersion (\( \sigma^2_i \)) | intergroup dispersion (\( \sigma^2_x \)) | heritability coefficient (\( h^2 \)) |
|-----------------|--------------------------------------|-----------------------------------------------|------------------------------------------|-------------------------------------|
| black-brown     | 0,0289                               | 0,0252                                        | 0,0037                                   | 0,128                               |
| bark brown      | 0,1110                               | 0,0990                                        | 0,012                                    | 0,108                               |
| brown           | 0,1233                               | 0,1137                                        | 0,0096                                   | 0,078                               |
| light brown     | 0,0207                               | 0,0223                                        | -                                        | -                                   |
One can see that the inheritance coefficients we obtained for the main color forms of sables bred at the Federal state unitary enterprise “Russkiy Sobol are black-brown $h^2=0.128$; dark brown $h^2=0.108$ and chestnut $h^2=0.078$ are close to the data established earlier for the closely related sable species (American mink).

In particular, it was found that in the standard black mink, the inheritance of intensely dark hair color ranges from $0.20-0.30$ [10]. In this connection, previously obtained by S. V. Pavlyuchenko [2] the values of the inheritance coefficients of the general coloration in sables in the range from 0.220 to 0.772 appear to be overestimated.

4. Conclusion

Thus, the population analysis on the heritability of the main color of various color forms of sables shows a high selective selection for dimming the hairline and its absence for the formation of a herd of “clarified” animals.

At the same time, the high birth rate of sables with a lighter color (chestnut) is most likely due to both the additive inheritance of the wild-type color tone and the possible influence of external environmental factors. Something is also indicated by higher values of the average intragroup dispersion ($\overline{\sigma_i^2}$) in lighter animals are black-brown 0.0252, dark brown 0.0990 and chestnut - 0.1137.

It is known that the higher the sensitivity of a particular genotype to environmental conditions, the greater its average intragroup dispersion. Accordingly, the proposed analysis method can be used in animal husbandry to assess the effectiveness of the breeding process to improve specific color forms of sables.

References

[1] Pavlyuchenko S V and Utkin L G 1979 Farm sable Breeding (Moscow: Koloss)
[2] Pavlyuchenko S V 1981 Variability and inheritance of coloration of the outer and down hair of sables (Moscow)
[3] Ilyina E D and Sobolev A D 1990 Fur farming (Moscow: Agropromizdat)
[4] Beketov S V, Koreshkov A R and Karpov K S 2016 Factors affecting fertility in fur animals of industrial breeding Rabbit breeding and fur farming 4 18–23
[5] Malykh S B, Egorova M S and Meshkova T A 1998 Fundamentals of psychogenetics (Moscow: Epidaurus)
[6] Glanz S 1999 Biomedical statistics (M: Practice)
[7] Antonisamy B, Premkumar P S and Christopher S 2017 Principles & Practice of Biostatistics Elsevier India p 390
[8] Beketov S V and Kazakova T I 2012 The relationship between hair color and reproductivity of female sables of cellular content Rabbit breeding and fur farming 2 16-9
[9] Beketov S V et al. 2019 Dimming of color as a marker of a decrease in reproductive ability in female sables (Martes zibellina) and minks (Neovison vison) Ecological Genetics 17 75-86
[10] Joergensen G 1985 Mink production (Hilleroed: Scientifur)