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# Genetic parameters of coat colour in golden fox (*Vulpes vulpes* L.)

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**Abstract.** Genetic parameters (heritability, genetic and phenotypic correlations) of chosen coat colour traits of golden fox were estimated. 1013 animals, born on the Śniaty fox farm (Poland) in 1985-1999 were evaluated. In 1993-1999 colour type was additionally assessed for 833 animals, by detailed evaluation of coat colour on the back and sides of the body, throat colour, belly colour and the amount of silver hair. The REML method was used to estimate genetic (co)variance components. Data were transformed using the probit transformation. Heritability estimates for coat traits were low (0.04 to 0.22). Values of most of the estimated genetic parameters ($h^2$, $r_G$, $r_P$) were comparable to those frequently reported for other colour types of silver fox.

**Key words**: coat colour, genetic parameters, golden fox, *Vulpes vulpes*.

## Introduction

Golden fox, one of the colour varieties of silver fox (*Vulpes vulpes* L.), is not widely bred on farms. The individuals of this colour variety were obtained by crossing silver foxes with wild red foxes. The crossbreds are usually more intensively red than wild foxes. Furthermore, red fox has a darker belly, tail and black limb endings as well as black outsides of ears. Coat silvering, caused by partly non-pigmented guard hairs and the presence of single white hairs in the coat, is inherited from the silver fox. Coat silvering is independent from the main colour and is usually richer when one of the parents is a black silver fox.

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There are three colour types among golden foxes: (1) dark, which is characterised by dark orange coat on the back and sides of the body, contrastable to non-pigmented hair and white or light grey throat and belly; (2) medium, with orange back and sides of the body, contrastable to non-pigmented hair and white or light grey throat; (3) light, with straw-coloured or light orange back and sides and throat of a different colour – from white to dark grey.

On breeding farms golden foxes are mated within the colour type or with foxes of other colour types, especially silver ones. Mating of golden foxes within the colour type gives 90-92% of offspring with golden coat and 8-10% with silver coat (FILISTOWICZ, KIECOŃ 1996, JEŻEWSKA 1987). Crossbreeding with other colour types of silver foxes gives a lower percentage of golden pups.

Variability of colour type of throat and belly, and the amount of silver hair in golden foxes is relatively high, although golden foxes are usually kept in small populations. High variability of coat colour in golden foxes is caused by a still unsatisfactory selection effectiveness (golden fox is bred in Poland only since the mid 1980s), mating of red foxes with silver foxes, and temporary enriching of the resources of genes determining red colour by crossing golden or silver foxes with wild red foxes (caught in nature). The increased frequency of wild red genes has led to significantly lower scores of general appearance. However, scores of the other coat traits are almost unchanged (KUYDOWICZ et al. 1999).

Available publications (FILISTOWICZ, KIECOŃ 1996, JEŻEWSKA 1987, KUYDOWICZ et al. 1999) do not present data on genetic determination of colour type in golden foxes including additional coat features (throat and belly colour, amount of silver hair). The main coat colours (red and black) are considered to be qualitative traits encoded by loci A and B, and inherited according to Mendelian rules (NES et al. 1988). Additional coat colour features mentioned above are determined by many genes (quantitative inheritance) and can be changed by selection (FILISTOWICZ et al. 1999, JEŻEWSKA 1987, WIERZBICKI 1999, WIERZBICKI 2000). Thus, an attempt has been made in this study to estimate the heritability of these features and genetic and phenotypic correlations between coat colour traits and total score of golden foxes.

## Material and methods

The material taken into account consisted of coat trait scores of 1023 young golden foxes bred on the Śniaty fox farm (Poland). All foxes were born on the farm in 1985-1999. The evaluation of coat traits was performed by the same judge, according to the grading standard (official instruction – CSHZ 1998), always when a fox fur was fully developed (in December). Scores from 1993-1999 were transformed into grades identical to those given during the first golden fox evaluation (in 1985). The following traits were considered: colour type, purity of main colour and total score – all expressed in points according to the grading standard from 1985 (Table 1).

In 1993-1999 a detailed evaluation of colour type of 833 young foxes was performed, including coat colour on the back and sides of the body, throat colour, belly colour and amount of silver hair. Each of the mentioned features was expressed on a scale of 1-3 (Table 1). Detailed evaluation of colour type was performed by the same judge during the December body conformation assessment.

Foxes of unknown pedigree and the ones culled during the body conformation assessment were not taken into account during analyses. Since 1986, one of the basic principles of the breeding work conducted on the farm has been avoiding of inbreeding (only animals related to each other less than 5% were mated). This policy, as well as import of foxes from other Polish farms, considerably reduced relationships and inbreeding. The number of animals considered in our study and statistical characteristics of their scores are presented in Table 2.

The (co)variance components were estimated using the Restricted Maximum Likelihood (REML) method under the mixed model:

$$Y_{ijklmn} = \mu_i + a_{ij} + b_{ik} + s_{il} + d_{ilm} + e_{ijklmn},$$

where: $\mu_i$ = overall mean of i-th trait, $a_{ij}$ = fixed effect of birth season (j = 1, 2), $b_{ik}$ = fixed effect of birth year (k = 1, ..., 14), $s_{il}$ = random effect of sire, $d_{ilm}$ = random effect of dam, $e_{ijklmn}$ = random error.

It is assumed that variances of random sire, dam and error effects are $\sigma^2_s$, $\sigma^2_d$ and $\sigma^2_e$, respectively. Moreover, null covariances between these random effects are assumed.

Before calculations the data were transformed from discrete to a continuous scale using the probit transformation, according to the procedure described by ŻUK (1989).

Heritability estimates were derived from a sire variance ($\sigma^2_s$). Genetic ($r_G$) and phenotypic ($r_P$) correlations between studied traits were estimated on the basis of sire (co)variance. Estimation of variance and covariance components was performed by the use of VARCOMP and NESTED procedures of SAS (SAS 1988).

## Results and discussion

The results of the official evaluation of colour type, purity of red colour and the detailed scores of colour type of red foxes were expressed on a scale of 1-3 (only purity of red colour was described by 6, 4 or 2 points) (Table 1). Comparison of means and standard deviations of these traits shows that during official evaluation, maximum and average scores were used more often than in colour type evaluation, where the whole scale of scores was applied. Due to these reasons, official scores of colour type were characterised by larger skewness than detailed evaluation of colour type (Table 2). Among the latter, the most noticeable skewness was

**Table 1**. Pattern of colour type evaluation applied in the present study

| Official grading[1] | | | Detailed colour type evaluation | | | | |
|---|---|---|---|---|---|---|---|
| Defects | Colour type | Red colour purity | Scores | Colour | | | Amount of silver hair |
| | | | | Back and sides | Throat | Belly | |
| Lack | 3 | 6 | 1 | dark | grey | grey | < 25% |
| Little | 2 | 4 | 2 | medium | light grey | light grey | 26-50% |
| Large | 1 | 2 | 3 | light | white | white | > 50% |

[1] animals with large coat defects were not included into analysis.

found for throat colour – white throat was recorded relatively often (3 points) while grey throat was very rare (1 point). Significant skewness of score distribution and narrow scale of trait scores needed to be corrected, which was achieved with the use of the probit transformation of the data set (ŻUK 1989).

**Table 2.** Number of studied animals and statistical description of colour type scores

| Trait | Average | Standard deviation | Extreme scores | Skewness |
|---|---|---|---|---|
| Official grading (1013 individuals)<br>– colour type | 2.70 | 0.71 | 1.0-3.0 | –1.90 |
| – red colour purity | 4.31 | 1.09 | 2.0-6.0 | 0.10 |
| – total score | 26.76 | 1.64 | 20.0-30.0 | –0.42 |
| Detailed colour type evaluation (833 individuals)<br>– back and side colour | 1.80 | 0.72 | 1.0-3.0 | 0.32 |
| – throat colour | 2.35 | 0.72 | 1.0-3.0 | –0.65 |
| – belly colour | 1.76 | 0.76 | 1.0-3.0 | 0.44 |
| – amount of silver hair | 1.88 | 0.56 | 1.0-3.0 | –0.03 |

Relatively low heritability estimates of the analysed traits (Table 3) were obtained. It should be stressed, that they carried quite noticeable standard errors due to the limited number of studied animals. Standard errors of heritability estimates of the traits officially evaluated on 1013 individuals varied from 0.08 (belly colour and amount of silver) to 0.14 (colour type and total score). The standard errors of heritability estimates of detailed evaluation of colour type (0.08 for belly colour to 0.09 for back and side colour) were smaller, although they were estimated on 833 animals only. The heritability estimates of total score and purity of the main colour (red) did not differ from average values of $h^2$ for silver fox (0.23 and 0.21,

Table 3. Heritability estimates (bold letters), standard errors (in brackets), genetic (above diagonal) and phenotypic (below diagonal) correlation estimates of studied traits

| Traits | 1. | 2. | 3. | 4. | 5. | 6. | 7. |
|---|---|---|---|---|---|---|---|
| 1. Colour type | **0.08** (0.14) | 0.34 | 0.63 | –0.75 | –0.03 | 0.08 | –0.37 |
| 2. Red colour purity | 0.26 | **0.19** (0.08) | 0.79 | 0.25 | 0.15 | 0.23 | –0.97 |
| 3. Total score | 0.63 | 0.77 | **0.22** (0.14) | 0.58 | 0.02 | 0.13 | –0.79 |
| 4. Back and side colour | –0.72 | 0.18 | 0.54 | **0.17** (0.09) | 0.05 | 0.06 | –0.18 |
| 5. Throat colour | –0.05 | 0.12 | 0.06 | 0.06 | **0.12** (0.09) | 0.78 | –0.12 |
| 6. Belly colour | –0.02 | 0.15 | 0.09 | 0.03 | 0.64 | **0.04** (0.08) | –0.14 |
| 7. Amount of silver hair | –0.26 | –0.96 | –0.76 | –0.25 | –0.14 | –0.21 | **0.10** (0.08) |

respectively – FILISTOWICZ, ŻUK 1995) and were higher than $h^2$ of the same traits in pastel foxes (JAKUBCZAK 2000). A similar value of $h^2$ for colour purity was reported by FILISTOWICZ et al. (1999), who performed *intra vitam* evaluation of silver foxes ($h^2 = 0.21$), and KENTTÄMIES (1989), who evaluated colour purity in bluefrost ($h^2 = 0.23$) and golden island ($h^2 = 0.22$) foxes – the results of crossing polar fox with silver fox. In another study, KENTTÄMIES (1990) found that blackness purity evaluated on living animals had a significantly lower heritability (0.13) than on prepared skins (0.31).

Heritabilities of total score for arctic fox were generally higher than for silver fox (FILISTOWICZ, ŻUK 1995, SOCHA 1994, WIERZBICKI 2000, WIERZBICKI, FILISTOWICZ 1999,).

The colour type heritability (Table 3) was markedly lower than the corresponding $h^2$ values obtained for silver fox (0.17 – FILISTOWICZ et al. 1999) and for pastel fox (0.21 – JAKUBCZAK 2000).

There are no available reports on the subject in question, which could be directly compared with the results obtained in our study (Table 3). Comparison of the heritability coefficients estimated for coat traits evaluated in detail with the $h^2$ values estimated for coat colour traits officially evaluated suggests that assessment of back and side coat colour should be a more effective selection criterion ($h^2 = 0.17$) than official evaluation of colour type ($h^2 = 0.08$). A relatively effective selection criterion might also be throat colour ($h^2 = 0.12$). It seems that selection towards colour type improvement, based on scores of back, sides and throat colour should be more effective than selection based on scores given during official evaluation of colour type. However, its effectiveness also cannot be high because of low $h^2$ values (Table 3).

As expected, very high genetic and phenotypic correlations between total score and its components – colour type and red colour purity were obtained (Table 3). Values of genetic and phenotypic correlations between total score and colour purity in silver fox population reported by FILISTOWICZ et al. (1999) and in pastel foxes reported by JAKUBCZAK (2000) were lower (0.28 and 0.45, 0.32 and 0.43, respectively). Correlation values between total score and colour type in pastel fox population (JAKUBCZAK 2000): $r_G = 0.44$ and $r_P = 0.38$ were also similar to parameters calculated for the golden fox population (Table 3). In contrast, significantly different values were obtained for silver fox ($r_G = -0.26$ and $r_P = 0.15$, FILISTOWICZ et al. 1999).

Generally, the magnitude of phenotypic correlations between all seven traits corresponded with genetic correlations (Table 3). Values of $r_P$ had the same sign (except few, slightly different from 0) and were similar to corresponding genetic correlations.

Very interesting are the associations between the detailed evaluation of colour type and official grading scores. High negative correlations were found between colour type and back and side coat colour ($r_G = -0.75$ and $r_P = -0.72$) and between red colour purity and amount of silver hair ($r_G = -0.79$ and $r_P = 0.76$). Sign '–' means that animals with dark coat on the back and body sides, and with slight coat silvering were preferred during official grading as the closest to the standard, whereas individuals with light back and sides coat and with noticeable silvering were treated as animals with significant defects of colour type and purity of the main colour (red). Relatively high positive correlations ($r_G = 0.58$ and $r_P = 0.54$) between back and side coat colour and total score might indicate that animals of light coat (3 points) often get a higher total score. It is possible that subjective selectioner preferences favoured lighter animals during the evaluation of size and body conformation (light animals seem to be larger) and during assessment of the main colour (richer hair silvering is less seen and is not in contrast with lighter hair coat).

The results obtained in the present study indicate that 30-point grading standard of fox coat obligatory in Polish fox breeding up to 1997 was a hardly useful criterion of selection towards improvement of colour type and amount of silver hair.

## Conclusions

Gold is a relatively rare colour variety of silver fox. It is bred in Poland since the mid 1980s. Here we present the first estimates of genetic parameters of coat and colour type traits in golden fox. Heritabilities of total score and purity of the main colour (red) in golden fox were comparable to the respective $h^2$ values in populations of silver and pastel foxes. Very low heritability was estimated for colour type ($h^2 = 0.08$). Higher $h^2$ values were obtained for red colour on the back and sides of the body (0.17) as well as throat colour (0.12) – both traits are important components in the total score of colour type. Thus the authors postulate to use the scores of coat colour on the back, sides of the body and throat as criteria of selection towards colour type improvement.

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