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INHERITANCE OF ORANGE PIGMENTATION AND SCALE PATTERN IN COMMON CARP (*CYPRINUS CARPIO* L.)

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Abstract. The aim of this study was to identify the type of genetic determination of orange pigmentation and scale pattern in carp. The parental fish used in the experiment were obtained from crossing two breeding strains, *i.e.*, the Polish Starzawa S strain with scaled phenotype and normal pigmentation and the Hungarian strain C with mirror scale pattern and orange pigmentation. The mating of the two parental pairs resulted in four groups of F_1offspring that were reared in ponds. It was observed that the two traits were inherited independently. Two pairs of alleles at two gene loci determined fish pigmentation. The orange fish were double recessive *aacc* homozygotes. All of the spawners used in the experiment were double heterozygotes with respect to color and scaliness *SsnnAaCc*.

Keywords: INHERITANCE, PIGMENTATION, SCALE PATTERN, COMMON CARP (*CYPRINUS CARPIO*)

INTRODUCTION

Carp, *Cyprinus carpio* L., individuals with orange pigmentation have been observed in pond farms in Poland in recent years. Although it has only occurred in mirror carp, this phenomenon is unfavorable. In Poland, where the sale of live carp is the prevalent way of trading this species, orange individuals are rejected by consumers. On the other hand, the pigmentation is not attractive enough so that orange individuals could be sold as ornamental fish. Therefore, it has become necessary to eliminate the orange fish from farm fishponds.

The infrequent occurrence of orange carp was noted at fish farms in Israel (Moav and Wohlfart 1968), Germany (Steffens 1975), and Poland (Irnazarow and Białowąs 2000) as well as in the lakes of North America (Shoemaker 1943). In the 1950s, the occurrence of blue carp was observed in Poland (Włodek 1963). Similar pigmentation was also observed in carp in Germany and Israel (Probst 1949, Moav and Wohlfart 1968). In most cases, colored individuals exhibited lower weight increases and poorer survival than fish with wild coloration.

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Knowledge of the genetic background of pigmentation is necessary to eliminate colored individuals from the breeding stock. Studies of carp spawners using gynogenesis indicated the presence of genes that determine orange coloration but did not explain the mechanism of color determination because of the low survival rate of gynogenetic individuals (Irnazarow and Białowąs 2000).

The aim of the present study was to identify the genetic mechanism of common carp coloration. Since two types of scale pattern, mirror and scaled, are used in common carp production, the relationship between scale pattern and fish coloration was also investigated.

MATERIALS AND METHODS

The study material was comprised of two females marked "A" and "E" and two males marked "4" and "7" obtained from crossing two breeding strains, *i.e.*, the Polish Starzawa S strain with scaled phenotype and normal pigmentation and the Hungarian strain C (Guziur et al. 2003) with mirror scale pattern and orange pigmentation. The pigmentation of this strain changes during fish ontogeny. During the third year of life, irregular gray spots appear on the skin of the orange fish, and this increases in successive years. Several test crossings have shown that pigmentation and scaliness are homozygous in both strains, and that they are dominant in the Starzawa strain and recessive in the Hungarian C strain. The spawners used in the study were scaled and had wild (normal) coloration. The males were backcrossed one year earlier with females of both parental strains. The progeny of the crossing with the Starzawa strain were scaled and had normal coloration. The crossing with the Hungarian C strain resulted in equed distribution of scaled and mirror type in progeny. Within each type of scale pattern, about 20% of the individuals were orange and the rest had wild coloring (Białowąs, unpublished data).

Spawning was conducted under controlled conditions. Four groups of progeny were obtained from the mating. Ponds with a surface area of 670 m^2 each were stocked with separate groups at 2500 larvae per pond. All of the ponds were as similar to each other as possible regarding environmental and fish treatment conditions. The fish were fed with wheat grain during rearing. After four months the fish were caught and sorted according to their pigmentation and scale pattern. The survival of each group was estimated. The number of individuals with the various scale patterns and pigmentation were determined in each group.

The χ^2-test was used to compare the anticipated and observed frequencies of different phenotypes (Sokal and Rohlf 1995).

RESULTS

The effects of reproduction, the number of fish of different phenotypes, and the survival of groups in the rearing period are given in Table 1. Orange pigmentation was observed in the early stage of larval development. Hatching varied from 87.1 to 90.4%, while the survival of the groups in the rearing period ranged from 59.6 to 90.6%.

TABLE 1

Survival by group of reared common carp, number of fish (N) in each group and the observed frequency ratio (R) of fish of a particular phenotype

Mating (female x male)	Survival (%)	Fish phenotype								χ^2	Probability
		Normal (wild) coloration				Orange color					
		Scaled		Mirror		Scaled		Mirror			
		N	R	N	R	N	R	N	R		
A x 4	90.6	1581	63.2	575	23.0	93	3.7	25	1	0.236	P < 0.971
A x 7	59.6	1043	43.4	342	14.2	80	3.3	24	1	0.072	P < 0.995
E x 4	64.1	1180	84.3	367	26.2	72	5.1	14	1	0.274	P < 0.965
E x 7	77.0	1383	55.3	439	17.6	79	3.2	25	1	0.106	P < 0.991

The ratios of scaled normal: mirror normal: scaled orange: mirror orange were 45: 15: 3: 1 (Table 1). The observed ratio for scale cover was 3:1, and for color type it was 15:1. The χ^2-test showed the accordance of the expected phenotype frequency with the observed one (Table 1). The independent inheritance of both the traits of scaling and pigmentation was determined.

DISCUSSION

The genetic determination of scale cover in common carp is known. Two unlinked autosomal loci – *S* and *N*, each with two alleles, are responsible for basic scaly types (Kirpichnikov 1999). In the case of orange pigmentation, the system of genetic control has not yet been fully explained. According to Katasonov et al. (1999), the normal coloration of ornamental Koi carp is determined by the occurrence of two types of pigment cells – melanophores and xanthophores. The absence of dark pigmentation (melanophores) is due to a pair of recessive $b_1b_1b_2b_2$ genes. Such an individual exhibits orange coloring due to the occurrence of xanthophores only. In turn, recessive *r* genes

determine the absence of colored xanthophores. This is phenotypically manifested by bluish (steel-gray) coloration. The $b_1b_1b_2b_2rr$ genotype determines the absence of both types of pigment cells. Such an individual is white. The effects of inhibitory *i* genes should also be taken into consideration. They modify the action of pigment genes described above according to the model of the recessive $ii \rightarrow B_1$, B_2 and *R* epistasis (Katasonov et al. 1999). It should be added that at the stage of hatching $b_1b_1b_2b_2$ homozygotes are transparent (no black pigment cells – melanophores) while their orange pigmentation develops later on.

In the current study, larvae already exhibited orange pigmentation at the hatching stage, thus suggesting a different type of genetic control of coloration. Hence, in the Punnett square presenting the formula of color and scaling inheritance in the mating conducted (Table 2), different letter symbols were used to indicate the pigment conditioning genes.

TABLE 2

Punnett square for mating of two heterozygous common carp S*snnAaCc*

		Male gametes (*SsnnAaCc*)							
		SnAC	*SnaC*	*SnAc*	*Snac*	*snAC*	*snaC*	*snAc*	*snac*
Female gametes (*SsnnAaCc*)	*SnAC*	*SSnnAACC* scaled normal	*SSnnAaCC* scaled normal	*SSnnAACc* scaled normal	*SSnnAaCc* scaled normal	*SsnnAACC* scaled normal	*SsnnAaCC* scaled normal	*SsnnAACc* Scaled normal	*SsnnAaCc* scaled normal
	SnaC	*SSnnAaCC* scaled normal	*SSnnaaCC* scaled normal	*SSnnAaCc* scaled normal	*SSnnaaCc* scaled normal	*SsnnAaCC* scaled normal	*SsnnaaCC* scaled normal	*SsnnAaCc* Scaled normal	*SsnnaaCc* scaled normal
	SnAc	*SSnnAACc* scaled normal	*SSnnAaCc* scaled normal	*SSnnAACc* scaled normal	*SSnnAacc* scaled normal	*SsnnAACc* scaled normal	*SsnnAaCc* scaled normal	*SsnnAACc* Scaled normal	*SsnnAacc* scaled normal
	Snac	*SSnnAaCc* scaled normal	*SSnnaaCc* scaled normal	*SSnnAacc* scaled normal	*SSnnaacc* scaled orange	*SsnnAaCc* scaled normal	*SsnnaaCc* scaled normal	*SsnnAacc* Scaled normal	*Ssnnaacc* scaled orange
	snAC	*SsnnAACC* scaled normal	*SsnnAaCC* scaled normal	*SsnnAACc* scaled normal	*SsnnAaCc* scaled normal	*ssnnAACC* mirror normal	*ssnnAaCC* mirror normal	*ssnnAACc* mirror normal	*ssnnAaCc* mirror normal
	snaC	*SsnnAaCC* scaled normal	*SsnnaaCC* scaled normal	*SsnnAaCc* scaled normal	*SsnnaaCc* scaled normal	*ssnnAaCC* mirror normal	*ssnnaaCC* mirror normal	*ssnnAaCc* mirror normal	*ssnnaaCc* mirror normal
	snAc	*SsnnAACc* scaled normal	*SsnnAaCc* scaled normal	*SsnnAACc* scaled normal	*SsnnAacc* scaled normal	*ssnnAACc* mirror normal	*ssnnAaCc* mirror normal	*ssnnAACc* mirror normal	*ssnnAacc* mirror normal
	snac	*SsnnAaCc* scaled normal	*SsnnaaCc* scaled normal	*SsnnAacc* scaled normal	*Ssnnaacc* scaled orange	*ssnnAaCc* mirror normal	*ssnnaaCc* mirror normal	*ssnnAacc* mirror normal	*ssnnaacc* mirror orange

Two pairs of alleles at two loci determined the coloration. The orange individuals were double recessive *aacc* homozygotes. Two analyzed trait types of scale cover and color type are inherited independently. The observed ratio for scale cover was scaled: mirror = 3:1 and for color type it was wild: orange = 15:1. The analysis of genotypic ratios (Table 2) indicated that all spawners used in the experiment were double heterozygotes with respect to color and scaliness *SsnnAaCc*.

CONCLUSION

In order to eliminate orange fish from the breeding stocks of commercial common carp farms, all spawners used for reproduction should be tested for the presence of the *ac* genes. The spawners should be mated with double recessive *aacc* homozygotes or the *AaCc* heterozygotes used in the present experiment. If orange pigmentation does occur in the progeny, then the spawner should be eliminated from reproduction. These tests can be conducted at farms that deal with carp reproduction.

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STRESZCZENIE

DZIEDZICZENIE POMARAŃCZOWEGO UBARWIENIA I UŁUSZCZENIA U KARPIA (*CYPRINUS CARPIO* L.)

Celem prezentowanego doświadczenia było określenie typu genetycznej determinacji ubarwienia pomarańczowego, jakie zaczęło się pojawiać u karpi w gospodarstwach stawowych w Polsce. Ubarwienie to obserwowano tylko u osobników posiadających ułuszczenie lustrzenia. W doświadczeniu użyto tarlaków otrzymanych w wyniku krzyżowania dwóch linii hodowlanych karpia: polskiej starzawskiej S posiadającej ułuszczenie pełnołuskie i ubarwienie dzikie oraz węgierskiej C posiadającej ułuszczenie lustrzenia i ubarwienie czerwone. W wyniku kojarzenia dwóch par tarlaków otrzymano cztery grupy ryb, które cho-

wano w stawach. Obserwowana frekwencja fenotypów typu ułuszczenia wynosiła 3:1, a typu ubarwienia 15:1. Stwierdzono niezależne dziedziczenie obu cech. Ubarwienie determinowane było dwoma parami alleli w dwóch loci. Ubarwienie czerwone posiadały podwójne recesywne heterozygoty *aacc*. Analiza frekwencji genotypów wykazała, że wszystkie tarlaki użyte w doświadczeniu były heterozygotami pod względem ułuszczenia i ubarwienia *SsnnAaCc*.