The Fish Biology Journal MEDAKA, **5**: 37–38 (1993)

A study on the transparent-scaled mutant *ne*^{3} of the crucian carp, *Carassius auratus langsdorfii*

Hideo Tomita

Laboratory of Freshwater Fish Stocks, BioScience Center, Nagoya University, Chikusa-ku, Nagoya 464-01, Japan

Abstract There are two reproductive forms in crucian carp, *Carassius auratus langsdorfii*. The bisexual form produces females and males in a ratio of 1:1, whereas the unisexual form is reproduced gynogenetically. A mutant with transparent scales (*ne*^{3}) was found in the bisexual form, which belonged to the *ne* alleles (+>*ne*^{3}>*ne*). In the unisexual form, four transparent-scaled females resembling the *ne* and *ne*^{3} mutants were found in the field, but genetic analysis to confirm their relationship to these genes was not possible because of their gynogenetic nature. Their progenies were transparent-scaled females. In some cases, two variants with a similar scale transparency but differing in the distribution pattern of the transparent scales among the whole scale population were segregated in the progenies.

Introduction

Natural populations of crucian carp consist of bisexual and unisexual forms (Cherfas, 1972; Yamamoto and Kajishima, 1984). Unisexual females are inseminated by males, but the male characteristics are not inherited. In the bisexual form, the nacreous-like transparent-scaled mutant (*ne*) has been analyzed (Yamamoto, 1977). Only a small amount of guanine is deposited in iridocytes of scales and of the eye reflective layer in this mutant. The *ne* gene exerts no effects on melanophores and xanthophores.

I purchased in a pet shop a bisexual variant of the crucian carp resembling *ne* but definitely different from it, and genetic analyses proved that this mutant *ne*^{3} belonged to the *ne* alleles. Transparent-scaled fish of the unisexual form resembling *ne* and *ne*^{3} were also purchased or collected from the field, but genetic analysis to define their relationship to *ne* and *ne*^{3} was not possible because of their gynogenetic nature. This paper describes the results of genetic analyses and phenotypic expression of the *ne*^{3} gene and other *ne*- and *ne*^{3}-like genes. These mutant genes have previously been listed by Tomita (1992).

Materials

In 1979, a transparent-scaled female was collected from the western suburbs of Nagoya. This fish had a considerable number of completely transparent scales amongst normal scales. This transparent-scaled characteristic was different from the *ne* phenotype. Almost all scales of the *ne* mutant have an attenuated amount of guanine, exhibiting nacreous-like transparent appearance, and normal, metallic scales are almost absent.

In 1985, a transparent-scaled male which was very similar in appearance to the 1979 female was purchased from a pet shop in Nagoya. The proprietor of this shop told that this fish had been caught in Lake Biwa.

In 1988, a transparent-scaled female was again collected from the western suburbs of Nagoya.

In 1989, a nacreous-like transparent-scaled female (*ne*-like) was found in the western suburbs of Nagoya.

In 1992, a transparent-scaled female was collected.

In 1992, a transparent-scaled male was purchased from a pet shop in Nagoya. This fish had been caught in Shonaigawa (Shonai river) in Nagoya.

Altogether, one *ne*-like female fish and three female and two male fish resembling *ne* but differing in having some completely transparent scales amongst normal scales were thus obtained, and they were subjected to genetic analysis.

Results

To assess the reproductive form, a transparent-scaled female in question was mated with a dominant transparent-scaled goldfish male (*T/t*). If the female is bisexual, the progeny should be segregated into fish with normal scales and those with dominant transparent scales in a ratio of 1:1 and the sex ratio should be 1:1. If the female is unisexual, the progeny should be all transparent-scaled females.

A wild-type female was mated with the transparent-scaled male (*ne*^{3}) purchased in 1985.

The F_1 progenies were 12 wild type (female 5, male 7). Four pairs of the F_1 progenies were used for the test crosses. The F_2 progenies from the first pair were 18 wild type and 4 *ne*^{3}. The second F_2 progenies were 22 wild type and 2 *ne*. The third F_2 progenies were 10 wild type and 3 *ne*^{3}. The fourth F_2 progenies were 11 wild type and 3 *ne*^{3}. The results indicated that the parent *ne*^{3} male was the heterozygote of *ne* and a novel mutant gene allelic to *ne* that I designated *ne*^{3}.

Two crosses were made between the *ne*^{3} females and *ne*^{3} males that were obtained in the above experiment. In one cross, the progenies were 23 *ne*^{3}. In the other cross, the progenies were 14 *ne*^{3} and 4 *ne*. In this case, the parent fish were therefore the heterozygotes of *ne*^{3} and *ne*. The *ne*^{3} and *ne* genes are the alleles, and the *ne*^{3} gene is dominant over the *ne* gene ($+>ne^3>ne$).

An *ne* female derived from the *ne* mutant that was established by Yamamoto (1977) was mated with an *ne*^{3} male produced in the first experiment. The progenies were 9 *ne*^{3} and 8 *ne* in a ratio of 1:1. The parent *ne*^{3} male was therefore heterozygous (ne/ne^3).

The *ne*^{3}-like female collected in 1979 was mated with a *T/t* goldfish male. The progenies were 16 transparent-scaled females. The *ne*^{3}-like female was therefore gynogenetic.

The *ne*^{3}-like female collected in 1988 was mated with a *T/t* goldfish male. The progenies were 14 *ne*^{3}-like females and 2 (*ne*^{3}-like)' females. The (*ne*^{3}-like)' females were distinct from the *ne*^{3}-like females in that the majority of scales were transparent and only a few normal, metallic scales were present, contrasting with the *ne*^{3}-like females which had many transparent scales but the majority of scales were normal, amongst which the transparent scales were locally distributed. One of the two *ne*^{3}-like females obtained above was mated with a *T/t* goldfish male. The progenies were all *ne*^{3}-like females (36 fish).

The parent *ne*^{3}-like female used in the preceding experiment was again mated with another *T/t* goldfish male. The progenies were 65 *ne*^{3}-like females and one (*ne*^{3}-like)' female. The *ne*^{3}-like females produced mostly the *ne*^{3}-like females and a few (*ne*^{3}-like)' females. Thus, the 1988 *ne*^{3}-like female reproduced gynogenetically and the progenies were segregated into two slightly different types.

The nacreous-like transparent-scaled female (*ne*-like) collected in 1989 was mated with a *T/t* goldfish male. The progenies were 42 *ne*-like females, indicating that the *ne*-like mother was a gynogenetic form. These *ne*-like females had often a few metallic scales amongst the nacreous-like transparent scales.

The *ne*^{3}-like female collected from the field in 1992 was mated with a *T/t* goldfish male. The progenies were 60 *ne*^{3}-like fish (The sexes were not discerned because the fish were still juvenile when this paper is being prepared). The *ne*^{3}-like mother was therefore most probably gynogenetic.

Discussion

Two types of transparent-scaled mutants have previously been described, i.e., the incomplete dominant *T* in the goldfish (Chen, 1928) and the recessive nacreous-like transparent-scaled in the goldfish (*n*: Matsui, 1993; *g*: Kajishima, 1977) and in the crucian carp (*ne*: Yamamoto, 1977). The *T* gene affects the expression of melanophores, xanthophores and iridocytes. The *T* homozygote (*T/T*) often lacks iridocytes, melanophores and xanthophores, and shows transparent, colorless body. The *T* gene exerts a pleiotropic action on the pigment cells.

The *n* mutant of Matsui (1933) was lost. The mutant *g* established by Kajishima (1977) was similar to *n* of Matsui. The *g* and *ne* genes have been inferred to be the same gene (Kajishima, personal communication).

In the present study, I have described a novel mutant gene *ne*^{3} of the crucian carp, which is allelic to *ne*. Four more mutants which are apparently *ne*-like or *ne*^{3}-like were found, but whether they are allelic to *ne* or *ne*^{3} was not confirmed because of their gynogenetic nature.

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