



An evolutionary origin and selection process of goldfish

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ABSTRACT

Many different physical characteristics of goldfish (*Carassius auratus auratus*), such as celestial and telescopic eyes, fancy but uncontrollable shapes of tail fin, an unfittingly fat body, and loss of dorsal fins, provide us with a unique opportunity of studying artificial selection on phenotypic changes on the basis of molecular evolution. The aim of the present study is to elucidate the evolutionary origin and history of goldfish, taking into account the different characteristics of goldfish and human culture. Collecting 44 samples of a variety of goldfish from Japan and China as well as common and Crucian carps, we determined the nucleotide sequences for a substantial portion of mitochondrial genome including eight gene regions (*D-loop*, *12SrRNA*, *16SrRNA*, *ND1*, *ND2*, *COI*, *ND5* and *Cyt b*) of approximately 11,180 bps. We, then, constructed phylogenetic trees for a total of 78 fishes, adding the 19 sequence data available in the international DNA database DDBJ/EMBL/GenBank to our 59 sequence data determined. From the phylogenetic trees obtained, we found that Japanese goldfish are not relative to Japanese Crucian carp (*Carassius auratus langsdorfi*) and that all the goldfish examined were originated from one of the two groups of the Chinese Crucian carp “Gibelio” (*Carassius auratus gibelio*). Moreover, we found that the process of artificial selection began from losing the dorsal fin followed by diversification of other characters such as eyes. This is supported by our further observations that the improvement of celestial and telescope eyes took place independently at different times, implying that goldfish was imposed by strong artificial selection only to meet diversified needs of human preferences in a unsystematic way.

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1. Introduction

Goldfish (*Carassius auratus auratus*) are widespread throughout the world as the most famous companion fish. Goldfish were derived by the traditional breeding on the oriental cultural background to appreciate fish with beautifully unique phenotypes. From its own history and breeders' passionate efforts, it is no doubt that the goldfish has evolved together with the human culture under artificial selection because human have continuously bred them for the ornamental purpose and preference (Matsui, 1963; Kojima and Takai, 1995; Suzuki, 1997; Smartt, 2001). Goldfish were thought to be originally for social and religious ceremonies (Smartt, 2001). Since their domestication started, however, human preference has strongly influenced alteration of various traits of goldfish. Thus, goldfish are the most prominently domesticated fish in the world, being still one of the most commonly kept aquarium fish.

There are many varieties of goldfish with unique and extreme phenotypes such as celestial and telescopic eyes, fancy but uncontrollable shapes of tail fin, an unfittingly fat body, and loss of dorsal fins

that satisfied human preference and curiosity. Major types of goldfish include varieties that are called Common, Fantail, Comet, Ranchu, Oranda, Shubunkin, Celestial eye, Telescope eye, and Bubble eye.

Common has a normally shaped fish, and its head is without scales, relatively short and wide. For example, Wakin, which is a typical Common, can be basically considered as a common goldfish with twin tails and double anal fins. The body is similar in conformation to almost all other goldfish. Fantail is usually a shorter fish with double tails being forked and united at the base with stiff rays. For example, Ryukin, which is a typical Fantail, has a greatly shortened and deep body with a full, rounded abdomen and long flowing fins. Its caudal tail is a double-tail and is deeply indented even longer than the body. Comet is more like the common goldfish but with longer fins and a slimmer body. It has a more slender look than the common goldfish.

Ranchu does not have a dorsal fin but it does have head growth. It is not long and slender but more circular in shape. Oranda has a lion head with a dorsal fin and head growth. It also has a twin divided tail with weaker rays that allow the lobes to droop in a flowing manner. Shubunkin has generally longer tails; the length of the caudal is actually intermediate in length between that of the Common goldfish and the Comet.

Celestial (also called as Chotengan) is a double-tailed breed of goldfish that has a pair of telescope eyes which are turned upwards,

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pupils gazing skyward. Telescope eye (Demekin) comes in a variety of shapes, having large eyes that stick out similar to a telescope. Moreover, it is double-tailed and has a short round body. For example, Black Moor, a typical Telescope eye, is double-tailed. Bubble eye has a distinctive feature that the bubble sacs are present under each eye. Its body is similar in shape to a cigar without a dorsal fin. However, double fins in proportion to their bodies.

Goldfish is a relatively small member of the carp subfamily (Cyprininae) that also includes the common carp (*Cyprinus carpio*) and Crucian carps (Genus: *Carassius*). In Chinese, this Crucian carp, particularly the orange one, is pronounced as “ji yu” and they have kept them as edible fish (Zhen, 1988). It has known that a Crucian carp can easily change its grey body color to red. This red coloration was first recorded during the Tsin dynasty period of China (265–419 A.D.). Then, the goldfish may have originated from a natural mutation of the Crucian carp in China at the Song (Sung) dynasty, approximately 960–1279 A.D., which originally had a drab olive body color and a single tail fin (Darwin, 1868; Zhen, 1988; 1998). Until the Ming dynasty (1368–1644 A.D.), much fancier goldfish were improved in body colors, shape and fins (Zhen, 1988; Bremster et al., 2004).

The selection on goldfish was mainly pointed to double or triple tails, dorsal finless and short body. The mutations that gave rise to the goldfish may have been taken over from other cyprinid species such as the common carp and tench. In fact, Linnaeus (1758) originally gave to goldfish a species name of *Cyprinus auratus*, because he thought that goldfish was morphologically closer to the common carp. Later on, goldfish was regarded as being closer to Crucian carp than the common carp, and it is renamed as *C. auratus auratus*.

It is said that goldfish were exported to Japan around 1500 A.D. (Matsui, 1963; Kojima and Takai, 1995; Suzuki, 1997; Smartt, 2001), and to Europe sometime around 1700 A.D. (Smartt, 2001; Brewster and Fletcher, 2004). The historical sequences of events in the development of the ancestry of goldfish varieties are reasonably clear. However, the origin of these varieties is unclear, in spite of the apparent influence by human culture. In addition, there has been no detailed evolutionary analysis of various goldfish so far. In particular, molecular evolution of the goldfish with no dorsal fin and with Celestial and Telescope eyes is unclear.

In the present study, we examined an evolutionary origin of goldfish and its selection process during domestication. As for the evolutionary origin in particular, we focused on the two important problems: The first problem is from which species all the goldfish were originated, common carp or Crucian carp, and the second is that if they were originated from the Crucian carp, we asked whether the goldfish originated from a particular group or any group of the Crucian carp, particularly Chinese Crucian carp. Then, we discussed how the artificial selection was imposed in the domestication process of the goldfish, inferring it from the phylogenetic trees.

2. Materials and methods

2.1. Sample collection

The varieties of goldfish examined in the present study are listed in Table 1. Mitochondrial DNA (mtDNA) was isolated from the blood of goldfish. We obtained a total of 78 fish samples 38 goldfish were

Table 1
The number of samples for the goldfish, Crucian carp and common carp examined in the present study

English name Scientific name	Japanese name	Location	Accession no. (D-loop)	Accession no. (ND5)	Accession no. (D-loop, 12SrRNA, 16SrRNA, ND1, ND2, COI and Cyt b)
Goldfish	G18:Kurodemekin (Telescope eye)	Japan (Shizouka)	–	AB378293*	AB379915*
<i>Carassius auratus auratus</i>	G19:Shubunkin	Japan (Shizouka)	–	AB378294*	AB379916*
	G21,G47:Ranchu (no dorsal fin)	Japan (Shizouka)	–	AB378295*, AB378298*	AB379917*,AB379920*
	G40:Chotengan (Celestial eye & no dorsal fin)	Japan (Shizouka)	–	AB378296*	AB379918*
	G43:Oranda-shishigashira	Japan (Shizouka)	–	AB378297*	AB379919*
	G56:Ranchu (no dorsal fin)	China (Guangzhou)	–	AB378299*	AB379921*
	Japanese other goldfish (32samples)	Japan (Tokyo and Shizouka)	AB379923* –AB379954*	–	–
Chinese other goldfish (5samples)	China (Guangzhou)	AB379955* –AB379959*	–	–	
Crucian carp	Gibelio	China	EF633631, EF633632, EF633633, EF633634, EF633635 (Li and Gui, 2007)	–	–
<i>Carassius auratus gibelio</i>	F11:Gibelio	China (Kai Ping)	–	AB378300*	AB379922*
<i>Carassius auratus subsp.</i>	F12,13,15,21,22,24,26:Giberio	China (Kai Ping)	AB377293*–AB377299*	–	–
	F4:Kinbuna	Japan (Tokyo)	AB377291*	–	–
<i>Carassius auratus langsdori</i>	F14:Kinbuna (Hibuna)	Japan (Shizouka)	AB377290*	–	–
	Ginbuna	Japan	AB006953, AB008851, AB012094 (Murakami et al., 1998)	–	–
<i>Carassius auratus cuvieri</i>	Gengorobuna	Japan	AB045144, AB007838 (Murakami et al., 1998)	–	–
Carp	C1,2:Koi (Nishiki-goi)	Japan (Shizouka)	AB377303*,AB377304*, AB15881 (Mabuchi et al., 2005)	–	–
<i>Cyprinus carpio</i>	Koi	Japan (Shiga; Biwa Lake)	AB158808, AB158809, AP009047 (Mabuchi et al., 2005, 2006)	–	–
	C8,9,10:Koi	Thai (Bangkok)	AB377300* –AB377302*	–	–
	Koi	Vietnam	AY597949, AY597951, AY597953 (Thai et al., 2005, 2006)	–	–
	Koi	China	AY345331, AY345334 (Zhou et al., 2003)	–	–

We obtained a total of 78 fish samples; 44 goldfish, 13 Crucian carps “Gibelio”, 7 Japanese Crucian carps, six Japanese common and ornamental carps, three Thai carps, two Chinese carps and three Vietnamese carps. – none.

* This study

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