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Comparative studies on the feeding selectivity of silver carp *Hypophthalmichthys molitrix* and bighead carp *Aristichthys nobilis*

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Silver carp and bighead carp exhibited size-selection for food particles in aquarium experiments, but did not select their preferred species of plankton actively when they were distributed evenly in the water. They also possessed the capacity of selection for feeding area. The removal rates (% g^{-1} fish weight) of silver carp for smaller plankton (phytoplankton) were higher than those of bighead carp. The removal rates by the latter for bigger plankton (zooplankton) were higher than those of silver carp, but for plankton about 70 μm dia. the rates by the two species were almost equal.

Key words: silver carp; bighead carp; feeding selectivity.

I. INTRODUCTION

Silver carp *Hypophthalmichthys molitrix* (Val.) and bighead carp *Aristichthys nobilis* (Rich.) are two species of planktivorous fish that are used widely in aquaculture. Feeding selectivity is an important feature in aquaculture and has two aspects, the selection of particular food particles and the selection of feeding areas in which there are different species or densities of food particles.

Differences in the feeding habits of the two carp species have been reported. Silver carp feed mainly on phytoplankton and bighead carp feed mainly on zooplankton (Ni & Jiang, 1954; He & Li, 1975; Cremer & Smitherman, 1980; Spataru *et al.*, 1983; Burke *et al.*, 1986; Colman & Edwards, 1987; Wang, 1988; Xie, 1989; Shie & Liu, 1991). Several authors have found differences between the gut content of silver carp and the composition of food particles in the water environment, and have concluded that silver carp select certain species of phytoplankton (see reviews in He, 1987 and Colman & Edwards, 1987). However, Smith (1989) found that the retention efficiency of silver carp for various food particles increased with the increase in food particle diameter. There are few reports on food particle selectivity by bighead carp, although Wang (1988) reported its preference for some species of phytoplankton.

He (1987) reported that silver carp might select feeding areas, but this selectivity has not been proved experimentally. Our paper deals with these aspects of selectivity for both silver carp and bighead carp.

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II. MATERIAL AND METHODS

SOURCE AND SIZE OF EXPERIMENTAL FISH

The fish used in the experiments were obtained from the Jiaonan Fish Breeding Farm, Qingdao. The standard lengths of silver carp and bighead carp were $7{\cdot}3 \pm 1{\cdot}5$ and $8{\cdot}3 \pm 1{\cdot}3$ cm, and their weights were $7{\cdot}4 \pm 4{\cdot}9$ and $13{\cdot}4 \pm 1{\cdot}9$ g, respectively.

FOOD PARTICLES USED IN EXPERIMENTS

Food particle size was expressed as equivalent spherical diameter (ESD), by measuring the three dimensions of at least 30 individual particles under a microscope or a dissecting microscope. The rotifers *Brachionus calyciflorus* ($88{\cdot}7 \pm 12{\cdot}6$ μm) and *Moina dubia* (493 ± 144 μm) used in experiments were cultured artificially. A copepod (439 ± 174 μm) and nauplii ($86{\cdot}0 \pm 26{\cdot}9$ μm) were collected from ponds. *Chlorella pyrenoidosa*, *Scenedesmus obliquus*, *Pediastrum* sp. and *Pandorina morum* ($3{\cdot}2 \pm 0{\cdot}49$, $5{\cdot}3 \pm 1{\cdot}84$, $18{\cdot}6 \pm 4{\cdot}15$ and $19{\cdot}8 \pm 4{\cdot}78$ μm, respectively) were obtained from the Hydrobiological Institute of Academia Sinica. *Glenodinium* sp. and pine pollen ($16{\cdot}1 \pm 6{\cdot}14$ and $60{\cdot}0 \pm 7{\cdot}44$ μm) were collected from ponds or fields. The densities of food particles were determined under a microscope or a dissecting microscope.

AQUARIA AND OPERATION

The aquaria used in Experiment 1, in which selectivity for special food particles was measured, were $50 \times 35 \times 25$ cm glass tanks. The aquarium used in Experiment 2, in which selectivity for feeding area was measured, was a $600 \times 100 \times 100$ cm glass tank. Water temperature in Experiment 1 was 20° C, and in Experiment 2 was about 22° C.

Experiment 1 was conducted with 13 tanks: one tank without fish acted as control, nine contained 11 silver carp per tank, and the other three contained nine bighead carp per tank. Each tank contained 20 l aerated water. Equal amounts of food particles were added to each tank. The density of various food particles other than zooplankton did not differ greatly. The experiment lasted 2 h.

In Experiment 2, the tank contained aged tap water to a depth of 32 cm. Twenty-one to 25 fingerlings, starved for 2 or 3 days, were stocked in the tank. After they had been acclimatized in the tank for several hours, the fish at one end of the tank ($1{\cdot}5$ m^2) were counted. In 30 min the fish in the area were counted 10 times. One type of food particle was then slowly added to this area of the tank and, after several minutes, fish were counted again. Finally, the fish were collected and the water discharged.

III. RESULTS

EXPERIMENT 1: SELECTIVITY FOR SPECIAL FOOD PARTICLES

The removal rate, or proportion of food particles ingested by the fish during the experiment, was used as an index of selectivity. The results (Table I) show that for phytoplankton, pollen and small zooplankton (rotifers and nauplii) the removal rates (%) increased with increase in food particle diameter. The relationships were:

$$Rh = 11{\cdot}0 \ln \mathrm{ESD} + 1{\cdot}6 \tag{1}$$

$$Ra = 21{\cdot}6 \ln \mathrm{ESD} - 24{\cdot}7 \tag{2}$$

where *Rh* and *Ra* are the removal rates of silver carp and bighead carp, respectively, and ESD is the food particle diameter (μm). The regression accounted for $90{\cdot}8$ and $81{\cdot}7$% of the variation in removal rates ($P<0{\cdot}01$), respectively.

TABLE I. The removal rates (%) of some food particles by silver carp and bighead carp

No.	*Ch*	*Se*	*Gl*	*Pe*	*Pa*	Po	Na	*Br*	Cl	Co
Silver carp										
1	12·9	14·6	42·9	22·2	34·1	54·2	59·1	61·8	31·4	11·1
2	24·3	13·3	33·3	29·4	33·7	46·3	12·9	43·2	40·4	27·7
3	26·5	11·3	20·0	16·7	33·0	48·8	34·7	46·4	55·3	43·8
4	13·0	20·8	25·0	44·4	56·0	49·5	58·3	60·2	12·3	52·4
5	5·4	14·0		50·0	48·8	48·3	54·4	31·9	31·1	50·0
6	11·5	8·5		25·0	35·1	60·2	52·8	66·8	42·9	33·3
7	2·5	20·0		38·2	46·3	45·7	42·3	52·7	34·4	22·6
8	21·5	19·5		20·9	43·8	39·4	39·1	51·6	42·2	22·6
9	23·9	13·0		47·1	52·7	44·1	54·8	52·0	31·6	7·5
Mean	15·7	15·0	30·3	32·7	42·7	48·5	45·4	51·8	35·7	30·1
Bighead carp										
1	10·6	7·1	20·0	20·0	31·9	54·0	92·8	86·4	77·3	65·8
2	19·7	16·6	16·7	5·0	41·3	63·2	93·4	87·0	85·4	65·6
3	16·0	8·1	16·7	40·0	24·2	34·2	75·8	75·0	63·3	25·4
Mean	15·4	10·6	17·8	36·7	32·5	50·5	87·3	82·8	75·3	52·3

Abbrevations: *Ch*, *Chlorella*; *Se*, *Scenedesmus*; *Gl*, *Glenodinium*; *Pe*, *Pediastrum*; *Pa*, *Pandorina*; Po, pollen; Na, nauplii; *Br*, *Brachionus*; Cl, Cladocera; Co, Copepoda.

The removal rates of the fish for Cladocera and Copepoda were smaller than those for other food particles.

EXPERIMENT 2: SELECTIVITY FOR FEEDING AREA

The results (Table II) show clearly that silver carp and bighead carp stayed in the area in which there was a high plankton density. After zooplankton was added to the area, the fish changed their routine circling swimming activity, concentrated on the area and stayed there for a long time. In the experiment, the sensitive distance of the fish for food particles was short and, only when the fish swam into the area, did their filtering frequency become high and the filtering intensity become vigorous. Fish selectivity for the feeding area which contained *Scenedesmus* seemed to be weaker than for the area which contained zooplankton.

IV. DISCUSSION

FEEDING SELECTIVITY OF THE FISH

Both silver carp and bighead carp are pump filter feeders. They do not snap at individual prey nor do they orient or move towards zooplankton swimming in front of them. Thus the feeding selectivity of these fishes has a very special meaning. As noted in the Introduction, the feeding selectivity of the fish should include food particle selection and feeding area selection. If the fish possess only one of these two aspects, they may obtain the food particles in amounts disproportionate to the amount in water.

Silver carp and bighead carp show size-selection for food particles [Table I, equations (1) and (2)]. However, they are not able to select actively their

TABLE II. The number of feeding and non-feeding fish in the chosen aquarium study area (1·5 m^2)

Conditions	No. ($\bar{X} \pm$ S.E.)	t	Probability
Silver carp:			
Without food	4·0 ± 2·0		
Scenedesmus	7·0 ± 3·2	2·54	<0·05
Without food	5·0 ± 2·3		
Scenedesmus	7·8 ± 4·0	1·84	<0·1
Without food	5·9 ± 1·2		
Rotifera	16·4 ± 1·4	17·44	<0·001
Without food	6·5 ± 4·4		
Cladocera	18·8 ± 1·7	2·25	<0·05
Without food	5·9 ± 3·0		
Copepoda	16·6 ± 1·5	9·97	<0·001
Bighead carp:			
Without food	11·2 ± 6·6		
Scenedesmus	21·2 ± 2·4	2·86	<0·02
Without food	7·4 ± 6·1		
Scenedesmus	20·1 ± 1·7	6·04	<0·001
Without food	7·7 ± 2·7		
Rotifera	17·4 ± 4·0	6·05	<0·001
Without food	4·7 ± 2·8		
Cladocera	15·3 ± 3·6	6·92	<0·001
Without food	7·0 ± 2·6		
Copepoda	20·1 ± 1·9	13·1	<0·001

preferred species of plankton which are distributed evenly in the water. Their feeding is mainly a passive, mechanical process using gill rakers. Smith (1989) formed a similar conclusion from an experiment with silver carp. Other mechanisms in the feeding process of silver carp have been discussed (Colman & Edwards, 1987; He, 1987).

Behaviour of plankton affects the feeding selectivity of the fish. The removal rates of the fish for Rotifera and nauplii are higher than those for Cladocera and Copepoda owing to their weaker escape action. The escape capacity of Copepoda to fish predation is greater than that of Cladocera (Drenner *et al.*, 1978) and so removal rates of the fish for the former are smaller than for the latter.

Some authors have reported that silver carp and bighead carp prefer feeding on some particular species of phytoplankton (see reviews in He, 1987; Colman & Edwards, 1987; Wang, 1988). However, they cannot select particular species of plankton actively although size-selection may cause the differences between gut contents and the plankton composition in the water environment.

Silver carp and bighead carp possess the ability to select a feeding area (Table II). Thus, they are able to seek and stay in an area in which there is a high plankton density or in which there are preferred species of plankton. In the experiment, fish did not swim directly into the area after plankton were added. However, while they swam in the area, their filtering frequency and intensity clearly changed. This means that the fishes reactive distance by smell or sight is

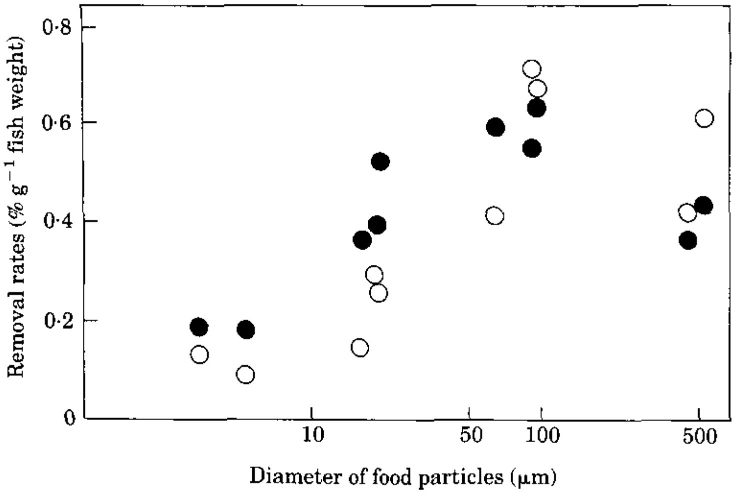

FIG. 1. Removal rates of various food particle sizes by silver carp (●) and bighead carp (○).

not long, or else their selectivity for feeding area is not based on the senses of smell and sight, but is based mainly on taste. This opinion is supported by the presence of many taste buds on the epithelia of their filtering organs. The selection of feeding area enables the fish to adjust to the environment and, especially, to use plankton resources more efficiently, to balance the nutrition, and to avoid the toxicity of some species of phytoplankton.

From the experiment it can be concluded that in smaller waters, such as in ponds in which plankton is normally distributed evenly, the fish are not able to select their preferred species of plankton. Instead, their feeding habits are ruled by the composition and behaviour of plankton. However, in larger waters in which plankton is usually distributed in patches, the fish can swim to their favoured feeding area and feed more on their preferred species of plankton, although they are not able to select them from the plankton community.

THE DIFFERENCES OF FEEDING SELECTIVITY BETWEEN THE FISHES

People usually consider silver carp as a phytoplankton feeder and bighead carp as a zooplankton feeder. Sometimes, silver carp also feeds on zooplankton (Chen, 1982; Zhou & Lin, 1990), and bighead carp on phytoplankton (Chen, 1982; Wang, 1988). The reasons for these complex results are the differences between their capacity for food selection and realization of that capacity. The removal rates per unit body weight of the fish can be used to compare the selectivity for particular food particles (Fig. 1). The removal rates by silver carp for smaller plankton (phytoplankton) are higher than those of bighead carp. The removal rates by the latter for bigger plankton (zooplankton) are higher than those by the former, and for food particles about 70 μm in diameter the removal rates by the two species are almost equal. The higher removal rates by silver carp for phytoplankton is due to their dense gill rakers. The higher removal rates of bighead carp for zooplankton are due to their greater suction volume during ingestion (Dong *et al.*, 1992). Silver and bighead carp are able to feed on either zooplankton or phytoplankton in natural waters. However, changes in the concentrations of phytoplankton or zooplankton can instigate passive changes in their feeding habits.

The results of Experiment 2 show that the selectivity of silver carp for feeding area is weaker than that of bighead carp. Compared with silver carp, bighead carp is more sensitive to the addition of food particles, which may be because there are more taste buds on the filtering organs of bighead carp.

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