Theor Appl Genet (1990) 79: 693–698

Genetic differences between the Chinese and European races of the common carp

6. Growth of fish in cages

G.W. Wohlfarth and R. Moav †

Agricultural Research Organization, Fish and Aquaculture Research Station, Dor, M.P. Hof Hacarmel, 30820, Israel

Received January 7, 1990; Accepted January 22, 1990
Communicated by H.F. Linskens

Summary. Relative growth rates of six genetic groups of common carp were compared in small netting cages and in earthen ponds. These groups of carp included an isolate of the Chinese 'Big Belly Carp', its crossbred with a European isolate, and four European progenies, purebreds or crossbreds. Five different environments were produced in the ponds, mainly by varying the stocking rates of carp. Each of the (ten) cages was treated as a different environment. Each cage and each pond were stocked with random samples of each genotype, i.e., 'communal testing' was carried out. The performance of a given genotype in a given environment was estimated from its weight gain in that environment. The mean weight gain of all groups, stocked into a given environment, was taken as an estimate of that environment as it influenced the growth of carp. The characteristics of the regression of growth of a given genotype on the environment in which it grew [i.e., the coefficient of regression (*b*) and the Y intercept (*a*)] are taken as measures of its adaptation to that environment. No real differences in adaptation to pond versus cage conditions were isolated for four of the tested groups, the Chinese × European crossbred, the two European crossbreds and one of the European purebreds. The Chinese carp showed a specific adaptation to growth in ponds (or a lack of adaptation to growth in cages), whereas Dor-70 was specifically adapted to cage conditions. These results may be explained by the genetic history of the two lines. The Big Belly Carp was domesticated under conditions of Chinese subsistence aquaculture, which apparently generated an adaptation to gathering and utilizing natural foods. These are prominently absent in cages. Dor-70 was produced in a long-term selection experiment, which apparently generated a response for growth in cages. These results may be of applicative value, if common carp were to be considered as candidates for commercial cage aquaculture. It would then be important to use strains like Dor-70, which are adapted to these conditions, and avoid strains like the Chinese Big Belly carp.

Key words: Common carp – Specific adaptations – Ponds – Cages

Introduction

Previous investigations in the Chinese and European races of the common carp and their crossbred have shown that European carp respond better to improvements in the environment, while Chinese carp adapt better to harsh environments (Moav et al. 1975; Wohlfarth et al. 1983, 1986). This is expressed most clearly in the characteristics of the response curves of the different genotypes on changes in the environment, i.e., the regression lines of growth of each genotype on the mean growth of all genotypes tested. Mean growth of all genotypes growing in a given environment is taken as an estimate of the quality of that environment, as it influences the growth of carp (Moav et al. 1975; Wohlfarth et al. 1983, 1986).

These lines show that the European carp possesses a higher coefficient of regression (*b*), but a lower intercept on the Y axis (*a*). The relative performance of the European carp (compared to the Chinese) improves in direct relation to environmental improvements. In poor environments, the response curves approach each other, and may intersect such that in very poor environments Chinese carp show a better growth than the European ones. The regression coefficient (*b*) of the response curve of the European × Chinese crossbred was somewhat lower than that of the European parent and higher than that of the Chinese parent. Its intercept on the Y axis (*a*) was higher than that of the European parent, but lower than that of the Chinese parent. The regression line of the European × Chinese crossbred intersected that of the European parent at a high environmental mean and that of the Chinese parent at a low environmental mean. The response curve of the crossbred was above those of its parents between these points of intersection, i.e., growth of the crossbred was faster than that of either parent over a fairly wide range of environmental means. The tests on which these results and conclusions are based were carried out in earthen ponds in which nutrient managements and stocking densities were varied, in order to produce different environments.

In the investigations described here, Chinese, European, and their crossbred carp were grown in small cages. The results obtained from this cage study are compared to those from a pond test, carried out simultaneously and stocked with samples of the same genetic groups. The pond results were discussed in previous publications in this series (Moav et al. 1975; Wohlfarth et al. 1986), though with a somewhat different approach. Growth of carp in these cages was lower than that in ponds at managements here employed. Growth of the Chinese carp, relative to the European one, was expected to be faster in cages than in ponds, since relative performance of the Chinese carp improves with a deteriorating environment.

Materials and methods

Genetic stocks and their crossbreds

A brief description of the genetic stocks tested is given here, since most have been more fully described previously (Moav et al. 1975; Wohlfarth et al. 1986).

The Chinese stock belongs to the most prevalent group of common carp in the Far East, the Big Belly Carp, which possesses a full-scale pattern. The isolate here tested was introduced from Taiwan in 1970. The other stocks all belong to the European race, and are mirror carp:

Dor-70 was developed from a mass-selection experiment for fast growth rate, carried out from 1965 to 1970 (Moav and Wohlfarth 1976).

Nasice is the product of several consecutive generations of mass selection for a high ratio of body height to body length, carried out the Nasice fish farm in Yugoslavia (N. Fijan, personal communication), and introduced to Israel in 1970.

Dutch. A line of carp introduced from Holland in 1962 (Moav et al. 1964).

Blue and Gold. Color mutants found at two different fish farms in Israel, brought to Dor and reproduced there. Both mutations are due to simple Mendelian recessives.

These stocks were used to produce the groups tested, i.e., Chinese, Chinese × Nasice, Dor-70, Nasice, Nasic × Dor and Dutch × (blue × gold).

Methods of testing

Details of the testing facilities are given in Table 1. Samples of all the genetic groups were stocked communally into each of 16 ponds of 400 m^2 at Dor (4 ponds at 1.1 carp/m^2, 8 ponds at 0.66/m^2, and 4 ponds at 0.31/m^2), a larger commercial fish pond at Yehiam (at 0.23/m^2), and 10 cages. The pond test, described previously (Moav et al. 1975; Wohlfarth et al. 1986), is here considered as a control for the test carried out in cages. Further progenies, stocked into these ponds but not into cages, are not pertinent to this investigation and are considered part of the common environment. Their results were reported in previous publications. After the terminaton of the test, the eight ponds stocked at 0.66/m^2 were divided into two groups of four ponds each, according to the mean weight gain of their carp. The four sets of ponds at Dor plus the pond at Yehiam constituted five different environments, characterized by their differences in mean weight gain. Ponds were stocked in July and the tests were terminated in November after 130–140 days. Feed in the form of fodder pellets at Dor and grain at Yehiam was presented daily, 6 days/week.

The cages were constructed from 6-mm iron rods, bent and welded into (0.5 m^3) constructions, and covered with half-inch corrugated iron netting. A lid made from the same materials and covering half the top of each cage (50 × 25 cm) made possible the stocking of the cages with fingerlings, the removal of the fish for periodic sample weighings, and the termination of the tests. Each cage was stocked with 28–31 carp (i.e., 120/m^2). The cages were placed on the bottoms of two 400 m^2 ponds (five cages pond). Water level was controlled so that the top 5 cm of each cage was not submerged. Feed was supplied once a day, 6 days/week, as in the ponds.

Presentation of results

Growth of different genotypes was compared by 'communal testing' (Moav et al. 1975; Wohlfarth and Moav 1985) in ponds and cages, and results are presented in terms of 'corrected weight gain'. This presents an estimate of growth of a given genotype in a given environment under conditions of cummunal testing not biased by variation in weight at stocking among the genetic groups tested.

Results

Pond test

The results of the pond test are shown in Table 2. Figures shown in this table present the mean performance of a given genotype in a given environment, computed from four replicated observations. The Chinese purebred had the lowest weight gain in all environments, and this was most emphasized at the medium and low stocking rates at Dor. At the high stocking rate, weight gain of the Chinese purebred was only a little below that of Nasice. Weight gain of the Chinese × European (Nasice) crossbred did not exceed that of either European crossbred or of the Dor-70 purebred in any environment.

Cage test

The results of the cage test are shown in Table 3. Figures in this table show the performance of a given genotype in individual cages. Growth of fish in cages was much slower than in ponds (compare Tables 2 and 3). In nine

Table 1. Technical description of the tests in ponds and cages

Facility	No. of units	Area (m^2)	No. of fish/unit	Date of		No. of days
				stocking	termination	
Ponds at Dor	4	400	426[a]	July 13	Nov. 23	133
	8	400	265[a]	July 13	Nov. 23	133
	4	400	125[a]	July 13	Nov. 23	133
Pond at Yehiam	1	ca. 15,000	ca. 3,500[a]	July 11	Nov. 29	141
Cages at Dor	10	0.5 × 0.5	28–31	July 19	Nov. 28	132

[a] Includes six further progenies, not considered in this study, since not stocked into cages. For details, see Moav et al. 1975

Table 2. Weight gains of six groups of common carp tested in communal ponds in five environments (after Moav et al. 1975)

Locating of testing ponds	Stocking density per pond	Corrected weight gain (g)						
		Chinese × Chinese	Chinese × Nasice	Nasice × Dor-70	Dor-70 × Dor-70	Nasice × Nasice	Dutch × (b × g)[a]	Mean
Dor	125	468	725	918	874	795	877	776
Dor	265	367	505	594	593	479	589	521
Dor	265	297	454	477	517	352	456	426
Yehiam	3,500	283	395	403	403	292[b]	416	365
Dor	426	264	378	399	394	279	356	345
Mean		336	491	558	556	439	539	487

[a] (Blue × gold)

[b] Computed value

Table 3. Weight gains of six groups of common carp tested in ten communal cages

Cage no.	Corrected weight gain (g)						
	Chinese × Chinese	Chinese × Nasice	Nasice × Dor-70	Dor-70 × Dor-70	Nasice × Nasice	Dutch × (b × g)[a]	Mean
38	79	200	295	340	220	182	219
31	160	196	261	269	191	215	215
36	92	145	253	328	184	277	213
32	69	158	284	284	234	232	210
35	83	144	258	274	190	233	197
37	83	154	239	263	188	212	190
34	100	131	208	193	147	150	155
33	56	118	196	168	126	162	138
39	61	121	162	166	136	152	133
40	97	103	145	179	89	122	122
Mean	88	147	231	246	171	194	179

[a] (Blue × gold)

cages, the Chinese purebred showed the lowest weight gain of all groups tested, but in the cage with the lowest mean weight gain (cage no. 40), growth of the Nasice purebred was slower than that of the Chinese purebred.

Comparison between pond and cage tests

The response curves (Figs. 1–4) associate the relative performance of a given genotype with the environment in which it was raised (as estimated by the mean performance of all carp genotypes in that environment). Figure 1 shows that for the Chinese purebred, the coefficient of regression of weight gain on mean weight gain of all groups tested is almost twice as high in ponds as in cages. This is the most unexpected result of the investigation. On the other hand, the response of the Chinese × European (Nasice) crossbred is similar in cages and ponds

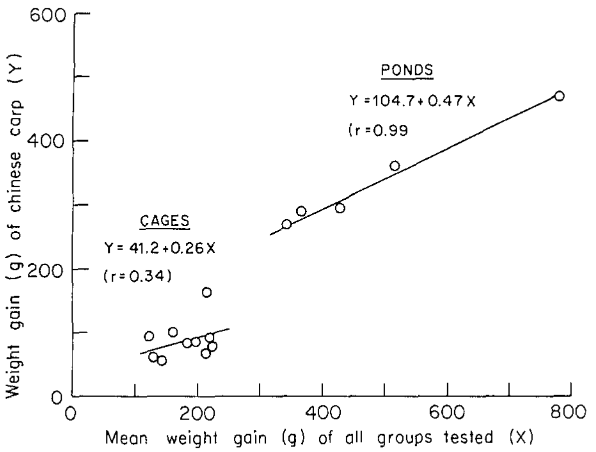

Fig. 1. Response curve of the Chinese (Big Belly) carp. The regression of weight gain on mean weight gain of all groups tested, in cages and ponds

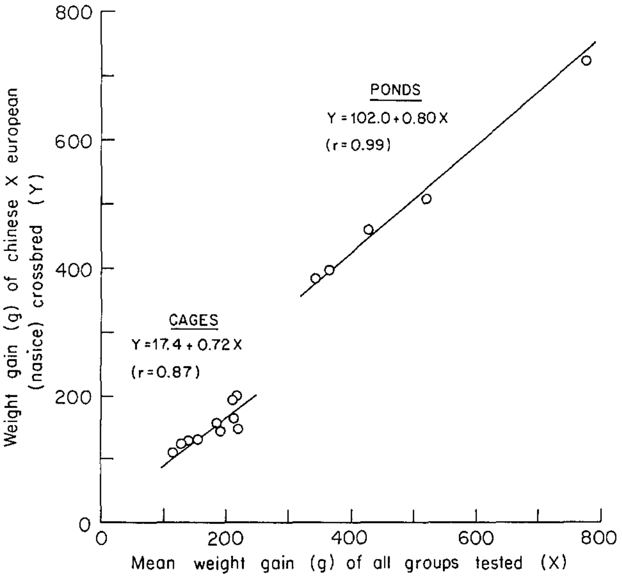

Fig. 2. Response curve of the Chinese × European crossbred. The regression of weight gain on mean weight gain of all groups tested, in cages and ponds

($b=0.72$ or 0.80, respectively); Fig. 2. The two European purebreds differ in their response to environmental changes in cages and ponds (Fig. 3). For Dor-70, the regression coefficient is higher in cages than in ponds ($b=1.62$ versus 1.12), whereas the coefficient is similar in cages and ponds for Nasice. The better response of Dor-70 to an improving environment in the poor conditions of cages, relative to the better conditions of ponds, is also quite unexpected. Figure 4 shows the similar response of the two European crossbreds to an improving environment in cages and in ponds.

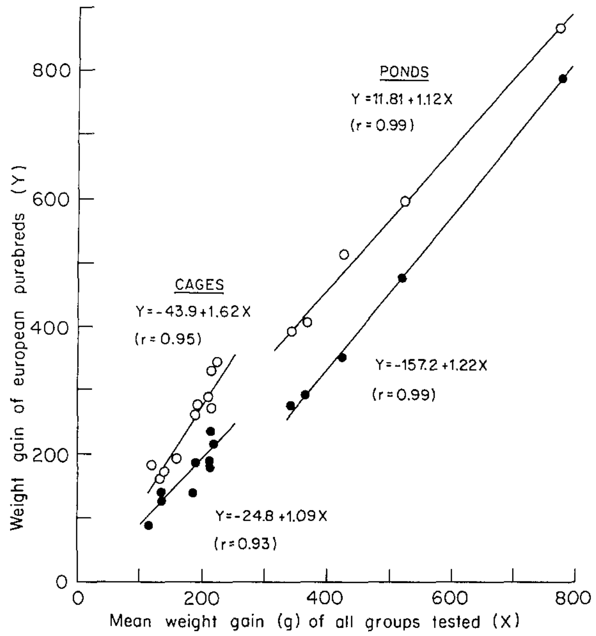

Fig. 3. Response curves of European purebreds. The regression of weight gain on mean weight gain of all groups tested, in cages and ponds. *Open circles* – Dor-70; *solid circles* – Nasice

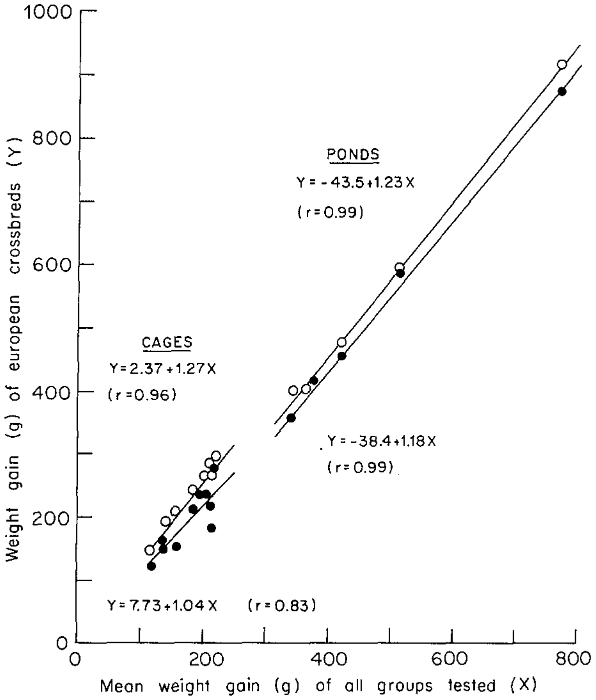

Fig. 4. Response curves of European crossbreds. The regression of weight gain on mean weight gain of all groups tested, in cages and ponds. *Open circles* – Dor-70 × Nasice; *solid circles* – Dutch × (blue × gold)

Discussion

Results of the present study appear to contradict some of the conclusions generated from pond tests in which the environment was manipulated by varying stocking rates and nutrient management (Moav et al. 1975; Wohlfarth et al. 1986). Relative growth rates of different progenies in the cages of the present investigation differed from those expected in ponds with similar slow growth rates. These apparent contradictions include: (1) the relatively low growth response of the Chinese carp to an improving environment in cages compared to ponds; (2) the failure of the Chinese × European crossbred to exhibit heterosis of growth in any of the tested environments; (3) the relatively high growth response of Dor-70 to an improving environment in cages compared to ponds. These points are discussed below.

Relative growth of the Chinese purebred

In cages, weight gain of the Chinese purebred relative to European purebreds and crossbreds deteriorates as mean weight gain decreases (Table 3). This is unexpected, since in ponds the relative performance of the Chinese purebred improves with a deteriorating environment. The performance of the Chinese carp to poor pond environments may be explained as a genetic adaptation to such environments, resulting from the conditions under which it was domesticated (Wohlfarth 1984). These include high and uncontrolled fish densities and a heavy reliance on natural foods, the production of which was stimulated by frequent applications of manure. The adaptation of the Chinese carp to these circumstances, in addition to their ability to survive these harsh environments, may consist principally of efficient grazing on, and utilization of, natural foods. In cages, growth of fish is almost totally dependent on supplemental feeds. The amount of natural food in closely stocked cages must be negligible, and in any case much smaller than in ponds, irrespective of stocking rate. Thus, the specific ability of Chinese carp to gather and utilize natural foods cannot express itself in cage conditions. In ponds, on the other hand, this ability becomes progressively more important as environmental conditions deteriorate, i.e., as dependence on, and competition for, natural food increases with increasing stocking rate. This is offered as an explanation for the better response of the Chinese carp to deteriorating conditions in ponds, relative to cages.

Relative growth of the Chinese × European crossbred

In pond studies, the Chinese carp showed a relatively fast growth under the worst conditions, while the European carp showed fast grouth under the best conditions. Over a wide range of intermediate conditions, the Chinese × European carp was heterotic for growth, especially when manure was the principal nutrient input (Wohlfarth et al. 1983, 1986). Growth of this crossbred did not exceed that of its parents in either ponds or cages in the present study. These ponds were not manured, and we have seen that in cages, the Chinese carp do not possess any growth advantage over the European. Therefore, there is no reason to expect heterosis of growth of the Chinese × European crossbred under any of the conditions generated in this study.

Relative growth of Dor-70

A specific adaptation of Dor-70 to growth in cages was demonstrated in this study. Dor-70 is descended from the better replicate of the up-selection line of a mass-selection experiment in which the larger fish were chosen in each generation, after growing in ponds. Response to selection was estimated in both ponds and cages. The paradoxical result of this experiment was that there was no response to selection for growth in ponds, but in cages growth of the up-select line was faster than that of control lines (Moav and Wohlfarth 1976). We do not have an explanation for this paradoxical result of lack of response under selection conditions and a positive response under a different set of conditions. It appears, however, that in an unexplained manner, mass selection has generated a specific growth response for cage conditions in Dor-70. This apparently expresses itself in an improved ability to utilize cage conditions and, the worse the conditions, the greater the expression of this ability; thus, the greater response of Dor-70 to deteriorating conditions in cages compared to ponds, as isolated in this study.

Growth of carp in cages

The slow growth rate of carp in these cages, compared to that in ponds (Tables 2 and 3), was probably a result of the feed being applied only once a day. In later experiments, feed was applied via clock-operated feeders, which disposed the feed over ca. 12 h/day. Growth of fish fed continuously, with the aid of these feeders, was several times greater than that of fish fed once a day (unpublished results). It appears that in cages, application of the whole feed ration in a single dose is much less effective than in ponds, possibly because in cages feed becomes unavailable soon after its application.

Applications to aquaculture

Cage aquaculture, formerly in use on a small scale primarily in Southeast Asia, has been practiced as a commercial method of fish production largely in the second half of the present century (Beveridge 1987). In northwest Europe, Atlantic salmon are grown in cages on a large scale. Cage culture of tilapias has been investigated on an experimental scale, mainly in Africa, Asia, and Latin America (Coche 1982). Carp farming has been until recently restricted to cultivation in ponds. Their cage growth was tested in a cage of 16 m^2, 3 m deep, standing in a reservoir, stocked at a rate of 71 carp/m^3. During a growth season of 125 days, the caged carp grew ca. 4 g/day, similar to carp growing in the reservoir. The cage yielded 36 kg/m^3, and food conversion ratio was ca. 2 (Milstein et al. 1989). It is feasible, therefore, that cage culture of carp may become a commercial practice in the future. Commercial cages are very different in their construction from our simple rod and netting structures, but the common denominator to both is the almost total reliance on supplemental food. The results of the present study emphasize that the choice of genetic stock is as important in cage as in pond aquaculture. One of the reasons for the success of the Norwegian salmon farming industry in cages is their careful choice of genetic stock (Gjedrem 1979). The present study illustrates this with common carp. The Chinese stock is specifically unadapted to cage culture, presumably as a result of its method of domestication. Neither does the Chinese × European crossbred show any advantage in cage culture over European stocks. On the positive side, Dor-70 appears to be specifically adapted to cage conditions and its use as a purebred is recommended, since its growth rate in ponds exceeds that of European crossbreds.

References

Beveridge M (1987) Cage aquaculture. Fishing New Books, Farnham, England

Coche AG (1982) Cage culture of tilapias. In: Pullin RSV, Lowe McConnel RH (eds) The biology and culture of tilapias ICLARM Conf Proc Manila, The Philippines 7: 205–246

Gjedrem T (1979) Selection for growth rate and domestication in Atlantic salmon. Z Tierz Zuechtungsbiol 96: 56–59

Milstein A, Feldlite M, Mozes N, Avnimelech Y (1989) Limnology of reservoirs used for fish farming and crop irrigation, with integrated free and cage fish culture. Isr J Aquacult Bamidgeh 41: 12–22

Moav R, Wohlfarth G (1976) Two way selection for growth rate in the common carp (*Cyprinus carpio* L.). Genetics 82: 83–101

Moav R, Wohlfarth G, Lahman M (1964) Genetic improvement of carp. VI. Growth rate of carp imported from Holland, relative to Israeli carp, and some crossbred progeny. Bamidgeh 16: 142–149

Moav R, Wohlfarth G, Hulata G (1975) Genetic differences between the Chinese and European races of the common carp. I. Analysis of genotype-environment interactions for growth rate. Heredity 34: 323–340

Wohlfarth GW (1984) Common carp. In: Mason IL (ed) Evolution of domesticated animals. Longman, London, pp 375–380

Wohlfarth GW, Moav R (1985) Communal testing, a method of testing the growth of different genetic groups of common carp in earthen ponds. Aquaculture 48: 143–157

Wohlfarth GW, Moav R, Hulata G (1983) A genotype-environment interaction for growth rate in the common carp, growing in intensively manured ponds. Aquaculture 33: 187–195

Wohlfarth GW, Moav R, Hulata G (1986) Genetic differences between the Chinese and European races of common carp. 5. Differential adaptation to manure and artificial feeds. Theor Appl Genet 72: 88–97