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Possibilities of application of the heterosis effect in commercial production of common carp (*Cyprinus carpio* L.). 1. Production of fingerlings

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Abstract — Five crossbreds of carp produced on the basis of Polish breeding line 3 and the Hungarian lines W and T were tested by comparing them with the above lines. The results of the first production season are presented. A relatively strong heterosis effect was obtained in such features as survival rate, feed consumption, and yield per 1 ha. With respect to the growth rate the effect was slight or did not appear at all.

Key words: common carp, heterosis, crossbreeding.

1. Introduction

Intensification of pond production of fish has been made possible thanks to constant progress in four interrelated management activities. These are: improvement of feeding, optimization of the environment, attacking of epizoites, and breeding (Włodek 1972).

The basis task of the carp breeder is to supply high quality stock material for the production ponds. Inbreeding, however, which is the predominant practice in pond management, cannot provide good stock material, since with progressive inbred coefficient value the production parameters are reduced. The desired features of stock material for commercial production may be obtained by taking advantage of the heterosis effect. Heterosis consists in the superiority of the heterozygous genotypes of the hybrids over the parent homozygotes with respect to one or more features, and represents a phenotypic effect of the synergy of genes (Rieger et al. 1974). The heterosis effect may be considered as a phenomenon opposite to that of inbred depression. The value of the productive qualities of individuals, which is reduced as a result of the appearance of lethal and semilethal genes and disturbances in the favourable systems of polygenes in the homozygous systems, increases in heterozygous ones (K o ł ą t a j et al. 1973).

The heterosis effect is utilized on a large scale in plant production where several hybrid varieties of plant obtained as a result of crossing many highly inbred lines are used. In animal breeding the method is employed less frequently than in plant production. This is because the achievement of success by this method depends mainly on the breeding of many highly inbred lines, which is possible only where mating of closely related individuals may be prectised and where the generation gap is short. Nevertheless, even in such conditions to obtain a high degree of inbreeding is very difficult as the inbred individuals are much less prolific and less resistant to unfavourable environmental effects. It is for this reason that in animal breeding there is a tendency to obtain heterosis not through the crossing of lines but of races, since each race represents a separate group, genetically isolated from other races. Heterosis revealed in farm animals with respect to features of economic importance most frequently amounts to 4—8%, rarely exceeding the upper limit (Ż u k 1979).

In carp breeding the heterosis effect is obtained through crossing highly inbred and genetically distant breeding lines (W ł o d e k 1979, N o w a k et al. 1980). Until now interline crossings were most often obtained on the basis of Polish carp and carp imported from Hungary (R y c h l i c k i 1973, W ł o d e k, M a t l a k 1978, W r o n a et al. 1980).

In 1985 at the Fish Culture Experimental Station Gołysz of the Polish Academy of Sciences (PAN) systematic, long-term investigations were started with the aim of selecting those lines whose crossing would bring about the best results in fish production (D o b o s z, B i a ł o w ą s 1986, B i a ł o w ą s 1989). The aim of the present work is to discuss the results of the first year of the investigations on cross-breeding of Polish carp and Hungarian lines, reared at the Station. The investigations were carried out in 1988.

2. Material and method

The lack of possibility of a direct comparison of the progeny with the parents in pond breeding necessitates comparing the crossbred with the initial lines of the same age category and descending from the same parents.

As it is impossible in practice to mark the hatch of carp in vivo the particular experimental groups must be kept in separate ponds.

This makes difficult a direct comparison of the crossbreds since the differences between them result, among other things, from environmental differences between the particular ponds, the elimination of which is not practicable. Replications increase the accuracy of the estimation and partly iliminate the environmental effect. When evaluating the potential of the growth rate the highest accuracy is obtained when the control groups are mixed into the experimental groups which comprise full sibs and differ in phenotypes (Stegman 1965, 1967, Pokorny et al. 1983). It was assumed that the differences between the mean weights of the comparative groups from the particular ponds were due only to the environmental effects and that the environment of the given pond affects in the same way the experimental and the comparative group reared in the same pond. From this assumption there follows the formula of Kirk (Dobosz, Białowąs 1986), which corrects the mean weights of the groups obtained in the experiment:

$$Pc = P\bar{K}/K$$

where:

Pc — corrected mean weight of the experimental group,
P — mean weight of the experimental group from the i-th pond,
$\bar{K}$ — mean weight of the comparative group from the i-th pond,
K — mean weight of the comparative groups.

The comparative group in the present experiment were full scaled Starzawa carp, being full sibs, in the same age category as the experimental groups. The spawners of the Starzawa carp belonged to the first generation obtained at the Station from spawners brought from the fishery farm at Starzawa near Przemyśl in 1983. These were earlier tested with respect to the homozygous character of the dominating full-scaling. The experimental groups comprised full sibs with the scaling of the mirror carp. The selection of the breeding lines to be used in the experiments was determined by the intention of testing the crossbred of the Hungarian line W with the Polish line 3, regarded hitherto as the best obtained so far at the Station. The Hungarian line T was chosen in order to test its suitability for mass spawning.

The experimental groups were derived from one pair each of spawners of the Polish breeding line 3 and of the Hungarian lines W and T, while the comparative groups were obtained from a pair of the Starzawa carp S. The identification numbers of the spawners and milters and the mating scheme are shown in Table I.

The spawning of all breeders was conducted on the same day, 7th June, 1988. Such a late date of starting the experiment was due to a delay in putting a new experimental unit into service at Gołysz. Both spawn and milt were obtained applying the commonly used

Table I. Scheme of mating spawners when forming experimental groups

♀ \ ♂	3-766	T-2253	W-1088
3-2014	3x3	3xT	3xW
T-2204	Tx3	TxT	TxW
W-544	Wx3	WxT	WxW

methods in artificial reproduction of fish. Prior to spawning the fish were hypophysed with two injections, 24 and 12 hours before spawning, with a standard dose of 0.9 mg of pituitary homogenate per 1 kg of body weight of the spawners. Fertilization and treatment of the fertilized spawn were conducted according to the method of W o y n a r o v i c h (1962). Fertilized spawn was incubated in Weiss apparatuses at a temperature of 20—22°C. To assess the quality of the obtained sexual products of the spawners used for reproduction the survival of the spawn was calculated (Table II).

Table II. Spawing results

Experimental group	Survival rate after	
	12 h	24 h
3x3	68	59
3xT	89	81
3xW	67	64
TxT	57	50
Tx3	90	88
TxW	84	83
WxW	78	73
Wx3	82	77
WxT	85	82

Because of the limited number of experimental ponds it was not possible to test one crossing Tx3, chosen at random. On 12th June, 1988 16 ponds of the Gołysz complex (fig. 1) were stocked with hatch. Each pond had an area of 670 m^2 with average depth of about 1 m, the density of stocking being 50 thousand indiv. ha^{-1}. On the same day 8 ponds

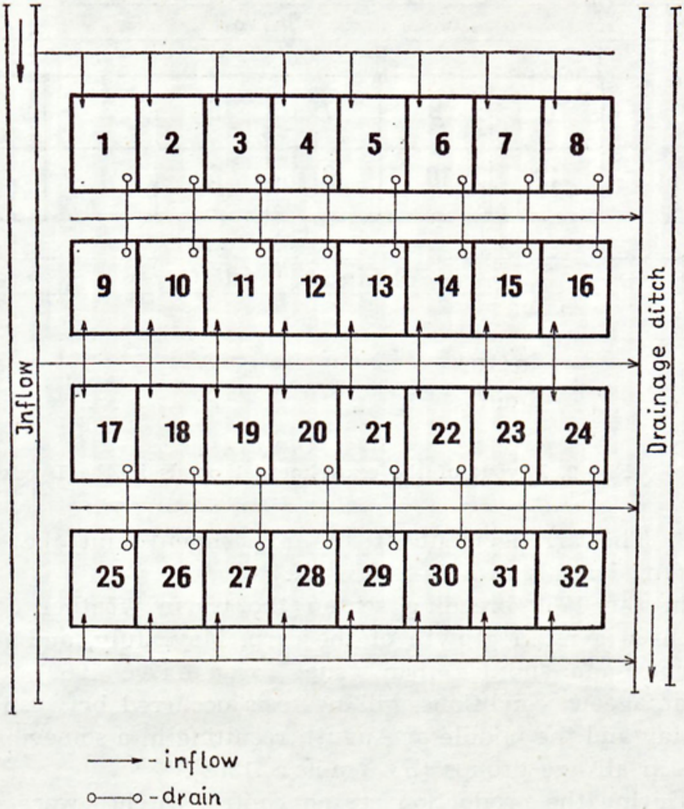

Fig. 1. Layout of the experimental ponds in the Gołysz complex

of the Byczki complex (fig. 2), each with an area of 120 m² and depth of 0.8—0.9 m, were stocked with hatch, with a density of 90 thousand indiv. ha^{-1}. Each pond of the Gołysz complex (G) was stocked with 3000 indiv. of the hatch of the experimental group and 300 of the comparative one. The ponds of the Byczki complex (B) were stocked with 1000 indiv. of the hatch of the experimental groups and 100 of the comparative group. Differentiation of the quality of the stock resulted from the designed programme of producing carp fingerlings of two weight categories: 30 and 60 g (Wolny et al. 1975).

Water from the Vistula was supplied to each pond through a conveyor common to all the ponds. Because of leakage in the newly built dyke fish from a neighbouring breeding pond penetrated into pond G 1, hence the results obtained from this pond were not taken inton considera-tion. During the reproduction season the fish were fed with high-protein pellets from the Experimental Feed Production Unit at the Fish Culture Experimental Station Gołysz of PAN.

Fisch from the ponds were caught in the period 26—29th September,

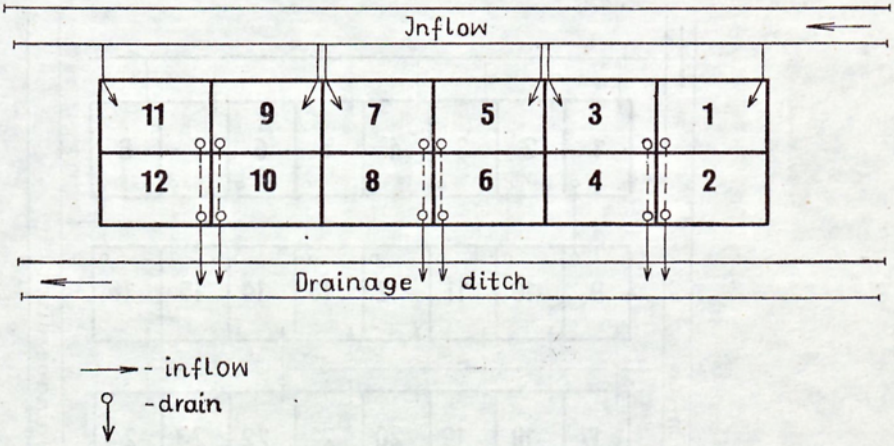

Fig. 2. Layout of the experimental ponds in the Byczki complex

1988. The arrangement of the experiment and the amount of food consumed are shown in Table III.

In the 1988 breeding season the warm weather conditions greatly favoured a rapid growth of the carp. May, July, and August are much warmer and sunnier than usual (Szumiec 1989). In spite of such advantageous conditions, gill necrosis occurred between the second half of May and the middle of August, resulting in a somewhat high mortality rate in all age groups (Szumiec 1989).

During the production season control catches were made four times in the ponds of complex G and twice in the ponds of complex B, and the growth rate of the experimental groups in the given pond was determined on the basis of an average of at least 10 individuals. During the catch 50 fingerlings were collected at random from each pond for measurement and 5 specimens for analysis of the chemical composition of the fish.

The particular experimental groups were evaluated by determination of the number and the mass of the caught fish, calculation of the survival rate, calculation of the food conversion efficiency, determination of the yield (kg ha^{-1}), and evaluation of the magnitude of the heterosis effect for particular features.

3. Results

The results of spawning are given in Table II. Survival after 12 h from the moment of fertilization was from 57 to 90% diminishing within the next 12 h by a few per cent. The crossbreds, except 3xW, showed a higher fertility rate than the initial lines.

Table III. Arrangement of the experiment, amount of feed used, and results of final catch. A — experimental group; C — comparative group; G — ponds of the Gołysz complex; B — pond of the Byczki complex

Pond No	Experimental group	Catch from the pond kg A	Catch from the pond kg C	Catch from the pond indiv. A	Catch from the pond indiv. C	Mean weight g A	Mean weight g C	Survival rate % A	Survival rate % C	Corrected mean weight g	Yield kg ha^{-1}	Feed consumption kg	Food conversion efficiency
G 2	WxW	97.7	31.2	1294	223	75.5	140.0	43.1	74.3	72.1	1923.9	373.2	2.90
G 3	3xT	111 7	22.2	1862	204	60.0	108.8	62.1	68.0	73.7	1998.5	373.2	2.79
G 4	TxT	102.1	25.0	1284	148	79.5	168.8	42.8	49.4	63.0	1897.0	373.2	2.94
G 5	3xW	108.3	22.1	1609	184	67.3	120.9	53.6	61.4	75.0	1946.3	373.2	2.86
G 6	Wx3	84.6	26.4	1187	194	71.3	136.3	39.6	64.6	70.0	1656.7	373.2	3.36
G 7	3x3	29.7	32.3	495	194	60.0	166.3	16.5	64.7	48.2	925.4	368.2	5.94
G 8	WxT	145.0	28.0	2035	238	71.3	117.5	67.8	79.4	81.1	2582.1	353.2	2.04
G 25	3xW	124.0	27.9	1810	251	68.5	111.3	60.3	83.6	82.3	2267.2	373.2	2.46
G 26	3xT	114.7	28.4	2085	287	55.0	98.8	69.5	95.8	74.4	2135.8	373.2	2.61
G 27	3x3	83.3	39.2	1515	238	55.0	165.0	50.5	79.2	44.6	1828.4	373.2	3.05
G 28	TxT	72.3	27 3	1563	193	46.3	141.3	52.1	64.4	43.8	1486.6	358.2	3.60
G 29	TxW	97.3	31.8	1710	245	56.9	130.0	57.0	81.5	58.5	1926.9	368.2	2.85
G 30	WxT	124.1	22.6	1742	210	71.3	107.5	58.0	70.1	88.7	2189.6	373.2	2.54
G 31	WxW	97.2	34.1	1236	218	78.8	156.3	41.1	72.7	67.4	1959.7	358.2	2.73
G 32	Wx3	109.1	35.5	1479	258	73.8	137.5	49.3	86.1	71.7	2158.2	373.2	2.58
B 1	3x3	3.0	9.5	98	75	30.6	127.3	9.8	75.0	23.0	1041.7	101.1	8.09
B 2	WxT	37.8	5.5	737	64	51.3	85.9	73.7	64.0	57.3	3608.3	101.1	2.33
B 3	3xW	19.5	7.2	520	94	37.5	75.7	52.0	94.0	46.9	2225.0	101.1	3.79
B 4	Wx3	33.6	8.9	655	96	51.3	92.5	65.5	96.0	53.2	3541.7	101.1	2.38
B 5	TxT	16 5	7.5	489	78	33.7	93.8	48.9	78.0	34.4	2000.0	101.1	4.21
B 6	3xT	24.0	7.8	619	78	38.8	100.0	61.9	78.0	37.2	2650.0	101.1	3.18
B 7	WxW	20.3	5.4	463	56	43.8	92.9	46.3	56.0	45.2	2141.7	101.1	3.93
B 8	TxW	32.5	5.5	634	56	51.3	92.8	63.4	56.0	50.1	3166.7	101.1	2.66

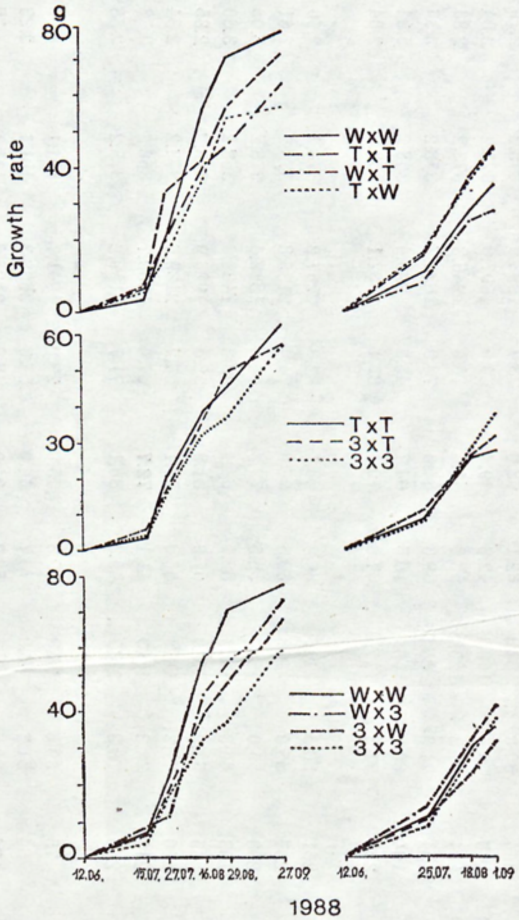

Fig. 3. Growth rate of crossbreds and of their initial lines in the ponds of the Gołysz (G) and the Byczki (B) complexes

Because of great environmental differences between the ponds in complexes G and B, which were mainly due to the different size of the stock and the fact that ponds G had just recently been built, the results obtained for the two experimental complexes were analysed and discussed separately. The growth rates of the crossbred and of the initial lines during the production season are shown in fig. 3.

The final results of the experiment, i.e. the catch results, are listed in Table III. The final catches of the experimental groups were rather high, amounting to 29.7 to 145.0 kg for the G ponds and 3.0 to 37.8 kg for the B ponds. In both complexes the lower limit for the catch was determined by the crossbred 3x3 and the upper one — by the crossbred

Table IV. Heterosis effect in crossbreds measured in percentage of the mean values of initial lines. Explanation of symbols as in Table III

Cross-bred	Growth rate		Survival rate		Food conversion efficiency		Yield	
	G	B	G	B	G	B	G	B
3xT	95.5	120.7	162.7	210.9	143.7	193.4	134.7	174.2
3xW	100.1	100.8	150.9	185.4	137.2	158.6	126.9	139.6
TxW	81.3	132.4	127.4	133.2	160.7	153.0	106.0	152.7
Wx3	107.7	137.9	117.5	233.5	122.9	252.5	114.9	222.2
WxT	101.9	132.4	140.6	154.8	132.7	174.7	131.3	174.0

WxT. Survival in the experimental groups was from 16.5 to 69.5% in ponds G and from 9.8 to 73.7% in ponds B. In the case of this feature the lowest values attained were also those of the crossbred 3x3. Food conversion efficiency was from 2.04 to 5.94 for ponds G and from 2.33 to 8.09 for ponds B. The highest values of food conversion efficiency were attained by the crossbred WxT and the lowest by the crossbred 3x3. The actual mean final weight varied from 46.3—79.5 g for ponds G, both values being determined by the experimental group TxT, and 30.6—51.3 g for ponds B. The values of the corrected mean final weight in which the potential capacity for growth (not revealed because of the occurring environmental differences) was taken into consideration, was 43.8—88.7 g in ponds g and 23.0—57.3 g in ponds B.

The magnitude of the heterosis effect is shown in Table IV and in figs 4—7. The effect of heterosis was particularly visible in such features as survival, food conversion efficiency, and production rate per 1 ha. On the other hand, it did not occur or was very small with regard to the growth rate. This was due to a low survival rate of the initial lines in the early breeding period and subsequent better feeding conditions both with regard to the natural and supplementary food. This observation was confirmed by the corrected value of the final weight (fig. 4).

It is difficult to decide which of the examined features is of greater importance for fish production in ponds. The growth rate, often regarded as the most important, under conditions of pond rearing depends to a great extent on the survival rate. Hence, it appears that the most important feature may be the yield per unit area, as a resultant of these two features. In the present experiment all crossbreds showed a positive effects of heterosis for this feature, this being especially distinct in less favourable environmental conditions (B ponds).

The effect of heterosis is somewhat different when the crossbreds

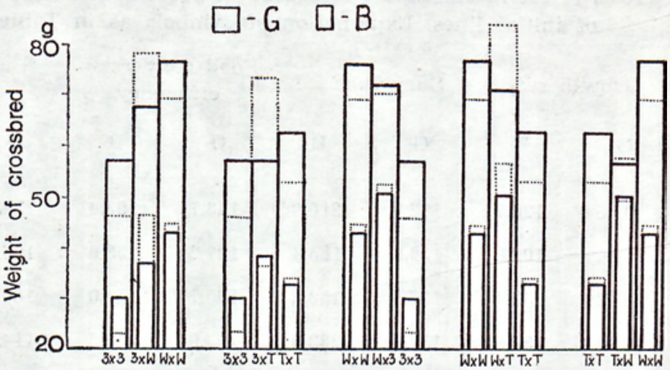

Fig. 4. Body weight of crossbreds compared with that of initial lines in ponds of the Gołysz (G) and Byczki (B) complexes. Broken line indicates values of corrected body weight

Table V. Comparison of crossbreds with the better initial lines. Explanation of symbols as in Table III

Crossbred	Growth rate		Survival rate		Food conversion efficiency		Yield	
	G	B	G	B	G	B	G	B
3xT	91.4	115.1	138.7	126.6	121.1	132.4	122.2	132.5
3xW	88.0	85.6	135.3	112.3	105.8	103.7	108.5	103.9
TxW	73.8	117.1	120.1	129.7	98.8	147.7	99.2	147.9
Wx3	94.0	117.1	105.6	141.5	94.8	165.1	98.2	165.4
WxT	92.4	117.1	132.6	150.7	122.9	168.7	122.9	168.5

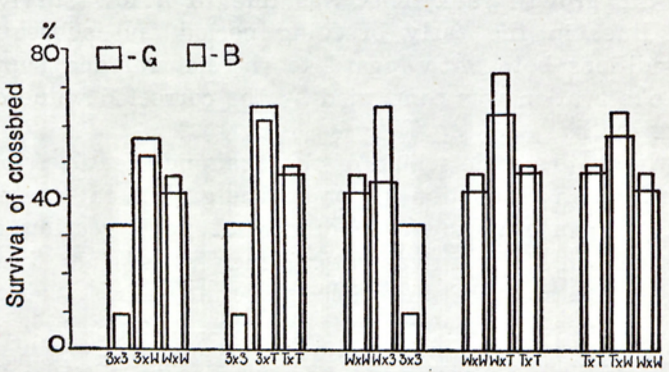

Fig. 5. Survival rate of crossbreds compared with that of initial lines in the ponds of the Gołysz (G) and Byczki (B) complexes

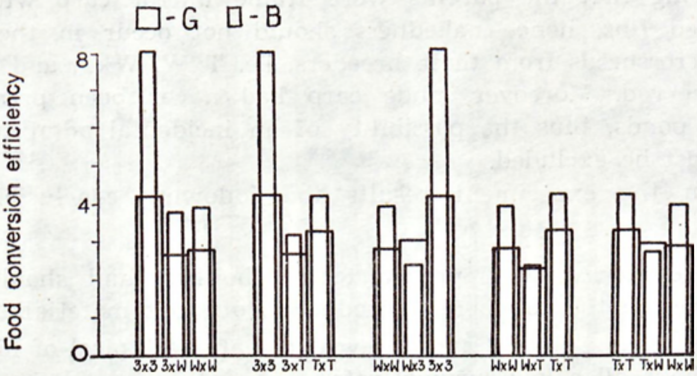

Fig. 6. Food conversion efficiency of crossbreds compared with that of initial lines in ponds of the Gołysz (G) and Byczki (B) complexes

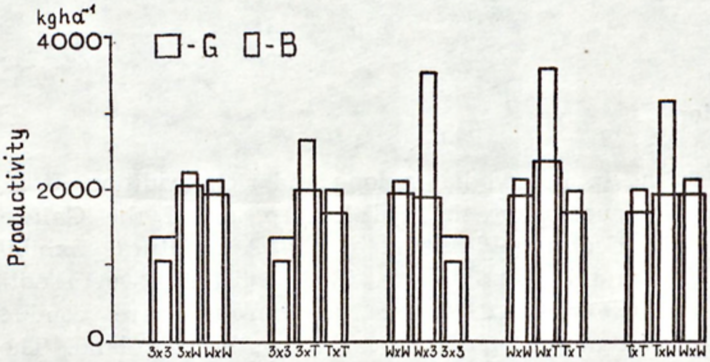

Fig. 7. Productivity of ponds stocked with crossbreds compared with that of ponds stocked with initial lines in ponds of the Gołysz (G) and Byczki (B) complexes

are compared not with the medium value of the given feature in the two initial lines, but with its value in the better line. Such a comparison is made in Table V. On this basis it may be deduced that the crossbreds Wx3 and TxW are not superior to the initial line WxW. The strong effect of heterosis was obtained mainly owing to the low values of the results for the variants 3x3 and TxT. The results obtained for all the crossbreds in ponds B, i.e. under less favourable environmental conditions (high density stock), were decidedly better. The effect of heterosis obtained was in all cases without exception stronger here than in ponds G.

About 30% of individuals caught in the variant TxT were nude, i.e. without scales, and had deformed fins. The pectoral, ventral, and dorsal fins showed a reduced number of rays, which were shorter and deformed. Caudal fins showed relatively the smallest deformation. This seems strange considering that the parents were frame mirror carp with correctly developed fins, hence nakedness should not occur in their progeny. In the crossbreds from these breeders, i.e. TxW, WxT, and 3xT, it was not observed. Moreover, nude carp had never been present in the Station ponds, thus the possibility of an incidental admixture of such carp must be excluded.

From the experiment results the following conclusions may be drawn:

1. The crossbred WxT proved to be the best and should be given preference in the commercial production of stock material.
2. The breeding lines 3 and T revealed features typical of highly inbred lines, above all a low survival rats.
3. The effect of heterosis was manifested in a higher survival rate, better consumption of feed, and increased yield per ha.
4. The effect of heterosis was stronger in less favourable environmental conditions.

4. Discussion

Fish breeding in Poland has a long and rich tradition. It is enough to mention the success of the Polish carp, called the Galician carp, which was awarded a gold medal at the Agricultural Exhibitions in Berlin in 1880 and in Hamburg in 1883. It is also worth noting that the first studies on carp genetics in Europe were conducted by E. Rudziński at the farm Osiek in southern Poland. They were concerned with crossing carp of various scaling (after Wołodek 1980).

According to Moav and Wohlfarth (1968), already the second inbred generation (F_2) of carp exhibits a strong inbred depression in the growth rate of the order of 10—20%. With the rainbow trout a 10% increase in the inbred coefficient (F) brings about a 10% reduction of fertilization, a 24% reduction in the survival of fingerlings, and a 3—7% reduction in body weight at the age of 2.5 years (Skjervold 1976). Moreover, even intensive selection had no great effect when the inheritance (h^2) of the selected features is low, as for example the inheritance of one of the basic characteristics, economically important, i.e. the growth rate, whose value is estimated to be from 0.2 (Kirpichnikov 1966) to 0.378 (Smisek 1979b).

The results obtained by other researchers in their experiments proved to be to some extent analogous to those described in the present paper. Bakos (1976) obtained fertilization of the order of 50—60% in bred lines, and over 80% in hybrids. The survival of the latter was also higher by 16% on the average. Smisek (1981b) examined crossbreds of carp from Hungary with those from Vodnany. Durding the first 60 days of rearing the survival of the crossbreds was from 28.0 to 43.0%, while for the initial line from Hungary it was 23.0%. The same author, when crossing carp from Ajszgrund with those from Hungary and Vodnany achieved a survival rate of the hatch during the first 30 days of rearing amounting to 41 to 66% (Smisek 1981a), while a crossbred of the carp from Hungary and Vodnany, produced earlier, exceeded, with regard to growth rate, the Hungarian line by 8% and the Vodnany line by 20% (Smisek 1979a). Suzuki and Yamaguchi (1980) when crossing different carp races from Japan, China, and Europe obtained a positive effect of heterosis on the growth rate, amounting to 177%, only in 7 out of 20 variant crossbreds. The best results were obtained by Sin (1982), who crossed the Israeli race „Dor-70" with females of the local one from Hong Kong. The effect of heterosis on the growth rate obtained by this author was as great as 200%. Slightly poorer results were obtained by Shimma et al. (1983), who crossed the Yamamoto carp with mirror carp of unknown origin and obtained the mass for hybrids 1.5 times greater than that of the initial races.

The occurrence of nakedness in the experimental group TxT probably affected the results since such carp do not grow as well as the mirror and full-scaled carp and their survival rate is poorer (Stegman 1965).

The phenomenon of the stronger manifestation of the heterosis effect in less favourable environmental conditions confirms the results of the studies by Andrijasheva (1966) according to which the overall resistance (adaptation) to disadvantageous conditions of the environment is the basic characteristic of the appearance of heterosis in crossbreeding of fish.

5. Polish summary

Potencjalne możliwości zastosowania efektu heterozji
w produkcji towarowej karpia (*Cyprinus carpio* L.)
1. Produkcja narybku

W przeprowadzonym doświadczeniu skrzyżowano linie hodowlane: polską 3 i węgierskie W i T (tabele I, II). Otrzymane krzyżówki: 3xW, 3xT, Wx3, WxT i TxW porównano do linii wyjściowych w takich cechach jak tempo wzrostu (ryc. 3), ciężar (ryc. 4), przeżywalność (ryc. 5), wykorzystanie pasz (ryc. 6) oraz produkcyjność (ryc. 7). W niniejszej pracy przedstawiono wyniki pierwszego sezonu produkcyjnego. Doświadczenie przeprowadzono na 16 stawach nowowybudowanego

kompleksu doświadczalnego Gołysz (G) (ryc. 1), stosując obsadę 50 000 szt. wylęgu na ha, oraz na 8 stawach kompleksu Byczki (B) (ryc. 2), stosując obsadę 90 000 szt. na ha (ryc. 1, 2). Stawy zarybiono 12 czerwca 1988. W trakcie sezonu ryby karmiono wysokobiałkowym granulatem. Odłów przeprowadzono od 26 do 29 września 1988, jego wyniki przedstawiono w tabeli III. Uzyskany efekt heterozji na stawach G (w nawiasie odpowiednio wyniki dla stawów B) wyniósł dla tempa wzrostu 81,3 do 107,7% (100,8—137,9%), dla przeżywalności od 117,5 do 162,7% (133,2—233,5%), dla wykorzystania pasz od 106,7 do 143,7% (153,0—252,5%) oraz dla wydajności z ha od 106,0 do 134,7% (139,6—222,2%) (tabela IV). Tak wysoki efekt heterozji został osiągnięty głównie dzięki niskim wynikom linii 3 i T, które wykazały cechy typowe dla linii wysokozinbredowanych, przede wszystkim niską przeżywalność. W celu lepszego zobrazowania „wyższości" krzyżówek nad liniami rodzicielskimi porównano je do tej linii wyjściowej, którą osiągnęła w danej cesze wyższy wynik. Okazało się, że w ten sposób mierzony efekt heterozji był znacznie niższy (tabela V). Spośród testowanych krzyżówek najkorzystniej wypadła WxT. W przypadku wszystkich cech osiągnięty efekt heterozji na stawach B był silniejszy niż na stawach G.

Podsumowując należy stwierdzić, że efekt heterozji wystąpił w przypadku przeżywalności, wykorzystania pasz i produkcyjności, oraz, że podstawową cechą przejawiania się heterozji jest podwyższona odporność na niesprzyjające warunki otaczającego środowiska.

6. References

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