Lessons from the Breeding Program on Common Carp in Hungary

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Abstract

Common carp is one of the most important cultured freshwater fish species in the world. Its production in freshwater areas is the second largest in Europe after rainbow trout. Common carp production in Europe was 146,845 t in 2004 (FAO Fishstat Plus 2006). Common carp production is concentrated mainly in Central and Eastern Europe. In Hungary, common carp has been traditionally cultured in earthen ponds since the late 19th century, following the sharp drop in catches from natural waters, due to the regulation of main river systems. Different production technologies and unintentional selection methods resulted in a wide variety of this species. Just before the intensification of rearing technology and the exchange of stocking materials among fish farms (early sixties), “landraces” of carp were collected from practically all Hungarian fish farms into a live gene bank at the Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) at Szarvas (Bakos and Gorda 1995; Bakos and Gorda 2001). In order to provide highly productive hybrids for production purposes starting from 1964, different strains and crosses between Hungarian landraces were created and tested. During the last 40 years, approximately 150 two-, three-, and four-line hybrids were produced. While developing parental lines, methods of individual selection, inbreeding, backcrossing of lines, gynogenesis and sex reversal were used. This breeding program resulted in three outstanding hybrids: “Szarvas 215 mirror” and “Szarvas P31 scaly” for pond production, and “Szarvas P34 scaly” for angling waters. Besides satisfying the needs of industry, the live gene bank helped to conserve the biological diversity of Hungarian carp landraces. Fifteen Hungarian carp landraces are still maintained today in the gene bank. Through exchange programs fifteen foreign carp strains were added to the collection from Central and Eastern Europe, as well as Southeast Asia (Bakos and Gorda 2001).

Besides developing the methodology to maintain live specimens in the gene bank, the National Carp Breeding Program has been initiated in cooperation with all the key stakeholders in Hungary, namely the National Association of Fish Producers (HOSZ), the National Institute for Agricultural Quality Control (OMMI), and the Research Institute for Fisheries, Aquaculture and Irrigation (HAKI). In addition, methodologies or technologies for broodstock management and carp performance testing have been developed. This National Carp Breeding Program is being implemented successfully since the mid-1990s.

Introduction

Common carp is one of the oldest and most cultured fish in the world. Its farming and breeding has a long history that started over 4000 years ago in China and several hundred years ago in Europe. During the last decades, India, Indonesia and Vietnam started to culture common carp, as a result of purposeful fish introductions.

To plan and develop a carp breeding program, it is important to have basic information about the existing carp populations, to know the applied production technologies and to be aware of consumers' demand and market requirements.

Local populations and landraces of common carp were developed within the cultivated species, as a result of various environmental conditions, and particular breeding efforts of fish farmers. The landraces differed in their genotypes, as well as in their qualitative and quantitative characters. These differences were inherited by their progenies. Systematic breeding and selection work of common carp started 45 years ago in Hungary, when the gradually intensifying farms required highly productive carp populations.

As a first step of the genetic improvement program, the most significant common carp strains with good performance were collected from Hungarian fish farms. Since 1962, fifteen Hungarian strains and an equal number of foreign strains represented the basis of the future breeding program and genetic research activities; they comprised a live gene bank at the Research Institute for Fisheries, Aquaculture and Irrigation, Szarvas, Hungary.

The main direction of selection was to improve those quantitative and qualitative traits, which directly or indirectly influenced productivity of carp under the given production-environmental conditions.

Viability, growth rate, food conversion, dressing yield and fat content were found to be the most important traits for both producers and consumers.

Productivity of 5-8 common carp strains were compared under similar environmental conditions every year by the following methods:

- Artificial propagation in the same hatchery;
- Nursing and fingerling rearing during the first year in the same farm;
- Group marking at the end of the first year;
- Wintering in a common pond in the same farm;
- Producing market-size fish during the second year in grow-out ponds in three different fish farms.

Individual or mass selection

During the process of selection, the specifically chosen individuals played a significant role in the development of new lines of broodstock. It was important to identify outstanding "line-founder" individuals, based on the knowledge of biological characters and productivity features of locally cultivated species. Individual selection was the basis for sorting young brood fish candidates in the breeding program. While accomplishing this breeding process, special attention was given to:

- the origin of the population;
- the performance of the given strain; and
- the typical external characteristics of the strains.

During the planning of the selection program, priority was given to the so-called parallel selection, meaning the selection for several important traits at the same time. In order to assist simultaneous evaluation of several characters, a so-called "selection index" has been developed. Ranking of the five most economically important quantitative traits is expressed by their "weight" in a 100-point valuation system: weight gain – 30 points; survival – 25 points; feed conversion – 20 points; dressing yield – 15 points; and fat content – 10 points. Results from a comparative test of five crosses and/or hybrids (in 1991) are shown as an example of applying the "selection index" (Table 1).

Every year several different strains were tested under similar conditions. To be able to compare their performance among themselves and during different years, a standard control group was used and a "group average" was calculated for each given year. Tested varieties were compared on one hand to the performance of the standard control group and on the other hand to the group average of the testing year.

Based on the results of the initial comparative performance tests, it is concluded:

1. There were measurable differences among the performance of the tested populations;
2. Traditional methods of individual and positive mass selection showed slow progress in some quantitative characters, because:
   - the variability of the tested traits was limited;
   - the probability of their heritability was low; and
   - the interval between consecutive generations was long.

Intraspecific hybridization

Based on the experiences mentioned above, priority was given to intraspecific hybridization from the mid-sixties. By that time, the method of artificial propagation of common carp made it possible to produce more crossing combinations annually. Starting from 1964, several landraces were crossed with one another with the expectation of a positive heterosis effect in the F1 generation of progenies. While developing the parental lines, various methods were used including individual selection, inbreeding, backcrossing of lines, gynogenesis and sex reversal.

However, not all the crosses resulted in positive heterosis. The F1 progenies sometimes have poorer performance than the parental lines. To obtain highly productive heterosis hybrids, not only is a high-level breeding program required, but also luck is sometimes needed. During the last 40 years, more than 150 crossing combinations of common carp strains were created and the performance of their progenies was tested in the Research Institute for Fisheries, Aquaculture and Irrigation. "Only" three outstanding hybrids with a high positive heterosis effect were established as being suitable for commercial-fish production. The "Szarvas 215" is a three-line mirror hybrid, the "Szarvas P31" is a three-line heterozygote scaly hybrid, and the "Szarvas P34" is a two-line homozygote scaly hybrid. Their breeding schemes are shown in Figures 1, 2 and 3).

The superiority of some hybrids is apparent mostly in their survival rate and adaptability. Differences between the parental and hybrid performances are not so noticeable if the production conditions are optimal; however, under poor conditions hybrids actually perform better than the parental lines (Bakos and Gorda 1995).

The heterosis effect can be increased by:

- crossing several genotypes with higher level of inbreeding, and
- creating three- or four-line hybrids.

By mating hybridized individuals among themselves, the heterosis effect can be decreased in the second and further generations (Hulata 2001; Kirpichnikov 1981). As an example, results of the performance of experimental crossings of hybrid "5x1" in Generations I and II are presented in Table 2. An important task during the breeding program is to avoid inbreeding depression. To maintain a commercially viable fish population, two lines "A" and "B" would be ideal to keep simultaneously in closed groups with strict selection in every generation. For example, females can be selected from line "A" and males from line "B" to ensure that fish farms with controlled quality brood fish produce high quality seed as shown in Figure 4 (Hulata 1995; Wohlfart 1993).

As a result of crossing experiments, three outstanding hybrids were produced:

- Szarvasi 215 three-line mirror;
- Szarvasi P31 three-line heterozygote scaled; and
- Szarvasi P34 two-line homozygote scaled.

All of them "obtained" the so-called "state-recognized hybrid" status because their performance (e.g. 15-20 per cent higher productivity) significantly exceeded the performance of other strains.

Distribution of highly productive hybrid populations was implemented by selling adults, ready for the propagation of maternal and paternal lines to fish producing farms.

During 1972-94, approximately 12,000 hybrid spawners were sold to commercial fish farms. During the eighties, about 80 per cent of the carp production in Hungary originated from the hybrids of the Research Institute for Fisheries, Aquaculture and Irrigation (HAKI), Szarvas.

Brood stock management

Broodstock management is an essential part of a well-designed breeding program. The main elements of brood stock management are as follows:

- Initial knowledge about the origin, domestication and breeding process of cultivated strains;
- Rearing and maintenance of brood fish;
- Selection of broodstock;
- Preparation of spawners for reproduction;
- Tagging and marking all the selected brood fish individually;
- Ensuring optimal environmental conditions of all populations;
- Keeping good accounts of the hatchery registration book;
- Separating males and females until the appropriate time for propagation;
- Feeding females and males with protein-rich food, complemented with vitamin A and E;
- Knowledge about the affinity of females and males, to avoid harmful inbreeding depression of the next generation. (See Table 3 for the results of a special crossing and back-crossing experiment of common carp full-sib and daughter mating, which caused deterioration in F_1 generation); and
- Elimination of anatomically deformed individuals when young brood stock candidates are selected.

Brood stock management is the basis for successful reproduction at hatcheries and fingerling production at specialized fish farms. Lessons in this area are published elsewhere (Varadi et al. 2002).

Breeding programs

The aim of a breeding program is to develop the most suitable fish population for satisfying specific needs (by farmers, anglers, conservationists, consumers, etc.). The breeding program includes all the genetic and selection methods that are suitable for improving productivity of a given fish population (Wohlfarth et al. 1987).

In a short-term breeding program, the fish breeder chooses the young brood stock that will be the parents of the next generation.

The criteria of brood fish selection include:

- Detailed information about the morphological and production characteristics of the population;
- Suitable market size fish of the same age within a population;
- Preferable average size and plus variants;
- Desirable sex ratio;
- Avoidance of inbreeding; and
- Marking of selected young brood fish candidates either individually or by group.

To fulfill a well-designed long-term breeding program, special personal, technical and biological conditions are needed, including several lines or varieties of cultivated species.

The consciously designed breeding programs should be directed to certain production or breeding purposes, such as:

- To increase the productivity of one or more quantitative traits;
- To improve the quality of the final product;
- To develop more disease-resistant strains:
- To achieve better adaptability to the environment of intensive production;
- To develop monosex female or male populations; and
- To maintain a live gene bank for the preservation of the basic genetic diversity.

Such a breeding program demands continuous and strict cooperation among the fish producers, researchers and the state officials controlling the breeding program. In the case of the Hungarian carp breeding program, 80 per cent of the Hungarian carp production was based on the hybrids of HAKI, developed during the 1980s. One of the lessons learned is that production and environmental conditions have strongly determined the breeding quality and spawning potential of the breeders. Production technology should be suitable to the biological and environmental requirements of common carp.

The national carp breeding program in Hungary is based on the following:

- A legal framework for animal production (Animal Breeding Act);
- Availability of carp populations kept in the state-owned live gene bank, or maintained at private farms;
- The National Institute for Agricultural Quality Control (OMMI) organizing performance tests, collecting data, and providing backstopping administration;
- The Hungarian "National Association of Fish Producers", serving as coordinator;
- The Research Institute for Fisheries, Aquaculture and Irrigation supervising the program;
- Financial support from the Ministry of Agriculture and Regional Development; and
- Meeting consumers' demands.

Fourteen Hungarian carp breeding farms, representing 14 per cent of the total number of fish farms, are members of the registered breeding units. They maintain, select and improve their own breeding material. Only these breeding farms with registered hatcheries can sell seed of common carp to other farms. If they do not register, fish farms can use their stocking material only in their own farms.

The breeding work is controlled by the OMMI. All the registered carp strains should be tested every five years. Production data are collected and registered in a computerized database.

The productivity of five different strains is tested annually in order to determine the genetic progress on the basis of the achieved quantitative traits.

In Hungary, a register book has been elaborated so that the following data are recorded:

- Origin of the given common carp strain;
- Morphological characteristics of the population; and
- Results of productivity under given environmental and production conditions.

Distribution of genetically improved carp seed is promoted by a state subsidy, of which the value is around 17 per cent of the price of fingerlings at the moment.

As a result of the existing carp breeding program, and efforts to improve the quality of the seed production in Hungary in 2002, about 80 per cent of the total fingerlings sold originated from certified breeders.

Conclusions

The breeding program of common carp has been successfully carried out in Hungary for more than forty years and has resulted in the following:

- The establishment of a live gene bank of common carp;
- The methodology to maintain live gene banks;
- The development of three productive hybrids for different conditions of fish farms and natural waters; and
- The establishment of the National Breeding Program for carp.

The proper implementation of the National Carp Breeding Program made it necessary for the development of these metodologies:

- Methodology of progeny performance testing;
- Methodology of licensing and controlling fish farms and hatcheries; and
- Methodology of controlled fish seed distribution.

Close cooperation among major stakeholders (National Association of Fish Producers, National Research Institute for Fisheries, Aquaculture and Irrigation (HAKI), and National Institute for Agricultural Quality Control (OMMI)) was the basis for implementing a successful breeding program of common carp in Hungary.

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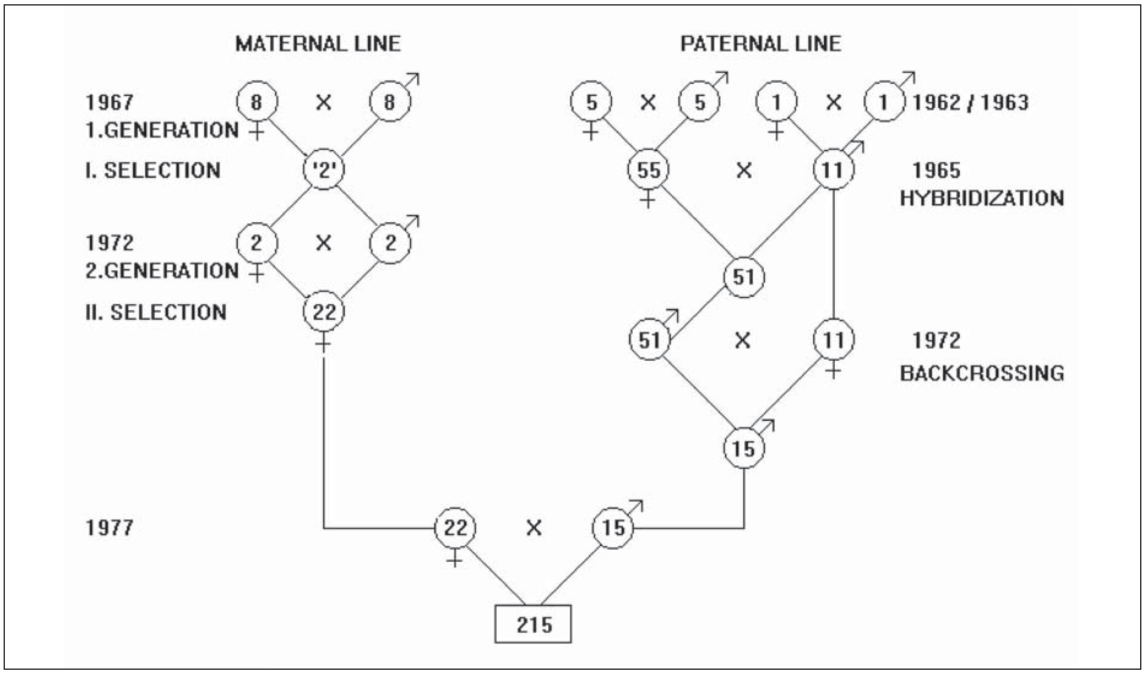


Figure 1. Breeding scheme of the Szarvas 215 hybrid.

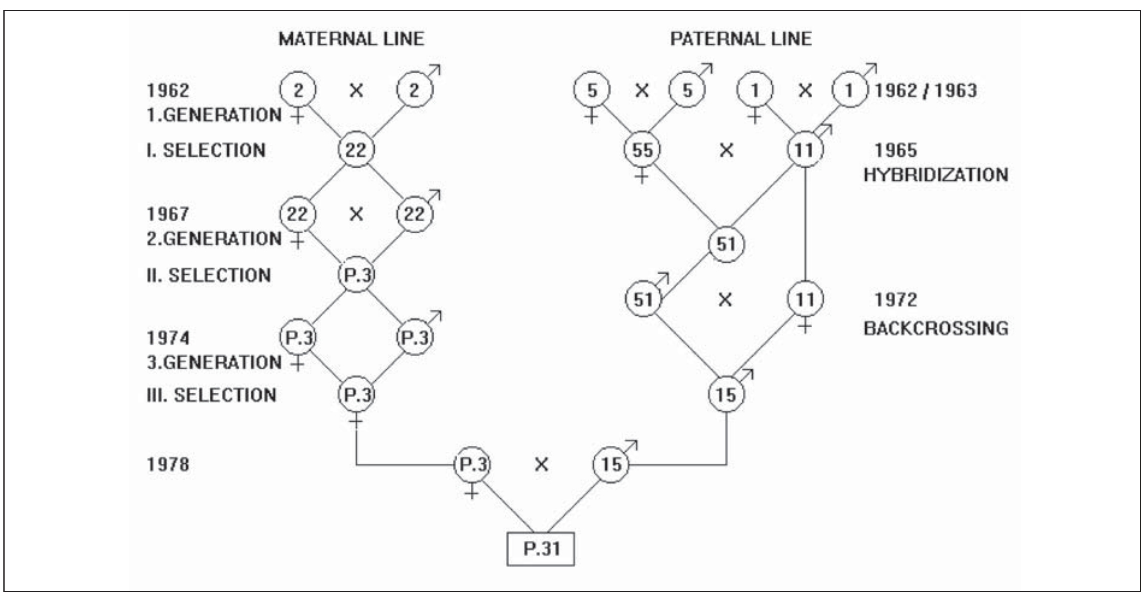


Figure 2. Breeding scheme of the Szarvas P31 hybrid.

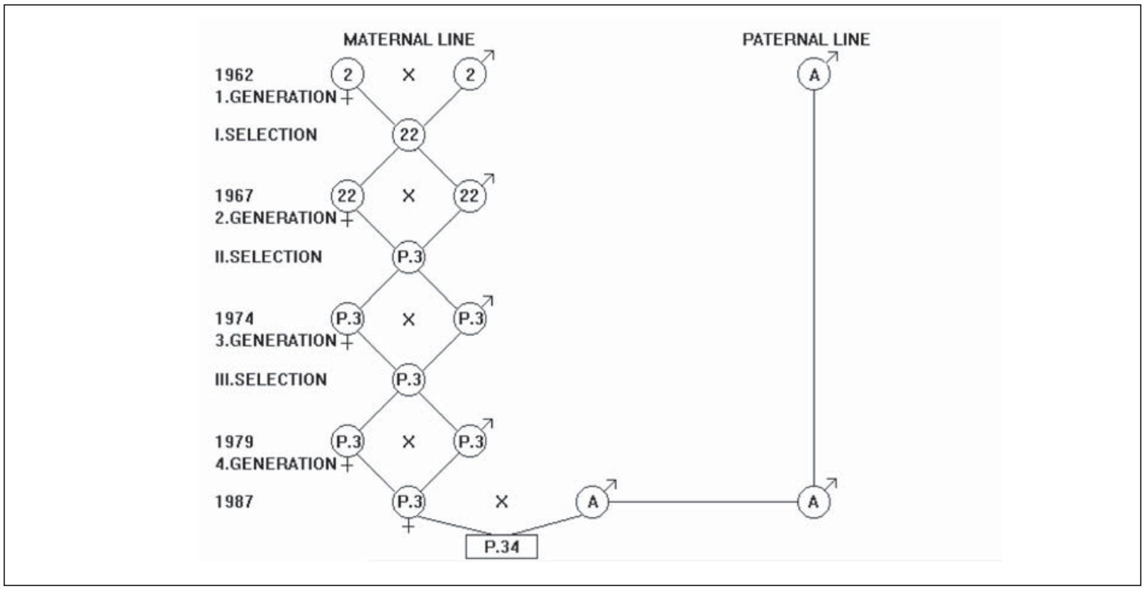
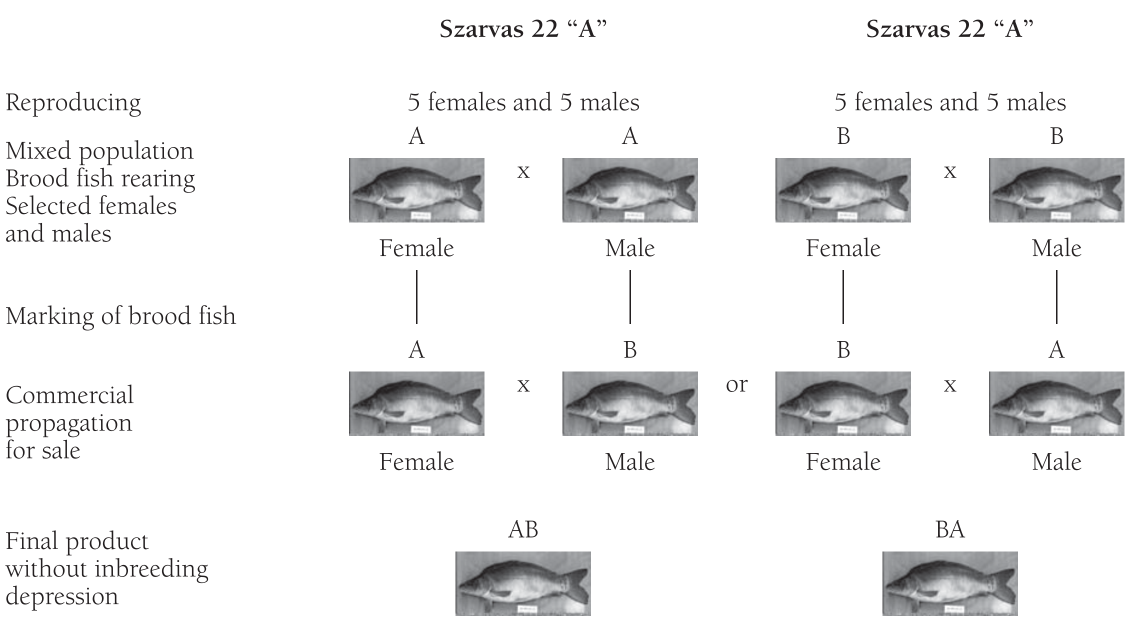


Figure 3. Breeding scheme of the Szarvas P34 hybrid.

Example of Szarvas 22 and Szarvas 5
Select two groups of spawners with a different origin

Common carp



Renew the parental stocks “A” and “B” every 5 years and select new young brood fish
Group marking system: fin clipping
Individual marking system: PIT-tag

Figure 4. Scheme for avoiding inbreeding by using two independent lines.

Table 1. Selection index (SI) as a practical way to compare productivity of hybrids on the basis of 5 economically important quantitative traits (tested in 1991, pond surface 2 ha).

Traits Groups	Weight gain		Survival		Feed conversion		Dressing yield		Fat content		SI Summation of scores
		Max. score		Max. score		Max. score		Max. score		Max. score	
	g	30	%	25	kg/kg	20	%	15	%	10	
Sz. 215	842	19.8	72.5	18.9	3.21	16.6	63.3	14.9	15.5	7.6	78.8
15 x D	752	17.7	48.0	12.5	4.53	11.7	62.8	14.8	11.9	10.0	66.1
N x D	830	19.5	52.0	13.5	4.32	12.3	63.5	15.0	12.9	9.1	69.7
Sz. P31	1176	27.7	187.5	22.8	3.23	16.5	61.0	14.4	14.5	8.2	89.7
Sz. P34	1272	30.0	95.6	25.0	2.96	19.8	60.0	14.1	12.2	9.7	98.7
Sz. P36	1232	29.0	82.0	21.4	2.67	20.0	61.0	14.3	14.2	8.3	93.2

Table 2. Decreasing of the heterosis effect in the F_2 generation of 5 x 1 hybrids compared to the 77 standard control population.

Characteristics		I. Generation			II. Generation		
		5 x 1	77	Deviation, %	51 x 51	77	Deviation, %
Survival	%	64.2	51.0	+13.2	46.0	40.1	+6.9
Growth	g	1446	1314	+10.0	1213	1174	+3.3
FQ	kg	1.53	2.15	-28.1	1.58	1.81	-12.9
Dressing yield	%	65.06	64.40	+0.66	63.89	64.43	-0.54
Fat content	%	14.77	16.91	-2.14	12.26	12.72	-0.46
Evaluation by the 100 point system		94.2	82.1	+14.7	82.7	76.8	+7.6

Table 3. Inbreeding depression of common carp by different inbreeding levels: decreasing the main quantitative traits.

Parent species Female x male	Initial weight g	Survival rate* %	Weight gain g	Dressing yield %	Fat content %	Body deformations %
A: 44 x 72	47	65.6	1040	62.2	13.8	0.0
B: 77 x 4	53	46.2	896	62.4	14.9	5.6
C: 54 x 4	44	46.5	728	62.2	13.1	10.6
D: 44 x 4	43	45.8	687	61.3	11.9	8.0
E: 44 x 44	47	41.6	695	62.8	9.7	5.7

* Survival rate is given for two growing seasons

A - Three-line hybrid
B - Two-line hybrid
C – Two-line hybrid, backcrossed with male 4
D - Inbreed line, father x daughter pairing
E - Inbreed line, full-sib pairing
The females of A, D and E are the same individuals of the inbred line 44
The males of B, C and D are the same individuals