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Effect of type of cross on litter size and litter weight of purebred and crossbred swine*

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ABSTRACT

Data on 321 litters from the first three gestations of purebred and single crosses of Duroc (D), Landrace (L), Yorkshire (Y) and Large White (LW) swine were analyzed by least squares to evaluate the effects of breed, general combining ability, specific combining ability, maternal and reciprocal effects and total and specific heterosis on total number of piglets at birth (TNPB), number of piglets alive at birth (NPAB), at 21 days (NP21), at weaning (NP35) and at the end of the growth period (NP 77) as well as litter weight at birth (LWB), at 21 days (LW21), at weaning (LW35) and at the end of the growth period (LW77). Purebred Large White litters had a better performance than Duroc litters for traits: NPAB, NP21 and NP35. Breed significantly affected LW35, though there were no differences among L, LW and Y breeds, which had heavier litters compared to Duroc. There was no significant effect of general combining ability either on litter size or litter weight. Specific combining ability significantly affected only LWB. Better performance was observed for D x Y and L x LW crosses. Maternal effect had no significant effect on litter size traits, but significantly affected LWB, LW21 and LW35. Lower litter weights were observed for LW breed (LWB) and D breed (LW21 and LW35). Reciprocal effect and total heterosis did not affect any of the traits. Significant effects of specific heterosis ($P \leq 0.05$) were observed only for D x Y crosses, with estimated values of 21.84% (LW35) and 22.50% (LW77).

INTRODUCTION

Experimental stations around the world started research on crosses comparing the performance of pure and crossbred around 1890. One of the first papers published by Otis (1904), according to Schneider (1976), indicated that crossbred swine had higher weight gains than purebred swine.

Between 1935 and 1955 in the United States of America researchers started experimental work with the objective of developing commercial lines of swine (Craft, 1958). Unfortunately those programs were based on the development of inbred lines, as used in hybrid maize production. The inbreeding depression in the reproductive performance of inbred lines, as a consequence of the increase in homozygosity, seems to be the main reason those programs did not contribute much to commercial production of swine (Bichard and Smith, 1971).

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One of the research works that supports the idea that breeds have different behavior when used in crosses was presented by Lush *et al.* (1939), cited by Schneider (1976), in studies involving Landrace and Poland China crosses. These results indicated that crossbred animals were superior to purebred animals in number of live piglets, vigor of the animals at birth, survival from birth to weaning and litter weight at weaning.

Dickerson *et al.* (1946), studying single crosses of Poland China inbred lines, observed that crossed animals had a larger litter size at birth, at 21, at 56 and at 154 days. They also observed that crossed animals were heavier at 56 and 154 days of age. In order to give a better understanding of the genetic aspects of swine crosses, Henderson (1948), cited by Schneider (1976), modified the statistical model proposed by Sprague and Tatum (1942), to estimate general and specific combining ability in single crosses involving inbred lines. The new proposed model involved the estimation of general and specific combining ability and maternal effects, as well as the reciprocal effect.

According to Hayman (1954), the diallel crosses involve a set of $\mathbf{n}^2$ possible crosses (among and within **n** homozygote lines) that, as indicated by Griffing (1956), make an **n x n** table composed of mean values of breeds **i** (Xii), of the single crosses of breeds **i** and **j** (Xij) and of the reciprocal crosses (Xji).

In general in research with animals all $\mathbf{n}^2$ combinations have been used. Harvey (1968) proposed a model by which it is possible to estimate the effects of purebred, general and specific combining ability, maternal effects, reciprocal effect and heterosis. Recently, Eisen *et al.* (1983) tried to include in the diallel crosses model, the genetic interpretation of significant maternal effects, which are expected in swine.

MATERIAL AND METHODS

In this study data on 321 litters from the first three gestations of purebred and single crosses of Duroc (D), Landrace (L), Yorkshire (Y) and Large White (LW) were analyzed by least squares to evaluate the effects of breed, general combining ability, specific combining ability, maternal and reciprocal effects and total and specific heterosis on total number of piglets at birth (TNPB), number of piglets alive at birth (NPAB), at 21 days (NP21), at weaning (NP35) and at the end of the growth period (NP77) as well as litter weights at birth (LWB), at 21 days (LW21), at weaning (LW35) and at the end of the growth period (LW77).

During the experiment 22 boars were used, five of the Duroc breed, six Landrace, five Yorkshire and six Large White, which were crossed with 124 gilts to produce 79 pure litters and 242 single crossed litters, with the number of litters in each combination varying from 15 to 27.

Although the number of litters in each combination was not the same, there was a sufficient number of litters to allow adequate estimates of each combination.

For each type of cross the first gestation of the remaining females, after the normal elimination due to reproductive problems, was evaluated. The total number of litters evaluated from the 1st, 2nd and 3rd gestations were 121, 105 and 93 litters, respectively. For each type of cross the females were mated to the same males for three consecutive gestations.

The females were fed 1.80 to 2.00 kg of ration during gestation and 4.0 to 5.0 kg during lactation. The piglets had access to pre-start ration from seven days of age and were weaned at approximately five weeks. The rations were formulated according to the nutrional requirements of swine for the different phases (Rostagno *et al.*, 1983), using corn and soybean meal with supplements of vitamins and minerals.

All the pigs were confined. The females were maintained in pens for six animals from weaning to the gestation period and these were surrounded by male pens. The gestation period was completed in individual pens, then the females were transferred to maternity where parturition occurred in individual pens. After weaning the piglets were transferred to suspended pens until they reached 20 to 25 kg (77 days).

All the piglets were identified and weighed individually at birth and at approximately 21, 35 and 77 days of age. The weights of the pigs obtained at different ages were adjusted to a fixed age.

The data on litter size and litter weight at birth, including mummified and stillborn piglets and number of piglets born alive and litter size at three, five and 11 weeks of age, were registered. The adjusted individual weights were added up for each litter to represent the litter weights for each of the three stages of development after birth.

Least squares methodology was used in the statistical analysis of the traits, according to the following model:

$$Y_{hijk} = \mu + a_h + p_{1ii} + g_{2i(2j)} + m_{2j} + c_{2ij} + r_{2ij} + e_{hijk},$$

where

Y_{hijk} = observation of kth-progeny from the cross of a female from breed j, with a male from breed i in mating type h (pure or crossed); μ = adjusted mean; a_h = common effect to all progeny from mating type h (pure or crossed), the difference between these effects gives an estimate of heterosis; p_{1ii} = common effect to all progeny from mating of one female of breed i with one male of breed i; $g_{2i(2j)}$ = effect of general combining ability of breed i with the remaining j breeds; m_{2j} = maternal effect of breed of female j; c_{2ij} = effect of specific combining ability of breed i with breed j; r_{2ij} = reciprocal effect, which measures the difference between reciprocal crosses after considering the differences in maternal ability between breeds i and j; e_{hijk} = random error, assumed to be $\sim NID(0, \sigma_e^2)$; (1) = indicates that the effects are measured only among the progenies of the first mating type (pure); (2) = indicates that the effects are measured only among the progenies of the second type of mating (crossed).

Two FORTRAN computer programs were used in the analysis (Oliveira, 1988). These programs were based on methodologies described by Harvey (1968).

The differences among effects were evaluated by Newman-Keuls test, described by Steel and Torrie (1960).

RESULTS AND DISCUSSION

Litter size from birth to the end of the growth period

The least square means of litter size traits from birth to the end of the growth period, the effects of breed, general combining ability, maternal effect and the specific combining ability, expressed as deviations of means for all analyzed traits are presented in Table I.

The TNPB, NPAB, NP21, NP35 and NP77 estimated averages are higher than those presented by Johnson (1981) in a review of swine cross experiments from different researchers.

The effects of breed were significant ($P \leq 0.05$) for NPAB, NP21 and NP35. The general combining ability, the maternal effect and specific combining ability did not affect any of the traits.

Large White breed litters had better performance than Duroc, considering NPAB, NP21 and NP35. These results are similar to those presented by Bereskin *et al.* (1974) and Schneider (1978).

The general combining ability did not have an important effect on the litter size. These results were similar to those obtained by Bereskin *et al.* (1974) and Schneider (1978).

The litter size traits analyzed were not significantly affected by maternal effect, probably due to the fact that the data only referred to single cross results. Schneider (1978) showed that maternal effect had a significant effect on litter size of live piglets, and litter size at 21, at 56 and at 154 days of age but he also showed that this effect tended to be smaller and less significant when compared with the breed of maternal granddam effect.

The specific combining ability was not significant for the litter size traits, these results are similar to those obtained by Hertzer *et al.* (1961), cited by Schneider (1978), although they are different from those obtained by Henderson (1948), cited by Schneider (1976), who found a significant effect of specific combining ability on litter size at birth, and by Schneider (1978), who observed significant deviations of specific combining ability for litter size at 21, at 56 and at 154 days of age.

The deviations of means due to reciprocal effect, total heterosis and specific heterosis for TNPB, NPAB, NP21, NP35 and NP77 are presented in Table II.

The reciprocal effect was not an important source of variation for litter size traits for all ages studied, and the lack of results in the literature did not allow any type of comparison.

The heterosis of the piglets was not significant for TNPB, NPAB, NP21, NP35 and NP77.

The total heterosis of the piglets had no important effect on litter size. This was as expected because there should be no heterosis for litter size in single crosses involving purebred females.

Although Schneider (1978) did not find a significant effect of heterosis, the estimated heterosis presented by Schneider (1978), Smith and King (1964), O'Ferrall *et al.* (1968), Bereskin *et al.* (1974) and Young *et al.* (1976) was higher than that found in this study.

The specific heterosis estimates of piglets also did not significantly affect the traits analyzed. Specific heterosis for number of piglets at 21, at 35 and at 77 days of age, for D x Y crosses, although not significant were greater than those presented by Schneider (1978) and smaller than those presented by Young *et al.* (1976) for the same cross (20.0% at 42 days). In a review of experiments involving swine crosses, Johnson (1981) concluded that the heterosis estimates for litter size at birth gave little evidence that litters from single crosses had a higher viability than litters from purebred breeds. The estimate presented by Young *et al.* (1976) of 1.25 ± 0.38 live pigs per litter at birth for Duroc x Yorkshire crosses was the only value found in the literature for this trait.

Table I - Means[1], and the effects[2] of breed, general combining ability (GCA), maternal effect (ME) and specific combining ability (SCA) on total number of piglets at birth (TNPB), number of piglets alive at birth (NPAB), at 21 days (NP21), at weaning (NP35) and at the end of the growth period (NP77)[3].

Item[4]	No.	TNPB No.	NPAB No.	NP21 No.	NP35 No.	NP77 No.
μ		10.151 ± 0.18	9.195 ± 0.18	7.881 ± 0.18	7.769 ± 0.18	7.309 ± 0.18
Breed		ns	*	*	*	ns
D	15	-0.597 ± 0.71 a	-1.165 ± 0.71 b	-1.303 ± 0.71 b	-1.395 ± 0.71 a	-1.235 ± 0.71 a
L	22	-0.083 ± 0.58 a	-0.071 ± 0.58 ab	0.572 ± 0.59 ab	0.589 ± 0.59 ab	0.425 ± 0.59 a
Y	20	-0.464 ± 0.61 a	-0.148 ± 0.61 ab	-0.387 ± 0.62 ab	-0.329 ± 0.62 ab	-0.252 ± 0.62 a
LW	22	1.145 ± 0.58 a	1.384 ± 0.58 a	1.118 ± 0.59 a	1.135 ± 0.59 a	1.062 ± 0.59 a
GCA		ns	ns	ns	ns	ns
D	71.5	-0.443 ± 0.45 a	-0.287 ± 0.45 a	-0.009 ± 0.45 a	0.014 ± 0.45 a	0.059 ± 0.45 a
L	84.5	-0.118 ± 0.46 a	-0.140 ± 0.46 a	-0.157 ± 0.46 a	-0.124 ± 0.46 a	-0.188 ± 0.46 a
Y	82.0	0.551 ± 0.46 a	0.555 ± 0.46 a	0.382 ± 0.46 a	0.300 ± 0.46 a	0.420 ± 0.46 a
LW	83.0	0.011 ± 0.59 a	-0.128 ± 0.59 a	-0.216 ± 0.59 a	-0.190 ± 0.59 a	-0.291 ± 0.59 a
ME		ns	ns	ns	ns	ns
D		0.017 ± 0.50 a	-0.456 ± 0.50 a	-0.852 ± 0.50 a	-0.907 ± 0.50 a	-0.766 ± 0.50 a
L		0.012 ± 0.49 a	0.190 ± 0.49 a	0.371 ± 0.49 a	0.341 ± 0.49 a	0.365 ± 0.49 a
Y		-0.503 ± 0.49 a	-0.076 ± 0.49 a	0.156 ± 0.49 a	0.256 ± 0.49 a	0.165 ± 0.49 a
LW		0.474 ± 0.49 a	0.342 ± 0.49 a	0.325 ± 0.49 a	0.310 ± 0.49 a	0.235 ± 0.49 a
SCA		ns	ns	ns	ns	ns
D x L = Y x LW		-0.177 ± 0.40 a	-0.065 ± 0.40 a	-0.189 ± 0.41 a	-0.219 ± 0.40 a	-0.191 ± 0.40 a
D x Y = L x LW		0.056 ± 0.40 a	-0.088 ± 0.40 a	0.055 ± 0.40 a	0.068 ± 0.40 a	0.109 ± 0.40 a
D x LW = L x Y		0.121 ± 0.40 a	0.153 ± 0.40 a	0.134 ± 0.40 a	0.151 ± 0.40 a	0.082 ± 0.40 a

1 - Estimated least square means ± standard errors.
2 - Estimated least square deviations of the means ± standard errors.
3 - The estimated deviations of the means, with different letters in the column, within each effect, are statistically different ($P \leq 0.05$) by Newman-Keuls test.
4 - Duroc (D), Landrace (L), Yorkshire (Y) and Large White (LW).
* - Significant at 5% level by F test.
ns - Not significant at 5% level by F test.

Heterosis estimates for litter size at birth have values of 0.38 ± 0.26 (Young *et al.*, 1976) and of -0.29 ± 0.19 (Schneider, 1978), similar to the estimate found in this study (0.21 ± 0.36).

The heterosis for litter size at 21 days of age had an important effect on piglet survival after birth. The estimated heterosis of 0.09 ± 0.36 for live pigs per litter was not significant due to the use of purebred females in the crosses. The use of crossed females in the crosses is the main reason for the different estimates published by Young *et al.* (1976) of 0.65 ± 0.23 and by Schneider (1978) of 0.23 ± 0.17 pigs. These estimates are usually greater than those for litter size at birth, showing an important effect of heterosis on pig survival. However, Johnson (1981) indicated that the observed differences are probably due to the differences found in litter size at birth.

Litter weights from birth to the end of the growth period

The estimated means for litter weights from birth to the end of the growth period and the effects of breed, general combining ability, maternal effect and specific combining ability expressed as deviations of the means for these traits are presented in Table III. These averages are greater than those presented by Johnson (1981).

Litters from L and LW breeds were significantly heavier ($P \leq 0.05$) than Duroc litters at 35 days of age and Y litters did not differ from litters of the other breeds. The estimated deviations were 10.79, 5.40, 0.13 and -16.32 for litter weights of Landrace, Large White, Yorkshire and Duroc breeds, respectively, showing higher performance at weaning for the first

Table II - Reciprocal effect (RE), total heterosis (TH) and specific heterosis (SH) effects[1] on total number of piglets at birth (TNPB), number of piglets alive at birth (NPAB), at 21 days (NP21), at weaning (NP35) and at the end of the growth period (NP77)[2].

Item[3]	TNPB No.	NPAB No.	NP21 No.	NP35 No.	NP77 No.
RE	ns	ns	ns	ns	ns
D x L = -L x D	0.426 ± 0.44 a	0.367 ± 0.44 a	0.163 ± 0.45 a	0.127 ± 0.44 a	-0.047 ± 0.44 a
D x Y = -Y x D	-0.606 ± 0.44 a	-0.242 ± 0.44 a	-0.146 ± 0.44 a	-0.128 ± 0.44 a	0.021 ± 0.44 a
D x LW = -LW x D	0.180 ± 0.44 a	-0.125 ± 0.44 a	-0.017 ± 0.45 a	0.001 ± 0.45 a	0.026 ± 0.45 a
L x Y = -Y x L	0.651 ± 0.43 a	0.328 ± 0.43 a	0.037 ± 0.44 a	0.000 ± 0.44 a	-0.100 ± 0.44 a
L x LW = -LW x L	1.033 ± 0.44 a	0.608 ± 0.44 a	0.309 ± 0.44 a	0.255 ± 0.44 a	-0.068 ± 0.44 a
Y x LW = -LW x Y	0.044 ± 0.44 a	0.086 ± 0.44 a	-0.109 ± 0.44 a	-0.128 ± 0.44 a	-0.079 ± 0.44 a
	ns	ns	ns	ns	ns
TH	-0.227 ± 0.36	-0.205 ± 0.36	0.087 ± 0.36	0.079 ± 0.36	0.015 ± 0.36
%	-2.21	-2.21	1.13	1.03	0.21
SH	ns	ns	ns	ns	ns
D x L	-0.614 ± 0.64	-0.212 ± 0.64	-0.141 ± 0.65	-0.130 ± 0.65	-0.100 ± 0.65
%	-6.16	-2.45	-1.88	-1.77	-1.45
D x Y	0.224 ± 0.64	0.365 ± 0.64	1.014 ± 0.65	0.998 ± 0.65	1.046 ± 0.65
%	2.30	4.22	14.50	14.54	15.95
D x LW	-0.566 ± 0.65	-0.634 ± 0.64	-0.172 ± 0.65	-0.113 ± 0.65	-0.313 ± 0.65
%	-5.37	-6.74	-2.23	-1.49	-4.34
L x Y	0.355 ± 0.59	0.530 ± 0.59	0.619 ± 0.60	0.575 ± 0.59	0.507 ± 0.59
%	3.55	5.76	7.81	7.31	6.86
L x LW	-0.567 ± 0.59	-0.951 ± 0.59	-0.726 ± 0.60	-0.702 ± 0.59	-0.798 ± 0.60
%	-5.25	-9.56	-8.37	-8.17	-9.92
Y x LW	-0.196 ± 0.61	-0.329 ± 0.61	-0.060 ± 0.61	-0.149 ± 0.61	-0.251 ± 0.61
%	-1.85	-3.32	-0.73	-1.73	-3.26

1 - Estimated least square deviations of the means ± standard errors.
2 - The estimated deviations of the means, with different letters in the column, within RE, are statistically different ($P \leq 0.05$) by Newman-Keuls test.
3 - Duroc (D), Landrace (L), Yorkshire (Y) and Large White (LW).
ns - Not significant at 5% level by F test.

two breeds. These results contrast with those obtained by Schneider (1978) who did not find significant effects of breeds for all analyzed traits.

The general combining ability was an important source of variation for litter weight. This result is similar to those obtained by Schneider (1978). Nelson and Robinson (1976) also found significant effect of general combining ability for litter weight at different ages, the significant differences among paternal breeds, published by Young *et al.* (1976) suggested that progenies from Yorkshire boars had higher individual weight performance and lower total litter weight at 21 and at 42 days of age. Similarly, Nelson and Robinson (1976) concluded that litter from Hampshire boars were lighter at 140 days of age and small differences were observed for litters from Duroc and Yorkshire boars. In the present study these differences for litter weights at birth, at 21 and at 77 days of age were not observed. At weaning time (LW35) litter weights from Duroc and Yorkshire boars were lower.

Differences due to maternal effect were significant for LWB, LW21 and LW35. These results are similar to those obtained by Bereskin *et al.* (1974) and Schneider (1978). Litter weights of LW females were lower at birth and those from Duroc females were lower at 21 and 35 days of age. The superiority of maternal ability for total litter weight presented by Landrace females at birth, probably is due to heavier individual piglet weights at birth. The same result was observed for the Yorkshire breed at 21 days of age. Maternal ability inferiority for total litter weights of the Duroc breed at 21 and at 35 days of age probably is related to the fact that they presented smaller litters at the mentioned ages.

Among all the traits related to total litter weight there was a significant effect of specific combining ability only on birth weight, with D x Y and L x LW (deviation of 0.36 kg) presenting better performances. Schneider (1978) also found significant deviations for litter weight at 21, at 56 and 154 days of age. The deviation due to specific combining ability seems to mainly reflect the differences in individual pig weight.

The reciprocal effects, total heterosis and specific heterosis expressed as deviations of the means are presented in Table IV.

Table III - Means[1] and effects[2] of breed, general combining ability (GCA), maternal effect (ME) and specific combining ability (SCA) on litter weight at birth (LWB), at 21 days (LW21), at weaning (LW35) and at the end of growth period (LW77)[3].

Item[4]	No.	LWB kg	LW21 kg	LW35 kg	LW77 kg
μ	321	14.005 ± 0.24	36.758 ± 1.19	59.141 ± 1.34	171.895 ± 4.23
Breed		ns	ns	**	ns
D	15	-0.611 ± 0.94 a	-9.240 ± 4.70 a	-16.317 ± 5.29 b	-21.603 ± 16.64 a
L	22	1.783 ± 0.77 a	6.188 ± 3.88 a	10.794 ± 4.36 a	12.418 ± 13.74 a
Y	20	-1.006 ± 0.81 a	0.442 ± 4.07 a	0.125 ± 4.58 ab	-6.522 ± 14.41 a
LW	22	-0.167 ± 0.77 a	2.610 ± 3.88 a	5.398 ± 4.36 a	15.707 ± 13.74 a
GCA		ns	ns	ns	ns
D	71.5	-0.592 ± 0.59 a	1.587 ± 2.96 a	1.704 ± 3.34 a	4.555 ± 10.51 a
L	84.5	0.074 ± 0.61 a	1.664 ± 3.03 a	0.903 ± 3.41 a	-3.980 ± 10.74 a
Y	82.0	-0.407 ± 0.61 a	-4.089 ± 3.05 a	-2.407 ± 3.44 a	4.012 ± 10.83 a
LW	83.0	0.925 ± 0.78 a	0.838 ± 3.92 a	-0.200 ± 4.41 a	4.588 ± 13.88 a
ME		**	**	**	ns
D		0.219 ± 0.66 ab	-8.967 ± 3.31 b	-9.577 ± 3.73 b	-17.780 ± 11.73 a
L		1.496 ± 0.64 a	2.965 ± 3.22 a	3.306 ± 3.63 a	7.523 ± 11.43 a
Y		-0.214 ± 0.64 ab	6.833 ± 3.23 a	8.289 ± 3.63 a	13.825 ± 11.43 a
LW		-1.502 ± 0.65 b	-0.831 ± 3.26 ab	-2.018 ± 3.67 ab	-3.569 ± 11.55 a
SCA		*	ns	ns	ns
D x L = Y x LW		-0.849 ± 0.53 b	-0.244 ± 2.67 a	-1.752 ± 3.01 a	-7.208 ± 9.46 a
D x Y = L x LW		0.360 ± 0.53 a	-0.680 ± 2.66 a	1.183 ± 2.99 a	3.473 ± 9.24 a
D x LW = L x Y		0.489 ± 0.53 ab	0.924 ± 2.66 a	0.569 ± 2.99 a	3.735 ± 9.43 a

**Significant at 1% level by F test.
For symbols, see Table I.

Table IV - Reciprocal effect (RE), total heterosis (TH) and specific heterosis (SH) effects[1] on litter weight at birth (LWB), at 21 days (LW21), at weaning (LW35) and at the end of the growth period (LW77)[2].

Item[3]	LWB kg	LW21 kg	LW35 kg	LW77 kg
RE	ns	ns	ns	ns
D x L = -L x D	0.127 ± 0.59 a	-1.714 ± 2.93 a	-1.118 ± 3.30 a	-3.514 ± 10.39 a
D x Y = -Y x D	0.699 ± 0.58 a	2.209 ± 2.93 a	-1.582 ± 3.29 a	-1.116 ± 10.37 a
D x LW = -LW x D	0.571 ± 0.59 a	-0.495 ± 2.95 a	2.700 ± 3.32 a	4.630 ± 10.44 a
L x Y = -Y x L	0.670 ± 0.58 a	-1.536 ± 2.88 a	-1.147 ± 3.24 a	-3.890 ± 10.20 a
L x LW = -LW x L	0.826 ± 0.58 a	-3.924 ± 2.89 a	0.464 ± 3.26 a	-2.398 ± 10.27 a
Y x LW = -LW x Y	-0.029 ± 0.58 a	0.673 ± 2.90 a	-2.792 ± 3.26 a	-5.001 ± 10.27 a
	ns	ns	ns	ns
TH	-0.149 ± 0.48	-1.584 ± 1.68	-2.988 ± 2.70	-5.402 ± 7.86
%	-1.07	-4.27	-5.33	-3.38
SH	ns	ns	*	*
D x L	-0.946 ± 0.85	1.672 ± 4.27	3.382 ± 4.80	3.066 ± 15.13
%	-6.51	4.76	6.16	1.89
D x Y	0.320 ± 0.85	0.289 ± 4.27	10.833 ± 4.81*	34.360 ± 15.15*
%	2.44	0.89	21.84	22.50
D x LW	0.719 ± 0.86	1.906 ± 4.29	4.635 ± 4.82	6.210 ± 15.19
%	5.31	5.71	8.87	3.79
L x Y	0.557 ± 0.78	0.223 ± 3.93	2.304 ± 4.42	21.727 ± 13.92
%	3.89	0.56	3.65	12.80
L x LW	0.697 ± 0.78	-1.370 ± 3.93	-2.665 ± 4.42	-6.947 ± 13.93
%	4.73	-3.33	-4.05	-3.84
Y x LW	-0.454 ± 0.80	-1.881 ± 4.03	-1.084 ± 4.53	2.985 ± 14.27
%	-3.40	-4.92	-1.79	1.74

*Significant at 5% level by F test.
For symbols see Table II.

The reciprocal effect did not affect any trait and there is no available data in the literature for comparison, but it is necessary to consider the reciprocal effect in studies involving swine crossing. The total heterosis was not a significant source of variation for the traits studied and the specific heterosis had a significant effect on D x Y litter weights at 35 days and at the end of the growth period. This probably can be attributed to the heavier individual weights of piglets. This result is similar to those presented by Young *et al.* (1976) who obtained significant estimates of heterosis for litter weights at 42 days of 20.7% for D x Y, 20.40% for D x Hampshire (H) and 6.00% for H x Y crosses; and by Schneider (1978) who found significant heterosis of 20.40% for litter weight at 56 days in Chester White (CW) x D crosses and of 25.70% for D x H crosses at 56 days. For litter weight at 154 days he found heterosis rates of 21.20, 22.00 and 27.10% for CW x H, CW x Y and CW x D crosses, respectively.

According to Johnson (1981) heterosis estimates for litter weight at 21 days are highly variable but part of this variation is due to the fact that similar crosses produce different estimates in independent experiments.

Mortality rate of pigs from birth to the end of the growth period

The estimated mortality rates of pigs at different ages and the effects of breed, general combining ability, maternal effect and specific combining ability, expressed as deviations of the means, for these traits are presented in Tables V and VI.

The high rate of mortality at birth and of mummified piglets (9.2%) in this experiment could be due to the use of only first parity females. The high coefficients of variation found in the experiment may be due to the nature of the traits. The homogeneity test of variance (Bartlett test) indicated the necessity of data transformation. However, the arc sin of the square root of the percentage, the square root plus 1/2, the square root plus

Table V - Means[1] and effects[2] of breed, general combining ability (GCA), maternal effect (ME) and specific combining ability (SCA) on mortality rate at birth (MRB), rate of mummified piglets (RMP) and mortality rate from birth to 21 days (MRB21)[3].

Item[4]	No.	MRB (%)	RMP (%)	MRB21 (%)
μ	321	6.062 ± 0.72	3.137 ± 0.49	13.736 ± 1.15
Breed		ns	*	ns
D	15	2.549 ± 2.84 a	3.447 ± 1.94 a	4.817 ± 4.52 a
L	22	-1.523 ± 2.35 a	1.826 ± 1.61 a	-6.501 ± 3.73 a
Y	20	0.325 ± 2.46 a	-3.018 ± 1.68 ab	0.937 ± 3.92 a
LW	22	-1.351 ± 2.35 a	-2.255 ± 1.60 b	0.747 ± 3.73 a
GCA		ns	ns	ns
D	71.5	-1.880 ± 1.80 a	0.332 ± 1.22 a	-3.272 ± 2.85 a
L	84.5	-0.112 ± 1.84 a	0.485 ± 1.25 a	0.261 ± 2.92 a
Y	82.0	-0.521 ± 1.85 a	0.117 ± 1.26 a	1.017 ± 2.94 a
LW	83.0	2.514 ± 2.37 a	-0.935 ± 1.62 a	1.993 ± 3.77 a
ME		ns	ns	ns
D		2.665 ± 2.00 a	1.800 ± 1.37 a	5.518 ± 3.19 a
L		-0.389 ± 1.95 a	-1.278 ± 1.33 a	-2.517 ± 3.10 a
Y		-3.278 ± 1.95 a	-0.356 ± 1.33 a	-1.624 ± 3.10 a
LW		1.001 ± 1.97 a	-0.165 ± 1.35 a	-1.368 ± 3.14 a
SCA		ns	ns	ns
D x L = Y x LW		-1.343 ± 1.62 a	0.217 ± 1.10 a	1.515 ± 2.57 a
D x Y = L x LW		0.985 ± 1.61 a	0.091 ± 1.10 a	-1.417 ± 2.56 a
D x LW = L x Y		0.358 ± 1.61 a	-0.309 ± 1.10 a	-0.099 ± 2.56 a

For symbols see Table I.

Table VI - Means[1] and effects[2] of breed, general combining ability (GCA), maternal effect (ME) and specific combining ability (SCA) on mortality rate from birth to weaning (MRBW), from birth to the end of the growth period (MRBEG) and from weaning to the end of the growth period (MRWEG)[3].

Item[4]	No.	MRBW (%)	MRBEG (%)	MRWEG(%)
μ	321	14.968 ± 1.15	19.625 ± 1.27	5.790 ± 0.75
Breed		ns	ns	ns
D	15	5.806 ± 4.54 a	4.261 ± 5.00 a	-1.180 ± 2.95 a
L	22	-6.524 ± 3.75 a	-3.848 ± 4.13 a	2.059 ± 2.44 a
Y	20	0.403 ± 3.93 a	-0.958 ± 4.33 a	-1.012 ± 2.56 a
LW	22	0.315 ± 3.75 a	0.545 ± 4.13 a	0.133 ± 2.44 a
GCA		ns	ns	ns
D	71.5	-3.556 ± 2.87 a	-3.905 ± 3.15 a	-1.057 ± 1.86 a
L	84.5	-0.099 ± 2.93 a	-0.056 ± 3.22 a	-0.219 ± 1.91 a
Y	82.0	1.776 ± 2.95 a	0.390 ± 3.25 a	-1.042 ± 1.92 a
LW	83.0	1.878 ± 3.79 a	3.572 ± 4.17 a	2.318 ± 2.46 a
ME		ns	ns	ns
D		6.206 ± 3.20 a	4.961 ± 3.52 a	-0.578 ± 2.08 a
L		-2.170 ± 3.12 a	-1.522 ± 3.43 a	0.301 ± 2.03 a
Y		-2.667 ± 3.12 a	-1.854 ± 3.43 a	0.378 ± 2.03 a
LW		-1.368 ± 3.15 a	-1.585 ± 3.47 a	-0.101 ± 2.05 a
SCA		ns	ns	ns
D x L = Y x LW		1.860 ± 2.58 a	1.428 ± 2.84 a	0.115 ± 1.68 a
D x Y = L x LW		-1.597 ± 2.57 a	-1.711 ± 2.83 a	-0.701 ± 1.67 a
D x LW = L x Y		-0.262 ± 2.57 a	0.282 ± 2.83 a	0.586 ± 1.67 a

For symbols see Table I.

1/3 of mortality were not fruitful transformations, so the analysis was done with the original data. Only rate of mummified piglets was affected significantly by breed and there were no significant effects for all the remaining sources of variation, i.e., general combining ability, maternal effect and specific combining ability.

The LW breed presented a lower rate of mummified pigs (-2.26%) than L (1.83%) and D (3.45%).

The reciprocal effect, total heterosis and specific heterosis on the mortality traits measured at different ages are presented in Tables VII and VIII.

There were no significant effects of reciprocal effect, total and specific heterosis in any of the traits. In most of the cases the heterosis estimates were negative and tended to decrease as the pigs were getting older.

Pig viability (survival) is one of the traits that producers pay attention to since it directly affects the profitability of any swine production system. The causes and prevention of mortality were revised by English and Morrison (1984). They mentioned that 75% of mortality at birth occurs during and the remaining 25% before parturition.

The mortality rate at birth of 6.06% found in this work, or of 9.2% if the mummified rate were included, is similar to that presented by Fahmy and Bernard (1971) 7.2% caused by death at birth and mummified pigs and by Hale *et al.* (1986) who found values varying from 6.9 to 9.8%. These mortality rates were not influenced by type of cross or breed of male, but were significantly affected by breed of female. English and Morrison (1984) found rates varying from 4 to 8% of stillborn pigs in their revision.

The mortality rate from birth to weaning obtained in this study (14.97%) is similar to those presented by Fahmy and Bernard (1971) who found 16.4% mortality up to weaning (56 days) and by Hale *et al.* (1986) who, found mortality rates at weaning (35 days) to vary from 10 to 20%. These mortality rates were not affected by type of cross and they were not reduced by changes in management. Other factors that can affect piglet mortality are birth weight, vigor of piglet at birth, nutrition and management (English and Morrison, 1984).

Table VII - Reciprocal effect (RE), total heterosis (TH) and specific heterosis (SH) effects[1] on mortality rate at birth (MRB), rate of mummified piglets (RMP) and mortality from birth to 21 days (MRB21)[2].

Item[3]	MRB %	RMP %	MRB21 %
RE	ns	ns	ns
D x L = -L x D	-0.410 ± 1.78 a	0.338 ± 1.21 a	2.130 ± 2.82 a
D x Y = -Y x D	1.255 ± 1.77 a	-1.699 ± 1.21 a	0.140 ± 2.82 a
D x LW = -LW x D	1.665 ± 1.78 a	1.361 ± 1.22 a	-2.270 ± 2.84 a
L x Y = -Y x L	1.513 ± 1.74 a	1.019 ± 1.19 a	2.572 ± 2.77 a
L x LW = -LW x L	0.845 ± 1.75 a	2.037 ± 1.20 a	1.991 ± 2.79 a
Y x LW = -LW x Y	0.258 ± 1.75 a	-0.679 ± 1.20 a	2.712 ± 2.79 a
	ns	ns	ns
TH	-0.226 ± 1.45	-0.670 ± 0.99	-1.896 ± 2.30
%	-3.66	-19.30	-12.91
SH	ns	ns	ns
D x L	-2.937 ± 2.59	-2.011 ± 1.77	-1.049 ± 4.11
%	-43.91	-32.92	-7.58
D x Y	-3.386 ± 2.59	0.378 ± 1.77	-6.502 ± 4.11
%	-44.48	10.25	-37.02
D x LW	2.000 ± 2.59	-1.361 ± 1.77	-3.980 ± 4.12
%	29.52	-33.45	-22.79
L x Y	-1.736 ± 2.38	-0.597 ± 1.63	-0.009 ± 3.78
%	-31.13	-20.76	-0.08
L x LW	4.904 ± 2.38	-1.536 ± 1.63	-0.123 ± 3.78
%	103.51	-47.14	-1.04
Y x LW	-0.202 ± 2.44	1.105 ± 1.67	0.287 ± 3.87
%	-3.57	132.21	1.85

For symbols see Table II.

Table VIII - Reciprocal effect (RE), total heterosis (TH) and specific heterosis (SH) effects[1] on mortality rate from birth to weaning (MRBW), from birth to the end of the growth period (MRBEG) and from weaning to the end of the growth period (MRWEG)[2].

Item[3]	MRBW %	MRBEG %	MRWEG %
RE	ns	ns	ns
D x L = -L x D	2.433 ± 2.84 a	3.965 ± 3.12 a	1.503 ± 1.84 a
D x Y = -Y x D	0.143 ± 2.83 a	-1.641 ± 3.11 a	-1.479 ± 1.84 a
D x LW = -LW x D	-2.577 ± 2.85 a	-2.324 ± 3.14 a	-0.024 ± 1.85 a
L x Y = -Y x L	3.033 ± 2.78 a	4.064 ± 3.06 a	0.702 ± 1.81 a
L x LW = -LW x L	2.290 ± 2.80 a	5.605 ± 3.08 a	2.981 ± 1.82 a
Y x LW = -LW x Y	3.176 ± 2.80 a	2.424 ± 3.08 a	-0.777 ± 1.82 a
	ns	ns	ns
TH	-1.751 ± 2.31	-0.643 ± 2.54	1.072 ± 1.50
%	-11.05	-3.22	-20.40
SH	ns	ns	ns
D x L	-1.169 ± 4.13	-1.663 ± 4.54	-0.666 ± 2.68
%	-7.55	-8.25	-11.70
D x Y	-6.463 ± 4.13	-5.968 ± 4.54	-0.731 ± 2.69
%	-34.11	-27.63	-17.58
D x LW	-4.333 ± 4.15	-1.409 ± 4.56	3.103 ± 2.70
%	-22.92	-6.31	65.58
L x Y	0.305 ± 3.80	0.688 ± 4.18	0.213 ± 2.47
%	2.38	3.92	3.69
L x LW	-0.234 ± 3.80	1.260 ± 4.18	1.473 ± 2.47
%	-1.84	6.89	23.19
Y x LW	1.387 ± 3.89	3.234 ± 4.28	3.042 ± 2.53
%	8.56	16.38	63.18

For symbols see Table II.

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RESUMO

Dados de 321 leitegadas oriundas dos três primeiros partos de cruzamentos simples em modelo dialélico entre as raças Duroc (D), Landrace (L), Yorkshire (Y) e Large White (LW) foram usados para estudar os efeitos de raça, capacidades geral e específica de combinação, efeitos materno e recíproco e heteroses total e específica sobre o número total de leitões nascidos (TNPB), número de leitões nascidos vivos (NPAB), aos 21 dias (NP21), à desmama (NP35) e ao final da recria (NP77), peso da leitegada ao nascer (LWB), aos 21 dias (LW21), à desmama (LW35) e ao final da recria (LW77). Leitegadas puras LW apresentaram um desempenho significativamente melhor ($P \leq 0,05$) somente em relação às leitegadas D em termos de NPAB, NP21 e NP35. O LW35 foi influenciado significativamente pela raça, não se verificando diferenças entre as raças L, LW e Y, sendo que L e LW produziram leitegadas mais pesadas do que as oriundas da raça D. A capacidade geral de combinação não se constituiu numa causa de variação significativa nem para tamanho nem para peso da leitegada nas idades consideradas, e a capacidade específica de combinação influiu significativamente ($P \leq 0,05$) apenas no LWB. Os melhores desempenhos para LWB foram observados nos cruzamentos D x Y e L x LW. As características de tamanho de leitegada não foram alteradas significativamente pelo efeito materno que, no entanto, influiu significativamente ($P \leq 0,05$) no LWB, LW21 e LW35, destacando-se os menores pesos das leitegadas oriundas de mães da raça LW quanto ao LWB e da raça D para LW21 e LW35. O efeito recíproco não se revelou uma fonte de variação significativa para as características de tamanho e peso da leitegada, o mesmo acontecendo com a heterose total. O efeito de heterose específica por cruzamento foi significativo ($P \leq 0,05$) apenas para o cruzamentos D x Y com taxas de heterose de 21,84% para o LW35 e 22,50% para o LW77.

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