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INDIVIDUAL HETEROSIS AND BREED EFFECTS FOR POSTWEANING PERFORMANCE AND CARCASS TRAITS IN FOUR BREEDS OF SWINE[1]

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ABSTRACT

Individual heterosis and direct and maternal breed effects for postweaning average daily gain (ADG), off-test age (AGE) and probed backfat thickness (BF) were estimated from data on 1,664 pigs produced in a complete diallel mating system involving the Duroc, Yorkshire, Landrace and Spotted breeds. The same genetic parameters were estimated for various carcass traits by analyses of data collected on 269 barrow carcasses. Significant breed X environment (i.e., year-season farrowed, parity and sex) interactions were found for ADG, AGE and BF. Specific heterosis estimates for ADG and AGE were all highly significant and reasonably consistent among crosses. Overall heterosis for BF was significant, although specific estimates were not. Overall heterosis estimates were .07 kg/d (10.5%) for ADG, −14 d (7.5%) for AGE and .83 mm (3.2%) for BF. Of 72 specific heterosis estimates for carcass traits, only seven were significantly different from zero, apparently at random. Duroc- and Spotted-sired pigs grew faster and were younger off-test than Yorkshire- and Landrace-sired pigs. Landrace-sired pigs had higher BF and Duroc-sired pigs lower BF than Spotted- or Yorkshire-sired pigs. Breed-of-dam effects for ADG were similar to breed-of-sire effects. Significant breed-of-sire effects for carcass traits reflected the superiority of Duroc-sired pigs for carcass backfat, loin muscle area, lean cuts yield and muscle quality (marbling and firmness). Maternal effects were important for carcass composition in crosses involving the Duroc. Such crosses produced leaner, more heavily muscled carcasses where the Yorkshire, Landrace and Spotted were used as the dam breed.

(Key Words: Pigs, Growth Rate, Carcass Composition, Heterosis, Breed Differences, Maternal Effects.)

Introduction

While the greatest benefits of crossbreeding in swine arise from moderate to high degrees of heterosis exhibited by sow productivity traits, the impact of heterosis and breed effects on postweaning performance and carcass traits should not be overlooked. Reported estimates of individual heterosis for feed-to-gain ratio and carcass measurements have, in general, been small and nonsignificant, although postweaning rate of gain appears to be moderately (6 to 10%) heterotic (Sellier, 1976; Johnson, 1981; Wheat et al., 1981; Toelle and Robison, 1983). Significant breed direct effects have been demonstrated for postweaning growth and carcass traits. Maternal effects, apparently negligible for postweaning rate of gain, appear to be important for feed-to-gain ratio and carcass traits (Johnson, 1981; Wheat et al., 1981).

Duroc, Yorkshire, Landrace and Spotted purebred and two-breed cross matings were made as part of an experiment carried out at the Oklahoma Agricultural Experiment Station. The relative paucity of experimental results for the Spotted and American Landrace breeds, which jointly accounted for 21% of transfers involving the eight major United States swine breeds in 1979 and 1980 (Hayenga et al., 1985), prompted their inclusion in the study.

Heterosis and breed effects for sow productivity traits from this experiment have been

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reported previously (Gaugler et al., 1984). The objectives of this present study were to estimate individual heterosis and breed direct and maternal effects for postweaning performance and various carcass traits for the Duroc, Yorkshire, Landrace and Spotted breeds of swine.

Materials and Methods

Experimental Procedure. Postweaning performance data were collected on 1,664 purebred and crossbred pigs produced in a complete diallel mating system involving the Duroc, Yorkshire, Landrace and Spotted breeds. Pigs were farrowed at the Oklahoma State University Experimental Swine Farm at Stillwater during five consecutive fall and spring seasons starting in the fall of 1976. Establishment and management of the purebred herds have been discussed by Hutchens et al. (1982) and Gaugler et al. (1984). Foundation boars and gilts of each breed were obtained from several different sources, and semi-annual introduction of at least one new boar of each breed was practiced in order to maintain a broad genetic base in the purebred herds. Each purebred herd consisted of seven to nine boars and 30 to 35 females.

Boars were randomly mated to at least one female of each purebred herd. Spring litters were farrowed in March and April, fall litters in September and October. Pigs had access to creep feed beginning between 2 and 3 wk of age until weaning at approximately 6 wk of age. The two heaviest boars at weaning from at least four litters of each breed group were left intact. All other males were castrated. At approximately 8 wk of age barrows and some of the gilts were moved to pasture lots, stocking approximately 50 pigs per lot. The remaining gilts were randomly alloted within litter to be grouped in pens of 10 and fed in an open-front confinement building adjacent to pens containing the boars. Hutchens et al. (1981, 1982) reported breed comparisons for age and weight at puberty, and relationships between these and growth performance traits, for these gilts.

Pigs were fed a 14% crude protein corn- or sorghum grain-based diet from approximately 8 wk of age until the end of the test period. Gilts were weighed off-test and probed for backfat thickness at approximately 91 kg. Boars and barrows were weighed off-test and probed at approximately 100 kg. Gilt records were adjusted to 91 kg, boar and barrow records were adjusted to 100 kg. Complete gain-test records were collected on 976 gilts, 403 boars and 285 barrows. Due to limited finishing facilities, a number of barrows, selected at random, were sold postweaning, resulting in the disproportionate number of males and females. All barrows completing gain-test were slaughtered at the Oklahoma State University Meat Laboratory. Carcasses were chilled for at least 24 h before carcass measurements were made.

Traits Measured. Postweaning performance traits measured were average daily gain, age off-test and probed backfat thickness. Records were adjusted to constant final weights of approximately 91 kg for gilts and 100 kg for males. Live slaughter weight (adjusted for differences in gut weight) and carcass weight, length, backfat, loin muscle area, quality scores and weight of belly and closely trimmed lean cuts (ham, shoulder and loin) were recorded for 269 barrows (210 crossbred and 59 purebred). One loin chop from each carcass was scored subjectively for marbling, firmness and color. Integer scores were used and ranged from 1 to 7. One (1) represented muscle devoid of marbling, very soft and pale; 7 represented muscle with abundant marbling, very firm and very dark, respectively. Backfat was measured at the first rib, last rib and last lumbar vertebra and averaged.

Statistical Analyses. The following linear model, with zero-sum restrictions on fixed parameters, was assumed in analyzing average daily gain, off-test age and probed backfat thickness:

y_{ijkmno} = an observable random variable;
μ = an unknown constant;
B_i = fixed effect of the i^{th} breed group, $i = 1,\ldots,16$;
F_j = fixed effect of the j^{th} farrowing season, $j = 1,\ldots,5$;
S_k = fixed effect of the k^{th} sex, $k = 1,\ldots,3$;
P_m = fixed effect of the m^{th} parity, $m = 1,\ldots,3$;
$(BF)_{ij}$ and similar terms represent interaction effects;
l_{nij} = random effect of the n^{th} litter nested within the ij^{th} breed-farrowing season combination, l's assumed iid $N(0,\sigma_l^2)$ and
e_{ijkmno} = random residual effect associated with the $ijkmno^{th}$ record, e's assumed iid $N(0,\sigma_e^2)$.

The SAS Harvey procedure (Joyner, 1983)

was used to compute these analyses. In the absence of a hierarchical design (dams were mated to different sires in different breeding seasons), it was practical to include either sires or litters in the model. Both produced similar results, but including litters was felt to describe the data more adequately. The effect of litter nested within breed × year-season was treated as random by including the estimated ratio of residual to litter variances (4.26, assuming heritability of .38 for all three traits and that σ_l^2 = one-half the additive genetic variance). Equations for litters were then absorbed. Where ratios of the variances are known, solutions for fixed effects are generalized least-squares constants (Harvey, 1982). Preliminary analyses indicated parity × year-season farrowed and parity × sex interactions to be nonsignificant (P>.10). These terms were therefore not included in the final model.

The linear model assumed in analyzing carcass data was:

$$y_{ijklm} = \mu + S_i + D_j + (SD)_{ij} + F_k + s_{li} + \beta w_{ijklm} + e_{ijklm},$$

where

y_{ijklm} = an observable random variable;

μ = an unknown constant;

S_i = fixed effect of the i^{th} breed of sire, i = 1,...,4;

D_j = fixed effect of the j^{th} breed of dam, j = 1,...,4;

$(SD)_{ij}$ = fixed breed-of-sire × breed-of-dam interaction effect;

F_k = fixed effect of the k^{th} farrowing season, k = 1,...,5;

s_{li} = random effect of the l^{th} sire nested within the i^{th} breed of sire; s's assumed iid N $(0,\sigma_s^2)$;

β = linear regression of the dependent variable on adjusted live slaughter weight (w_{ijklm}) and

e_{ijklm} = random residual effect associated with the ijklmth record, e's assumed iid N $(0,\sigma_e^2)$.

Carcass data were also analyzed using the SAS Harvey procedure (Joyner, 1983). The effect of sires nested within breed of sire was treated as random by including the estimated ratio of residual to sire variances for the traits. Heritabilities of .3 (carcass weight, quality scores), .4 (lean cut and belly weights) and .5 (carcass length, backfat and loin muscle area) were assumed. Equations for sires were absorbed. Preliminary analyses indicated breed × year-season interactions were not significant for any carcass traits, and they were therefore not included in the final model. Similarly, the covariable slaughter weight was not included in the model for carcass length or for the meat quality scores.

Breed-of-sire and breed-of-dam effects were obtained directly from carcass data analyses, and calculated by averaging breed parameter estimates for the postweaning performance traits. To estimate direct and maternal effects the following genetic model (after Dickerson, 1969) was assumed:

$$\bar{y}_{ij} = \mu + .5(g_i^I + g_j^I) + g_j^M + h_{ij}^I,$$

where

$\bar{y}_{ij}$ = purebred (i=j) or crossbred (i≠j) mean, i (breed of sire), j (breed of dam) = 1,...,4;

μ = the average of the four purebreds;

g^I, g^M = direct and maternal breed effects, respectively, subject to zero-sum restrictions and

h_{ij}^I = individual heterosis, $h_{ij}^I = h_{ji}^I$, = 0 if i = j.

Differences between reciprocal cross least-squares means (i.e., $\bar{y}_{ij} - \bar{y}_{ji}$) are therefore assumed to be due to differences in maternal effects $(g_j^M - g_i^M)$.

Assuming the preceding model, let D, Y, L and S represent the Duroc, Yorkshire, Landrace and Spotted breeds, respectively. Also, let $\overline{DF}$ and $\overline{DM}$ equal averages of least-squares means for the four breed groups having Duroc dams and sires, respectively, i.e.:

$$\overline{DF} = .25\ (\bar{y}_{DD} + \bar{y}_{YD} + \bar{y}_{LD} + \bar{y}_{SD}), \text{ and}$$

$$\overline{DM} = .25\ (\bar{y}_{DD} + \bar{y}_{DY} + \bar{y}_{DL} + \bar{y}_{DS}). \text{ Then:}$$

$$E(\overline{DM}) = \mu + .5g_D^I + g_D^M + .25(h_{DY}^I + h_{DY}^I + h_{DS}^I) \text{ and}$$

$$E(\overline{DM}) = \mu + .5g_D^I + .25(h_{DY}^I + h_{DL}^I + h_{DS}^I).$$

The differences between breed-of-sire and breed-of-dam effects, therefore, provides an unbiased estimate of maternal effects. Twice the breed-of-sire effect, however, does not provide an unbiased estimate of direct effects. Unbiased estimates were obtained by weighted least-squares analyses of breed group least-squares means assuming the above genetic model, i.e., as:

$$\hat{\underset{\sim}{\beta}} = (\mathbf{X'D^{-1}X})^{-1}\mathbf{X'D^{-1}y},$$

where

$\hat{\underset{\sim}{\beta}}$ = the 13 × 1 vector of parameter estimates, i.e., $\hat{\mu}$, $\hat{g}^I_D$, $\hat{g}^I_Y$, $\hat{g}^I_L$, $\hat{g}^M_D$, $\hat{g}^M_Y$, $\hat{g}^M_L$, $\hat{h}^I_{DY}$, $\hat{h}^I_{DL}$, $\hat{h}^I_{DS}$, $\hat{h}^I_{YL}$, $\hat{h}^I_{YS}$, $\hat{h}^I_{LS}$;

$\mathbf{X}$ = a known design matrix and

$\mathbf{D}^{-1}$ = $\mathbf{n'I}$, where $\mathbf{n}$ is a vector of the number of observations associated with the corresponding least-squares means in $\mathbf{y}$ and $\mathbf{I}$ is an identity matrix.

Standard errors of parameter estimates were obtained from:

$$\text{Var}\,(\mathbf{k'}\hat{\underset{\sim}{\beta}}) = \mathbf{k'}\,(\mathbf{X'D^{-1}X})^{-1}\,\mathbf{k}\,\sigma^2_e,$$
where σ^2_e = the residual variance.

Heterosis estimates were partitioned (after Eisen et al., 1983) as follows:

$$h_{ij} = z_i + z_j - 2w_{ij};\ i,j = 1,\ldots,p;\ p = 4;$$

where

$h_{ij} = (\bar{y}_{ij} + \bar{y}_{ji})/2 - (\bar{y}_{ii} + \bar{y}_{jj})/2;$

$z_i = (.5p)[(p-1)\,(\bar{y}^*_{i.} + \bar{y}^*_{.i} - \bar{y}_c) - (p-2)\bar{y}_{ii} - \bar{y}_a];$

$w_{ij} = (-.25)\,(\bar{y}_{ij} + \bar{y}_{ji}) + [(p-1)/4p]\,(\bar{y}^*_{i.} + \bar{y}^*_{.i} + \bar{y}^*_{j.} + \bar{y}^*_{.j}) + (.5p)\,(\bar{y}_{ii} + \bar{y}_{jj}) - [(p-1)/2p]\,\bar{y}_c - (.5p)\bar{y}_a;$

$\bar{y}_{ij}$ = least-squares mean of the ij[th] breed group;

$\bar{y}^*_{i.}(\bar{y}^*_{.i})$ = least-squares mean of the i[th] sire (dam) breed averaged over crosses with the remaining (p−1) breeds;

$\bar{y}_c$ = average of crossbred breed groups and

$\bar{y}_a$ = average of purebred breed groups.

Results and Discussion

Analyses of Variance. Mean squares and significance of F statistics for effects in the postweaning performance analyses are given in table 1. Differences among breeds, year-seasons farrowed and sexes were highly significant for postweaning rate of gain, off-test age and probed backfat thickness. The significant year-season × sex interaction reflected differences in the relative performance of gilts, boars and barrows, but not differences in how the sexes ranked across year-seasons. Boars were younger and leaner than barrows at 100 kg (172.9 ± 1.0 d and 24.1 ± .2 mm vs 184.6 ± 1.1 d and 30.4 ± .3 mm, respectively). Gilts, recorded to a different end point (91 kg), averaged 173.9 ± .7 d of age and 25.2 ± .2 mm probed backfat.

TABLE 1. GENERALIZED LEAST-SQUARES ANALYSES OF VARIANCE FOR POSTWEANING PERFORMANCE TRAITS

		Mean squares		
Source[a]	df	Avg daily gain (kg/d)	Off-test age (d)	Probed backfat (mm)
Breed group	15	.04230**	1,954**	47.15**
Year-season farrowed (YRS)	4	.09268**	4,465**	453.00**
Sex	2	.69722**	10,969**	2,930.29**
Parity	2	.00654	839*	53.50**
YRS × Sex	8	.03501**	1,406**	22.19*
Breed × YRS	60	.00792**	324**	12.56*
Breed × Sex	30	.00732*	331**	11.93
Breed × Parity	30	.00641†	255†	15.18*
Residual	1,512	.00556	216	10.76

[a]Equations for litters, treated as random effects in the model, were absorbed.

†P<.10.

*P< 05.

**P<.01.

Parity differences were significant for off-test age and probed backfat thickness, but not for postweaning rate of gain. Pigs were classified as having first-, second- or third-parity dams. Parity three represented sows of all parities greater than the second. Ranging from third to seventh parity, the "average" female in this group was a fourth-parity sow. Pigs from older dams were younger and fatter off-test. Parities one, two and three averaged 179.7 ± 1.3, 176.7 ± 1.9 and 175.0 ± 1.2 d of age and 25.9 ± .3, 26.7 ± .4 and 27.1 ± .3 mm probed backfat thickness, respectively.

The breed × parity interaction approached significance for growth rate, and was significant for probed backfat thickness. Breed × sex was significant for growth rate and breed × year-season farrowed significant for all three postweaning performance traits. Literature reports of genotype × parity interactions for growth rate are scarce. Significant genotype × sex and genotype × year and(or) season interaction have, however, been reported for growth rate by a number of researchers, although other studies have reported such interactions to be nonsignificant (McLaren, 1985).

Examination of subclass means suggested that the significant breed × sex and breed × parity interactions did not preclude examination of breed as a main effect. Rank changes between breeds were, in general, relatively minor. Averaging breed across sex (which included boars and a disproportionate number of females to males) resulted in parameter estimates that were biased with reference to a normal production population consisting of approximately equal numbers of barrows and gilts. Although influencing absolute values of breed parameters, the effect upon breed comparisons is assumed negligible. The 16 breed groups, in general, ranked similarly for both boar and barrow average daily gain and age off-test (although some rank changes did occur). The effect on parameter estimates from including boars should therefore be similar for all breeds, in most cases, resulting in negligible bias in breed comparisons.

Breed ranks were somewhat more variable across year-seasons farrowed. Many environmental factors undoubtedly contributed to the year-season effect, but seasonal temperature differences and fluctuating health status in the herd were probably both important. Barlow (1981) reviewed the evidence for heterosis × environment interactions in animals and concluded that heterosis for most traits appeared to be greater in suboptimal environments. Differences in purebred and crossbred performance levels might therefore be expected under various levels of disease and climatic stress. Estimating breed parameters for individual year-seasons would have little utility because we wish to make inference to the breeds in general. In making breed comparisons, therefore, we not only assume adequate sampling of the breeds, but also that year-seasons were representative of environments to which the population of inference is exposed.

Mean squares and significance of F statistics for effects in some of the carcass trait analyses are given in table 2. Preliminary analyses established that breed × year-season interactions were not significant. Breed of sire and breed of dam were significant for backfat thickness, weight of ham, shoulder, loin and total lean cuts, and for marbling and firmness scores. Breed of sire also was significant for carcass length, loin muscle area and weight of belly. The breed-of-sire × breed-of-dam interaction was significant for weight of ham, loin and loin muscle area. Breed effects were not significant for carcass weight or for loin chop color score.

Breed Effects. Breed group generalized least-squares means for postweaning performance and carcass traits are given in tables 3 and 4, respectively. Breed-of-sire and breed-of-dam effects for postweaning performance traits are given in table 5. As defined, breed effects include heterosis in addition to average effects. Where heterosis is important, therefore, breed effects are specific to the crosses involved in this study.

Growth rate was not significantly different between pigs with Duroc and Spotted sires, or between pigs with Yorkshire and Landrace sires. Duroc- and Spotted-sired pigs gained .020 ± .007 kg/d faster, and reached off-test weight 4.54 ± 1.34 d earlier, than Yorkshire- and Landrace-sired pigs. Landrace-sired pigs had 2.68 ± .44 mm greater probed backfat than pigs with Duroc sires; Yorkshire- and Spotted-sired pigs were somewhat intermediate.

Breed-of-dam effects for average daily gain, apart from a change in rank between Yorkshire and Landrace, were similar to breed-of-sire effects. Pigs with Duroc dams gained .019 ± .010 kg/d faster and took 6.46 ± 1.79 fewer days to reach final weight than those with Yorkshire dams. Pigs with Spotted and Landrace dams were 4.93 ± 1.95 and 4.18 ± 1.84 d

TABLE 2. GENERALIZED LEAST-SQUARES ANALYSES OF VARIANCE FOR SOME CARCASS TRAITS[a]

		Mean squares					
Source[b]	df	Length (cm)	Backfat (mm)	Loin muscle area (cm^2)	Total lean cuts (kg)	Belly (kg)	Marbling
Breed of sire (BOS)	3	7.93*	100.66**	126.48**	56.02**	2.63**	5.44**
Breed of dam (BOD)	3	4.33	93.48**	14.46	22.22**	.88	8.54**
Year-season farrowed	4	15.60**	131.32**	92.04**	138.50**	3.64**	15.43**
BOS × BOS	9	2.70	16.76	24.49**	6.55†	.47	1.23
Adjusted live wt	1		324.01**	53.50*	366.35**	50.96**	
Residual[c]	248	3.29	21.66	9.05	4.01	.55	1.52

[a]Analyses not shown for carcass weight, individual ham, loin and shoulder lean cut weights, and loin chop color and firmness scores.

[b]Equations for sires, treated as random effects in the model, were absorbed.

[c]249 df for length and marbling (no covariable in the model).

†P<.10.

*P<.05.

**P<.01.

younger off-test, respectively, than those with Yorkshire dams. Probed backfat thickness was not significantly different between pigs with Duroc and Landrace dams, or between pigs with Spotted and Yorkshire dams. Pigs with Duroc and Landrace dams, however, were 1.13 ± .30 mm fatter than pigs with Spotted and Yorkshire dams..

Results were similar to those presented by Johnson (1981) for postweaning average daily gain and age at 100 kg. Breed effects for age at 95 kg, from least-squares means reported by Wheat et al. (1981), showed Yorkshire-sired pigs to be significantly older (8.6 d) than Duroc- or Landrace-sired pigs, which were not significantly different. Pigs with Landrace dams, however, were approximately 10.4 d younger than pigs with either Duroc or Yorkshire dams.

Breed-of-sire and breed-of-dam effects for some of the carcass traits analyzed are given in table 6. The largest difference among sire breed effects for traits for which breed of sire was significant were due to superiority of the Duroc as a sire breed. Duroc-sired pigs were significantly leaner, with larger loin muscle area, heavier hams, shoulders and loins, lighter bellies and higher marbling and firmness scores than for Yorkshire-, Landrace- or Spotted-sired pigs. Pigs with Yorkshire, Landrace or Spotted sires did not differ significantly for carcass backfat, loin muscle area, weight of loin, shoulder or belly. Duroc-sired pigs, however, were 3.47 ± 1.00 mm leaner, with 4.18 ± .65 cm^2 larger loin muscle areas, .75 ± .15 kg heavier loins, .40 ± .15 kg heavier shoulders and .53 ± .15 kg lighter bellies than pigs sired by boars of the other three breeds. Hams of Duroc-sired pigs were .86 ± .17 kg heavier than those of pigs with Yorkshire or Spotted sires, which in turn were .56 ± .17 kg heavier than hams of pigs with Landrace sires. Total lean cuts yield of Duroc-sired pigs was 2.48 ± .40 kg greater than that of other sire breed groups. Spotted-sired pigs were not significantly different from other sire breed groups for marbling and firmness scores. However, Duroc-sired pigs scored .80 ± .25 and .65 ± .24 points higher for marbling and firmness, respectively, than did pigs with Yorkshire or Landrace sires. Yorkshire- and Landrace-sired pigs also had .85 ± .34 cm longer carcasses than those of pigs with Spotted or Duroc sires.

Breed-of-dam effects were generally dissimilar to breed-of-sire effects (table 6), indicating maternal effects were important for carcass

TABLE 3. PUREBRED AND F_1 CROSSBRED GENERALIZED LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE TRAITS

Breed group	No. pigs	Avg daily gain, kg/d	Off-test age, d	Probed backfat mm
Duroc (D)	125	.6625	183.8	24.98
Yorkshire (Y)	93	.6384	193.5	25.13
Landrace (L)	142	.6352	189.5	27.60
Spotted (S)	109	.6655	184.2	26.06
D X Y	85	.7187	174.9	23.94
D X L	110	.7318	171.7	25.85
D X S	102	.7400	170.1	25.71
Y X D	107	.7388	170.1	27.74
Y X L	108	.7003	175.4	27.15
Y X S	90	.6953	180.1	25.32
L X D	101	.7127	172.8	28.41
L X Y	87	.6809	183.8	27.61
L X S	87	.7293	170.1	27.56
S X D	107	.7305	171.7	27.76
S X Y	109	.7298	171.9	26.64
S X L	102	.7142	170.8	27.55
SE[a]		.0136	2.7	.60

[a]Average standard error of breed group means.

traits. Yorkshire was the most favorable dam breed for carcass backfat, loin muscle area and lean cut yields. Pigs with Yorkshire dams were 2.54 ± .76 mm leaner, had loins .35 ± .12 kg heavier and yielded 1.29 ± .32 kg more in total lean cuts than pigs with Duroc or Landrace dams. They also had loin muscle areas 1.10 ± .54 cm^2 larger than pigs with Landrace dams, and shoulders .41 ± .11 kg heavier than pigs with Duroc, Landrace or Spotted dams. Pigs with Yorkshire or Spotted dams had hams .55 ± .10 kg heavier than those of pigs with Duroc or Landrace dams. Pigs with Duroc or Spotted dams, however, had higher marbling and firmness scores (.60 ± .16 and .55 ± .15, respectively) than pigs with Yorkshire or Landrace dams.

Average Direct and Maternal Effects. Breed-of-dam effects represent a direct genetic contribution to progeny via chromosomal material in the ovum, plus any maternal effects due to cytoplasmic inheritance, prenatal environment and(or) postnatal milk production and mothering abilities.

Estimates of average direct genetic and maternal effects are presented in tables 7 and 8. Table 7 illustrates that, compared with direct effects, maternal effects were relatively unimportant for postweaning rate of gain. Maternal effects were proportionally greater for off-test age (table 7), as might be expected given the dam's influence on preweaning growth rate, and were substantial (relative to direct effects) for probed backfat and carcass traits (table 8) in many cases.

Johnson (1981) and Wheat et al. (1981) reported maternal effects to be important for carcass length, backfat and loin muscle area; Toelle and Robison (1983) found breed prenatal effects to be important for backfat and 154-d weight. A review of earlier work involving pigs (Robison, 1972) concluded that maternal effects were important for most traits, including 140-d weight and carcass backfat. A fairly consistent negative correlation between direct and maternal genetic effects was also noted, in agreement with findings of the present study. For example, average Duroc direct effects were for leaner pigs with lighter bellies, increased loin muscle area and increased lean cut yields relative to the other three breeds (table 8). However, Duroc maternal effects were for fatter pigs with heavier bellies, decreased loin muscle area and decreased weights of lean cuts. In contrast, average direct effects for the Yorkshire, Landrace and Spotted

TABLE 4. PUREBRED AND F_1 CROSSBRED GENERALIZED LEAST-SQUARES MEANS FOR SOME CARCASS TRAITS[a]

Breed group	No. carcasses	Length, mm	Backfat, mm	Loin muscle area, cm^2	Total lean cuts, kg	Belly, kg	Marbling
Duroc (D)	15	78.60	29.98	32.02	41.32	7.99	4.73
Yorkshire (Y)	11	80.50	31.45	28.08	41.15	8.36	3.14
Landrace (L)	20	80.23	33.47	29.30	39.51	8.47	3.02
Spotted (S)	13	78.55	33.94	27.73	40.18	8.58	3.98
D X Y	14	79.95	28.72	34.84	43.72	8.04	3.45
D X L	20	79.59	30.47	31.87	41.36	8.05	3.56
D X S	15	80.16	31.12	31.92	42.22	8.14	4.65
Y X D	21	79.68	36.08	27.83	39.73	8.69	3.60
Y X L	19	80.50	35.11	27.10	39.16	8.51	2.97
Y X S	17	79.82	32.14	30.89	40.83	8.16	3.24
L X D	19	80.08	34.35	28.50	38.95	8.77	3.29
L X Y	13	80.37	31.38	28.29	39.69	8.76	3.43
L X S	18	80.22	31.41	27.98	38.41	8.66	3.64
S X D	16	79.33	34.56	28.57	39.45	9.01	3.93
S X Y	21	79.43	33.08	29.52	39.93	8.62	3.54
S X L	17	79.00	35.60	28.04	39.15	8.40	3.16
SE[b]		.53	1.37	.89	.58	.21	.34

[a]Means not shown for carcass weight, individual ham, loin and shoulder lean cut weights, and loin chop color and firmness scores.

[b]Average standard error of breed group means.

breeds were for increased backfat, decreased loin muscle area and decreased lean cuts yield—whereas maternal effects were just the opposite (with the exception of backfat in the Landrace).

Differences between reciprocal cross means, attributable to maternal and sex-linked effects, are presented in tables 9 and 10. Differences were nonsignificant for postweaning average

TABLE 5. BREED EFFECTS (GENERALIZED LEAST-SQUARES CONSTANTS) FOR POSTWEANING PERFORMANCE TRAITS[a]

Item	Avg daily gain, kg/d	Off-test age, d	Probed backfat, mm
$\hat{\mu}$	.7015	177.15	26.56
SE[b]	.0035	.69	.15
Breed of sire			
Duroc	.0118	−2.03	−1.44
Yorkshire	−.0083	2.64	−.22
Landrace	−.0120	1.90	1.23
Spotted	.0085	−2.51	.43
Breed of dam			
Duroc	.0096	−2.56	.66
Yorkshire	−.0095	3.89	−.73
Landrace	−.0061	−.29	.47
Spotted	.0060	−1.04	−.40
SE[c]	.0059	1.16	.26

[a]Constants calculated using zero-sum restrictions.

[b]Standard error of $\hat{\mu}$.

[c]Average standard error of breed effects.

TABLE 6. BREED EFFECTS (GENERALIZED LEAST-SQUARES CONSTANTS) FOR SOME OF THE CARCASS TRAITS ANALYZED[a]

Item	Length, mm	Backfat, mm	Loin muscle area, cm²	Total lean cuts, kg	Belly, kg	Marbling
$\hat{\mu}$	79.75	32.68	29.53	40.30	8.45	3.58
SE[b]	.19	.50	.32	.21	.08	.12
Breed of sire						
Duroc	−.18	−2.61	3.13	1.86	−.40	.51
Yorkshire	.38	1.01	−1.06	−.08	−.02	−.34
Landrace	.47	−.03	−1.01	−1.16	.21	−.24
Spotted	−.67	1.62	−1.06	−.62	.20	.07
SE[c]	.30	.76	.49	.31	.11	.18
Breed of dam						
Duroc	−.33	1.06	−.30	−.44	.16	.31
Yorkshire	.31	−1.52	.65	.82	−.01	−.19
Landrace	.08	.99	−.45	−.50	−.09	−.41
Spotted	−.06	−.53	.10	.11	−.06	.29
SE[c]	.20	.52	.33	.22	.08	.13

[a]Constants calculated using zero-sum restrictions. Constants not shown for carcass weight, individual ham, loin and shoulder lean cut weights, and loin chop color and firmness scores.

[b]Standard error of $\hat{\mu}$.

[c]Average standard error of breed effects.

TABLE 7. AVERAGE DIRECT AND MATERNAL GENETIC EFFECTS (WEIGHTED LEAST-SQUARES CONSTANTS) FOR POSTWEANING PERFORMANCE TRAITS[a]

Trait[b]	$\hat{\mu}^c$	Duroc		Yorkshire		Landrace		Spotted		SE[d]	
		g^I	g^M	g^I	g^M	g^I	g^M	g^I	g^M	g^I	g^M
ADG	.650	.015[e]	−.003[e]	−.011[f]	−.001[e]	−.021[f]	.006[e]	.018[e]	−.003[e]	.008	.005
AGE	187.74	−3.50[e]	−.46[ef]	4.59[f]	1.20[e]	3.94[f]	−2.20[fg]	−5.03[e]	1.46[e]	1.50	.91
BF	25.94	−3.04[e]	2.08[e]	−.32[f]	−.49[f]	2.41[g]	−.75[f]	.94[h]	−.83[f]	.33	.20

[a] g^I = direct effect; g^M = maternal effect; calculated using zero-sum restrictions.
[b] ADG = postweaning average daily gain (kg/d); AGE = off-test age (d); BF = probed backfat thickness (mm).
[c] $\hat{\mu}$ = estimated purebred average.
[d] Average standard error of effect.
[e,f,g,h] *Effects of the same type for the same trait that do not have a common superscript differ (P<.05).*

daily gain. Yorkshire-Landrace pigs with Landrace dams, however, were significantly younger off-test than those with Yorkshire dams, and Yorkshire-Spotted pigs with Yorkshire dams were younger off-test than those with Spotted dams (table 9). Gaugler et al. (1984) reported a significant reciprocal cross difference for Yorkshire-Spotted litter size weaned. Pigs with Yorkshire dams were reared in litters that were 2.02 pigs larger at 42 d than pigs with Spotted dams, with no significant difference in litter weaning weights. Larger litters may have resulted in increased preweaning consumption of creep feed, with a subsequent advantage for early postweaning feed consumption. Such a carry-over effect might have been particularly evident during the first week postweaning–not considered in the rate of gain calculation, but included in days to off-test weight. Although the litter size weaned reciprocal cross difference for Yorkshire-Landrace was not significant, pigs with Landrace dams were reared in litters weaning .87 more pigs than those with Yorkshire dams.

Significant reciprocal differences for crosses involving the Duroc were found for probed backfat (table 9), carcass backfat, loin muscle area and weight of individual and total lean cuts and belly (table 10). No significant differences were detected for carcass weight or length, or for loin chop quality scores. Only one difference (Landrace-Spotted carcass backfat) was found to be significant for crosses not involving the Duroc. These results indicated an advantage for using the Duroc as the sire breed in such crosses, Duroc dams produced fatter pigs with smaller loin muscle areas and lower lean cut yields. Similar results have been reported for Yorkshire-Duroc crosses by Bereskin et al. (1971), Young et al. (1976), Bereskin and Davey (1978) and Bereskin and Steele (1986).

Although maternal effects for carcass composition in swine appear to be important, the mechanism by which such effects operate is obscure. Bereskin and Davey (1978) speculated that prenatal influences on fetuses might result in development differences that carried over to slaughter. This hypothesis seems reasonable given that number of muscle fibers appears to be essentially established by parturition (Young, 1974) and that most if not all extramuscular adipocytes are present at birth (Leat and Cox, 1980). Experiments involving embryo transfer would be required in order to test this working hypothesis. That maternal effects could be

TABLE 8. AVERAGE DIRECT AND MATERNAL GENETIC EFFECTS (WEIGHTED LEAST-SQUARES CONSTANTS) FOR CARCASS TRAITS[a]

Trait[b]	$\hat{\mu}^c$	Duroc		Yorkshire		Landrace		Spotted		SE[d]	
		g^I	g^M	g^I	g^M	g^I	g^M	g^I	g^M	g^I	g^M
CWT	67.41	$-.97^e$	$.01^{ef}$	$-.20^e$	$.25^{ef}$	$-.72^e$	$.39^e$	1.89^f	$-.65^f$	.59	.32
LTH	79.47	$-.73^e$	$-.14^{ef}$	1.08^f	$-.05^{ef}$	1.18^f	$-.41^e$	-1.52^e	$.60^f$	.50	.27
BF	32.21	-5.99^e	3.76^e	1.73^f	-2.49^f	$.29^g$	$.97^g$	3.97^h	-2.24^f	.33	.18
LMA	29.28	6.17^e	-3.44^e	-2.86^f	1.65^f	$-.52^f$	$.55^f$	-2.79^f	1.24^f	.82	.44
HAM	14.27	1.45^e	-1.10^e	$-.29^f$	$.46^f$	-1.01^g	$.40^f$	$-.14^f$	$.24^f$	.22	.12
LON	12.23	$.84^e$	$-.67^e$	$-.15^f$	$.26^f$	$-.21^f$	$.14^f$	$-.47^f$	$.26^f$	.20	.11
SLD	12.30	$.52^e$	$-.35^e$	$-.23^{fg}$	$.33^f$	$-.02^{eg}$	$.05^f$	$-.26^{fg}$	$-.04^e$	.20	.11
TLC	40.54	3.05^e	-2.28^e	$-.26^f$	$.87^f$	-1.68^f	$.65^f$	-1.12^f	$.76^f$	.55	.30
BLY	8.35	$-.91^e$	$.55^e$	$-.01^f$	$.02^f$	$.42^f$	$-.30^f$	$.50^f$	$-.27^f$	.20	.11
MRB	3.72	1.22^e	$-.21^e$	$-.73^f$	$.16^e$	$-.54^f$	$-.16^e$	$.05^f$	$.21^e$	.34	.18
FRM	4.39	$.85^e$	$-.06^e$	$-.55^{fg}$	$.18^e$	$-.36^{fg}$	$-.32^e$	$.06^{eg}$	$.20^e$	.33	.18
CLR	5.13	$-.13^e$	$.15^e$	$-.07^e$	$.03^e$	$-.16^e$	$-.11^e$	$.36^e$	$-.06^e$	.23	.13

[a] g^I = direct effect; g^M = maternal effect; calculated using zero-sum restrictions.

[b] CWT = carcass weight (kg); LTH = carcass length (cm); BF = carcass backfat thickness (mm); LMA = loin muscle area (cm^2); HAM = weight of ham (kg); LON = weight of loin (kg); SLD = weight of shoulder (kg); TLC = weight of total lean cuts (kg); BLY = weight of belly (kg); MRB = marbling score; FRM = firmness score and CLR = color score.

[c] Estimated purebred average.

[d] Average standard error of effect.

[e,f,g,h] Effects of the same type for the same trait that do not have a common superscript differ ($P<.05$).

related to litter size was investigated by including litter size born as a covariable in preliminary analyses of these carcass data. Litter size was, however, found to be nonsignificant for all 12 carcass traits investigated.

Heterosis Estimates. Individual heterosis estimates for postweaning performance traits are given in table 11. Specific estimates for average daily gain and off-test age were all highly significant and reasonably consistent between crosses. Although specific estimates for probed backfat thickness were not significantly different from zero, overall heterosis was significant. These data suggest that average heterosis values for growth rate and probed backfat should be adequate when comparing alternative crossbreeding systems involving the four breeds in this study. Overall performance

TABLE 9. DIFFERENCES AMONG RECIPROCAL CROSS GENERALIZED LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE TRAITS

Difference[a]	Avg daily gain, kg	Off-test, d	Probed backfat, mm
DXY – YXD	–.0201	4.75	–3.81**
DXL – LXD	.0191	–1.04	–2.56**
DXS – SXD	.0095	–1.57	–2.05*
YXL – LXY	.0194	–8.42*	–.46
YXS – SXY	–.0346†	8.12*	–1.32
LXS – SXL	.0151	–.69	.01
SE[b]	.0192	3.78	.84

[a]D = Duroc; Y = Yorkshire; L = Landrace; S = Spotted. First letter indicates breed of sire, second letter indicates breed of dam.

[b]Average standard error of the difference.

†P<.10.

*P<.05.

**P<.01.

TABLE 10. DIFFERENCES AMONG RECIPROCAL CROSS GENERALIZED LEAST-SQUARES MEANS FOR SOME CARCASS TRAITS[a]

Difference[b]	Length, cm	Backfat, mm	Loin muscle area, cm^2	Total lean cuts, kg	Belly, kg	Marbling
DXY – YXD	.26	–7.35**	7.01**	3.99**	.65*	.15
DXL – LXD	–.49	–3.88*	3.38**	2.41**	–.72*	.26
DXS – SXD	.83	–3.44†	3.34*	2.77**	–.87**	.72
YXL – LXY	.14	3.73†	–1.19	–.53	–.25	–.46
YXS – SXY	.39	–.94	1.37	.90	–.45	–.30
LXS – SXL	1.23	–4.19*	–.06	–.74	.26	.48
SE[c]	.73	1.87	1.21	.78	.29	.47

[a]Differences for carcass weight, individual ham, loin and shoulder (lean cut) weights and loin chop color and firmness scores not shown.

[b]D = Duroc; Y = Yorkshire; L = Landrace; S = Spotted. First letter indicates breed of sire, second letter indicates breed of dam.

[c]Average standard error of the difference.

†P<.10.

*P<.05.

**P<.01.

of crossbreds as a deviation from the contemporary purebred mean was .07 kg/d (10.5%) for postweaning average daily gain; −14 d (7.5%) for off-test age and .83 mm (3.2%) for probed backfat thickness.

Literature estimates of specific individual heterosis for postweaning rate of gain and age off-test are also reasonably consistent, both among crosses and experiments, in agreement with the findings of this study. Johnson (1981), in a weighted least-squares analysis of results from crossbreeding experiments in the United States and Canada, reported average heterosis of .06 kg/d (8.8%) for postweaning average daily gain. Sellier (1976), in a summary of mostly European experiments, reported a .04 kg/d (6.0%) crossbred advantage. A higher estimate (13.7%) reported by Toelle and Robison (1983) included data from mixed litters, i.e., purebred and crossbred pigs cross-fostered in the same litter. Vigor of crossbred pigs in these litters appeared to have a detrimental effect on the purebred pigs, thus inflating heterosis estimates. Ignoring mixed litter data, heterosis of 11.1% was calculated from means presented by Toelle and Robison (1983), similar to the 10.5% estimate of the present study, but somewhat higher than earlier reported estimates.

Heterosis estimates of −13 d (6.9%) and −10 d (5.0%) for age at 100 kg, and of −17 d (7.9%) for age at 95 kg have been reported by Johnson (1981), Sellier (1976) and Wheat et al. (1981), respectively. Ignoring mixed litters, heterosis of −8.0% was evident from results reported by Toelle and Robison (1983). Overall heterosis of −14 d (7.5%) obtained in the present study was in good agreement with previous estimates. Least-squares means presented by Toelle and Robison (1983), again excluding mixed litters, indicated a −6.6% heterosis for probed backfat thickness, in contrast to the 3.2% estimate of this study.

Reported experimental estimates of individual heterosis for carcass traits have in general been small and nonsignificant (Johnson, 1981; Wheat et al., 1981). Such was the case for estimates obtained in the present study (table 12). Two of six specific heterosis estimates for carcass weight and one each for weight of ham, loin and total lean cuts (all three for different crosses) were significantly different from zero. One specific heterosis estimate for loin muscle area and one for

TABLE 11. INDIVIDUAL HETEROSIS ESTIMATES FOR POSTWEANING PERFORMANCE TRAITS[a]

Reciprocal crosses[b]	Avg daily gain		Off-test age		Probed backfat	
	kg/d	%	d	%	mm	%
D-Y	.0783**	12.0	−16.2**	−8.6	.78	3.1
D-L	.0733**	11.3	−14.4**	−7.7	.84	3.2
D-S	.0713**	10.7	−13.1**	−7.1	1.22†	4.8
Y-L	.0539**	8.5	−11.9**	−6.2	1.02†	3.9
Y-S	.0607**	9.3	−12.9**	−6.8	.39	1.5
L-S	.0714**	11.0	−16.4**	−8.8	.73	2.7
SE[c]	.0137		2.7		.60	
Overall	.0682**	10.5	−14.1**	−7.5	.83*	3.2
SE[d]	.0079		1.6		.35	

[a]Heterosis = $(y_{ij} + y_{ji})/2 - (y_{ii} + y_{jj})/2$, where y_{ij} is the generalized least-squares mean for the ij[th] breed group.

[b]D = Duroc; Y = Yorkshire; L = Landrace; S = Spotted.

[c]Average standard error of specific heterosis (h_{ij}) estimates. Specific standard errors were used to test H_0: $h_{ij} = 0$ vs H_A: $h_{ij} \neq 0$.

[d]Standard error of overall heterosis estimate.

†P<.10.

*P<.05.

**P<.01.

TABLE 12. INDIVIDUAL HETEROSIS ESTIMATES FOR CARCASS TRAITS[a]

	Reciprocal crosses[b]								
Trait[c]	D-Y	D-L	D-S	Y-L	Y-S	L-S	SE[d]	Overall	SE[e]
CWT	1.43*	.71	1.21*	.40	−.02	−.38	.56	.56†	.32
LTH	.27	.42	1.17*	.07	.10	.22	.47	.33	.26
BF	1.69	.69	.88	.79	−.08	−.20	1.22	.64	.68
LMA	1.29	−.48	.37	−1.00	2.30**	−.51	.79	.26	.44
HAM	.08	−.31	−.11	.43*	−.03	−.33	.21	−.18	.12
LON	.54**	.17	.29	.09	.19	−.21	.19	.15	.11
SLD	.27	−.07	.06	−.02	.14	.26	.19	.02	.11
TLC	.49	−.26	.09	−.91†	−.28	−1.06*	.53	−.29	.29
BLY	.19	.18	.29	.22	−.08	.00	.20	.13	.11
MRB	−.41	−.45	−.07	.12	−.17	−.10	.32	−.18	.18
FRM	−.25	−.16	−.01	.19	−.37	.32	.31	−.13	.18
CLR	−.13	−.40†	−.16	−.00	−.36	−.07	.22	−.17	.12

[a]Heterosis = $(y_{ij} + y_{ji})/2 - (y_{ii} + y_{jj})/2$ where y_{ij} is the generalized least-squares mean for the ij^{th} breed group.

[b]D = Duroc; Y = Yorkshire; L = Landrace; S = Spotted.

[c]CWT = carcass weight (kg); LTH = carcass length (cm); BF = carcass backfat thickness (mm); LMA = loin muscle area (cm^2); HAM = weight of ham (kg); LON = weight of loin (kg); SLD = weight of shoulder (kg); TLC = weight of total lean cuts (kg); BLY = weight of belly (kg); MRB = marbling score; FRM = firmness score and CLR = color score.

[d]Average standard error of specific heterosis (h_{ij}) estimates. Specific standard errors were used to test H_0: $h_{ij} = 0$ vs H_A: $h_{ij} \neq 0$.

[e]Standard error for overall heterosis estimate.

†P<.10.

*P<.05.

**P<.01.

carcass length were also significant. No specific estimates for backfat, weight of shoulder or belly, or for quality scores were significant. Overall heterosis estimates for the 12 carcass traits measured were all nonsignificant.

Eisen et al. (1983) recommended partitioning direct heterosis as:

$$h_{ij} = z_i + z_j - 2w_{ij},$$

in order to enhance genetic interpretation of results from diallel crosses. They assumed no epistatic, sex-linked, paternal or grandmaternal effects for a random mating set of lines in Hardy-Weinberg equilibrium. The terms z_i and w_{ij} are functions of divergence of line gene frequencies from mean frequency across lines, and of dominance. Specifically:

$$z_i = \sum_k (q_{ik} - \bar{q}_k)^2 \, d_k,$$

$$w_{ij} = \sum_k (q_{ik} - \bar{q}_k)(q_{jk} - \bar{q}_k) \, d_k,$$

where

d_k = dominance direct value of the heterozygote;

q_{ik} = gene frequency of the favorable allele at the k^{th} locus in the i^{th} line (i=1,...,p) and

$\bar{q}_k = (1/p)\sum_i q_{ik}$.

Values of z_i (table 13) suggest that gene frequencies at loci with dominance effects on average daily gain and age off-test diverged considerably for all four breeds. The similar values of z_i for the breeds suggests comparable contributions to direct heterosis of a cross between the breeds. Values for probed backfat thickness were not significantly different from zero.

Values of w_{ij} are negative when net line deviations in gene frequency are of the opposite sign and positive when they have the same sign. Values of w_{ij} for postweaning rate of gain (table 14) were all negative, with four of the six values

TABLE 13. PARTITIONING HETEROSIS FOR POSTWEANING PERFORMANCE TRAITS: VALUES OF z_i^a

Breed	Avg daily gain, kg/d	Off-test age, d	Probed backfat mm
Duroc	.0302**	−5.62**	.399
Yorkshire	.0227**	−4.93**	.237
Landrace	.0241**	−5.36**	.337†
Spotted	.0253**	−5.29**	.273
SE[b]	.0051	1.01	.226

[a] $h_{ij} = z_i + z_j - 2w_{ij}$ (see text for discussion).

[b] Average standard error of z_i. Specific standard errors were used to test H_0: $z_i = 0$ vs H_A: $z_i \neq 0$.

†P<.10.

**P<.01.

TABLE 14. PARTITIONING HETEROSIS FOR POSTWEANING PERFORMANCE TRAITS: VALUES OF w_{ij}^a

Reciprocal crosses[b]	Avg daily gain, kg/d	Off-test age, d	Probed backfat, mm
D-Y	−.0127**	2.81**	−.074
D-L	−.0095*	1.70*	−.054
D-S	−.0079*	1.11	−.272
Y-L	−.0035	.80	−.223
Y-S	−.0064	1.32†	.060
L-S	−.0110**	2.86**	−.060
SE[c]	.0038	.75	.167

[a] $h_{ij} = z_i + z_j - 2w_{ij}$ (see text for discussion).

[b] D = Duroc; Y = Yorkshire; L = Landrace; S = Spotted.

[c] Average standard error of w_{ij}. Specific standard errors were used to test H_0: $w_{ij} = 0$ vs H_A: $w_{ij} \neq 0$.

†P<.10.

*P<.05.

**P<.01.

significantly different from zero. While not consistent (all six pairs can not have deviations of opposite sign), these results suggest possible deviations of opposite sign for the Duroc relative to the other breeds at loci with dominance effects on rate of gain. Three of the four crosses with significant negative values of w_{ij} for postweaning growth rate had significant positive values for off-test age, indicating the importance of different loci in determination of heterosis for the two traits. All values of w_{ij} were positive for age off-test, however, again presenting a logical inconsistency. Values for w_{ij} for probed backfat thickness were nonsignificant.

Conclusion

Results of this study indicated a moderate crossbred advantage for postweaning average daily gain and for age off-test, with low individual heterosis for probed backfat thickness and little or no heterosis for carcass traits. The superiority of Duroc-sired pigs for average daily gain, probed backfat thickness, loin muscle area and yield of lean cuts suggests utility of the Duroc as a sire breed.

Gaugler et al. (1984) reported Landrace and Yorkshire to be superior for litter productivity traits, relative to Duroc and Spotted dams. Taken in conjunction with these results, the postweaning performance and carcass data provided further evidence as to the utility of the Yorkshire and Landrace as maternal breeds in crossbreeding systems involving the Duroc. Such crosses produced leaner, more heavily muscled carcasses where the Yorkshire and Landrace were used as the dam breed.

The potential role of the Spotted breed in efficient commerical pork production systems in unclear. If more than one sire breed is required, it is important that each breed has desirable charcteristics. Thus a breed excelling in carcass merit while adequate in other respects might seem to be a logical adjunct to the Duroc. The Spotted breed did not fit this role.

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