SELECTION FOR MUSCLING IN DUROCS

by

PONGCHAN NA-LAMPANG

B.S., Chiengmai University, 1971

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

ANIMAL SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

Approved by:

John D. Wheat
Major Professor

ACKNOWLEDGMENTS

The author would like to express his sincere appreciation and thanks to Dr. John D. Wheat, major professor, for his assistance, guidance and encouragement during this study.

Appreciation is also extended to Dr. Donald H. Kropf, Dr. Robert R. Schalles and Dr. Berl A. Koch for their general guidance and assistance, and to Dr. Kenneth E. Kemp, without whose continued guidance and assistance in data processing and statistical analysis this study would not have been possible.

My special thanks go to two of my friends, Dr. Piyawat and Dr. Varunee Boon-Long, for their assistance and encouragement. Finally, I would like to thank the Royal Thai Government for its sponsorship and assistance during the whole study program.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The demand for pork with less fat and more muscle caused swine producers to exert considerable effort toward changing the genetic composition of their herds to meet this demand. Because backfat thickness (an easily measured indicator of total fatness) is moderately heritable, response to selection for reduced fatness was relatively rapid. From selection experiments for reduced backfat, several realized heritability estimates resulting from cumulative selection have been reported; .27 (Berruecos *et al.*, 1970); .32 (Gray *et al.*, 1968); and .48 for Durocs and .43 for Yorkshires (Hetzer and Harvey, 1967). This range in values indicates variation in rates of backfat reduction from herd to herd.

Use of ultrasonic methods to estimate fat and muscle mass has simplified reducing backfat, since they enable fat thickness to be measured accurately, quickly and painlessly in the live animal. Jones *et al.* (1970) reported that correlation between ultrasonic estimates and carcass measurements was quite large (from .75 to .89). That between estimated and actual *l. dorsi* depth was .67. In their study, ultrasonic measurement of fat thickness was effective in predicting carcass cutability. A multiple regression equation using ultrasonic fat depth and slaughter weight to predict percent lean cuts gave a multiple correlation of .81. However, the addition of ultrasonic *l. dorsi* depth or actual carcass *l. dorsi* area made no significant contribution to the multiple correlation coefficient (Jones *et al.*, 1970).

The objectives of this study were:

1. To compare animals in the two lines; a muscular line selected for maximum loin eye area and minimum backfat thickness estimated by an An-Scan machine and a control line, as to growth patterns, production traits and carcass quality.

2. To estimate genetic parameters for production and carcass traits.

3. To determine if an increase in muscling results in an increase in the occurrence of PSS (porcine stress syndrome) and/or PSE (pale soft exudative) carcasses.

CHAPTER II

LITERATURE REVIEW

Backfat Thickness and Selection

Hetzer, Zeller and Hankins (1956) found selection for high and low fatness effective in Duroc and Yorkshire pigs. Zeller and Hetzer (1960) reported that after five generations of selection for backfat thickness at 79.55 kg in Durocs, average backfat thickness of the high line increased 38% (from 3.78 in the foundation stock to 5.18 cm) and in the low line fat thickness decreased about 16% (to 3.23 cm). After 10 generations of selection in Durocs (Hetzer and Harvey, 1967), the high and low fat lines differed by 2.6 cm or 68% of the initial mean. Corresponding difference between the Yorkshire lines after 8 generations of selection, was 1.4 cm or 44% of the initial mean. Zoellner et al. (1963) also reported effective selection differentials for backfat thickness of -3.70 mm for the spring line and -4.50 mm for the fall line. Realized responses from the selection were -3.28 mm and -2.80 mm for the Spring and Fall lines. Average daily gain decreased as backfat thickness increased, but sow performance was not altered. Berruecos et al. (1970) reported that selection reduced backfat thickness by .065 cm per generation, when adjusted to 63.6 kg live weight. Correlated responses indicated a decline in litter size and individual weight as backfat thickness decreased.

Hetzer and Miller (1970) reported the correlated responses of 11 traits related to reproductive development and productivity of breeding females in two lines of Durocs selected for a single trait, backfat thickness. Compared with controls, conception rate declined in the low-fat line, but there was no change in the high-fat line. Number of services per conception remained essentially the same in all lines. Gestation length also showed no appreciable change. There were nonsignificant time trends in dam's weights and dam's weight changes. Dam's breeding weight was fairly conclusive evidence of a divergence in trends between the high and low lines, but none of the time trends in litter size were significant. Litter size tended to increase in the low line and decrease in the high line. As a whole, the results gave no clear indication of a consistent decline in reproductive fitness due to the selection for backfat thickness. They concluded that breeders could select for decreased fatness without lowering reproductive performance.

On the other hand, Berruecos _et al_. (1970) reported that selection for low backfat thickness significantly reduced litter size at birth and weaning, and weaning weight. Reduction in litter size and weight at 130 days was nonsignificant.

Bereskin _et al_. (1974) reported that, in Durocs, there were no significant differences between high and low fat lines in litter size at birth, 21 days and at 56 days. Low-fat line pigs tended to have higher total litter weight and average weight per pig at all three ages than those in the high-fat line.

Hetzer and Miller (1972) reported that in Durocs, selection for thicker backfat was accompanied by a decrease in weights at birth, 21, 56, 98 and 140 days, and days required to reach 79.4 kg. But the regression of weights on years were significant only at birth, 21 and 56 days. On the other hand, selection for thinner backfat resulted in significant increases in all traits mentioned above. Average daily gain from 56 days to 79.4 kg increased significantly in both the high and low lines.

Zoellner _et_ _al_. (1963) reported a decrease in average daily gain as backfat thickness increased.

Bereskin _et_ _al_. (1975) found that Durocs and Yorkshires in the high-fat lines ate more feed than those in the low-fat lines. Low-fat Durocs out gained high-fat Durocs, but the reverse was true for Yorkshires, resulting in an interaction of breed with line for gain. Barrows gained 7% faster ($P < .01$) and consumed 6% more feed ($P < .01$) than gilts. Both gain and feed consumption were significantly affected by interactions of line x sex and of breed x line x sex. Lines, but not breeds, differed significantly in feed efficiency; low-fat lines were more efficient.

Hetzer and Miller (1973) reported correlated responses of various carcass traits according to selection for high and low fatness in swine. When compared with the changes in backfat thickness, the relative divergences between the high and low Duroc and Yorkshire lines averaged, respectively, 76 and 83% for depth of carcass backfat, 73 and 82% for percent fat cuts, 56 and 60% for percent lean cuts, 51 and 26% for carcass length, 51 and 54% for percent fat in ham, 48 and 54% for percent lean in ham, 38 and 46% for loin eye area and 37 and 50% for ham weight. Of the remaining traits (dressing percentage, percent bone in ham, number of vertebra and number of ribs), only dressing percentage and percent bone in the ham in Durocs showed a divergence, averaging about 30 and 39%, respectively, of that of backfat thickness. Vertebra and rib numbers showed no significant change in the lines, but decreased somewhat in the high lines.

Bereskin and Darvey (1976) reported that in Durocs, after 17 generations of selection, the differences between low and high fat lines were -4.67 cm for average backfat thickness, 18.3 cm^2 for loin eye area, 11.6 cm for carcass length, 18.5% for percent lean of ham, -20.9% for percent fat of ham, 2.4% for percent bone of ham, 20.9% for percent lean cuts, and 1.05 kg/10 days for lean cuts gain. All the differences were significant. In Yorkshires, after 15 generations of selection, differences between the low and high fat lines were -3.75 cm for average backfat thickness, 16.3 cm^2 for loin eye area, 4.2 cm for carcass length. 15.8% for percent lean of ham, -17.9% for percent fat of ham, .9% for percent bone of ham, 17.1% for percent lean cuts, and .53 kg/10 days for lean cuts gain. All differences were significant.

In Durocs and Yorkshires selected for low and high backfat (Dickerson _et al_., 1976) at 100 kg live weight, deviations of low and high lines from the control line were, respectively, 5.1 and -6.9% in carcass length, 3 and -48% in muscling score, 29 and -22% in loin eye area, -33 and 48% in mean backfat thickness. Deviations in cut-out weights were, respectively, 19 and -26% for boneless defatted ham, 17 and -18% for trimmed loin chops, -41 and 32% for fat plus skin on loin and ham. Deviations in composition of untrimmed 10th rib chops were, respectively, 13 and -8% for separable lean; -16 and 12% for separable fat; 4.8 and -4.0% for protein; 13.5 and -10.5% for water; and -18.2 and 14.0% for fat in soft tissue. Deviations in percent composition of _l. dorsi_ muscle in the high and low lines were, respectively, .2 and -.8 for protein; .1 and -2.0 for water; and -.2 and 2.8 for fat. Deviations in muscle quality were, respectively, .3 and 0 for color (Iowa scores); 0 and 1.4 for marbling; 0 and .5 for firmness; -.3 and 0 for texture; 9 and -1 for light transmission, and .2 and -.6 kg/cm for Warner-Bratzler shear. Low fat line barrows dressed 2% below control and high lines.

Increased Muscling and PSS and PSE

Selection for more muscling and less backfat is probably related to the increase of PSS. This is due to an increase in meat/fat and meat/bone ratios (Stamm, 1975). Selecting meat type pigs and raising them in confinement was concurrent with an increase in proportion of the larger, white fibers in muscle (Schafer, 1972). These fibers have excellent abilities to convert glucose to lactic acid, but have poorly developed systems for further metabolizing the lactic acid. Moreover, pigs with large muscle masses of high percentage of white fibers often have poorly developed blood circulation and therefore cannot remove lactic acid fast enough when it is produced in large amounts. Their muscles suffer an irreversible pH drop causing heart failure and almost immediate rigor mortis. Apparently, PSS animals can produce either PSE muscle or very dark, firm and dry muscle depending on length of stress. Thus, the disqualification of PSE carcasses in carcass evaluation is not screening all pigs which may be stress susceptible. There are four tests which have shown the greatest potential for detecting PSS pigs. The first two involve a blood test. One to check the enzyme CPK (creatine phosphokinase) level. The other blood test is to determine the corticosteroid binding globulin level. High level of either indicates a stress prone pig. The third test involves testing a sample of muscle, obtained by a biopsy, for a high level of glucose-6-phosphate (Breeden, 1972). The fourth test involves using halothane anesthesia. Stress prone pigs are considerably less able to tolerate halothane than are normal pigs. Although this procedure has proven to be a highly reliable technique, it is cumbersome and it requires expensive equipment and knowledgeable operators. These handicaps plus the risk of transmitting disease from one herd to another via the equipment has limited its application (Christian, 1975).

Genetic Parameters

In the report of Gray *et al*. (1968) realized heritability for the average of the three backfat probes (shoulder, loin and ham) in Poland China pigs was .32±.09, while heritability estimated from intrasire regression of offspring mean on dam was .56±.09. Genetic correlations between backfat probes at three sites ranged from .59±.10 to .82±.06, suggesting that many of the same genes affected backfat at the different sites. Gray *et al*. (1968) also reported no significant effects of inbreeding on backfat thickness.

Hetzer and Miller (1970) reported heritabilities of backfat thickness, services per conception, gestation period length, weight change during suckling period, and litter size at birth, 21 days and 56 days of .34, -.22, .38, .13, .10, -.01 and .05, respectively. Only heritabilities of backfat thickness and gestation period were significant.

Berruecos *et al*. (1970) found heritabilities of litter size at birth, and weaning and weaning weight were very low (negative or near zero). On the other hand, estimates for litter size at 130 days, birth weight, weight at 130 days, and adjusted backfat thickness were .37, .21, .23 and .33, respectively.

Stanislaw *et al*. (1967) reported heritability estimates within purebreds were .03±.06, .28±.06 and .55±.12 for 56-day weight, average daily gain and probed backfat. Corresponding estimates within the crossbreds were .19±.09, .39±.10 and .47±.13. Genetic correlations in purebreds between 56-day weight and average daily gain and probed backfat were .29±.50, -.05±.53 and -.07±.18. Within crossbreds, corresponding estimates were .20±.21, .61±.16 and -.39±.13. They felt that, within purebreds, improvement in postweaning growth rate and probed backfat thickness must result almost entirely from selection pressure applied directly to these traits. However, within crossbreds, selection for less backfat would increase average daily gain.

Hetzer and Miller (1972) reported heritabilities for backfat thickness, birth weight, 21-day weight, 56-day weight, 98-day weight, 140-day weight and daily gain in Durocs of .56, .05, .09, .09, .10, .14 and .17, respectively. Corresponding estimates in Yorkshires were .50, .12, -.02, .07, .19, .30 and .33. Genetic correlations obtained from offspring-mid-parent covariances between backfat thickness and traits such as birth weight, 21-day weight, 56-day weight, 98-day weight, 140-day weight and daily gain were -.46, -.47, -.31, -.18, -.09 and .09. These estimates generally agreed both in magnitude and signs, with those calculated from observed responses.

Siers and Thomson (1972) investigated heritabilities and genetic correlations for certain carcass and growth traits in several breeds of pigs. In their study, only purebred pigs were used. They reported heritability estimates for loin eye length, depth, and area, ham and loin percent, 154-day weight, weaning weight, carcass length and backfat were about .60, .60, .70, .35, .25, .15, .50 and .25, respectively. Correlations between carcass length and other carcass traits were negative and small, the largest being with backfat (-.20). Carcass backfat was negatively correlated with each of the other five carcass traits. Correlations of loin eye length and depth with loin eye area and ham and loin percentage were positive. Loin eye depth correlations with loin eye area and ham and loin percentage exceeded those of loin length with the same two traits. The correlation of loin eye depth with ham and loin percentage was about equal to that between loin eye area and ham and loin percentage. There was a definite negative relationship between 154-day weight and weaning weight and the indicators of meatiness (loin eye area, depth and length and ham and loin percentage). Weaning and 154-day weights were positively correlated with carcass length and negatively correlated with backfat.

Siers (1975) reported phenotypic correlations between backfat thickness and average daily gain, feed efficiency, carcass length, ham and loin percentage, loin eye area, 56-day weight, age at 90.9 kg live weight, loin marbling score and loin color score were .21, .04, -.24, -.64, -.15, -.01, -.13, -.14 and .13, respectively. Only the correlations between backfat thickness and average daily gain and carcass length and ham and loin percentage were significant. Correlations between loin eye area and average daily gain, feed efficiency, carcass length, ham and loin percentage, 56-day weight, age at 90.9 kg live weight, loin marbling score and loin color score were -.03, -.04, .24, .11, .23, -.16, -.30 and .16, respectively. Only those between loin eye area and carcass length and loin marbling score were significant.

Bereskin and Darvey (1976) reported significant ($P < .01$) pooled phenotypic correlations in Durocs and Yorkshires between average backfat thickness and carcass length, percent bone and ham and percent lean cuts. Phenotypic correlations ($P < .01$) were calculated between loin eye area and average daily gain, percent lean and fat of ham and percent lean cuts.

Adams *et al.* (1972) reported that probed backfat thickness tended to be more closely associated with most carcass traits than was carcass backfat thickness. Shoulder probe correlations were of lower magnitude than either loin or rump probes. Probed backfat thickness and carcass backfat were more closely correlated with percent lean cuts of carcass weight (-.54 and -.52), than percent lean cuts of live weight (-.43 and -.36), or weight of lean cuts (-.26 and -.23). Correlations of .43, .52 and .57 were obtained for loin eye area with percent lean cuts of carcass weight, percent lean cuts of live weight and weight of lean cuts, respectively.

The study of Hetzer and Miller (1973) indicated that depth of carcass backfat, dressing percentage, percent fat trim and percent fat in ham were positively correlated genetically with backfat thickness. Genetic correlations between percent lean cuts and carcass length, loin eye area, ham weight, percent lean in ham, and percent bone in ham with backfat thickness were negative.

Aberle *et al.* (1971) found, in Duroc barrows and gilts, highly significant relationships between color-structure score, marbling score, percent reflectance and transmission value. Higher color-structure score was associated with lower reflectance and transmission value (r = -.63 and -.39). Shear value was related to color and marbling scores (r = -.15 and -.21) and with transmission value (r = -.17) indicating that lower quality muscle was less tender. Carcass length was not significantly related with any measure of muscle quality. As muscling increased and backfat decreased, tenderness tended to decrease (r = -.28 and -.17 between shear value and loin eye area and backfat). Heritability estimates (Aberle *et al.*, 1971) were as follows: color score .49±.23, marbling score .02±.20, percent reflectance .49±.26, transmission value .37±.20, shear value .04±.11, carcass length .23±.23, loin eye area .06±.25 and backfat thickness .17±.21.

The parameters indicated that muscle quality, as measured by color score, percent reflectance and protein solubility, was moderately heritable.

Jones et al. (1970) obtained simple correlations of .76, .89 and .75 between ultrasonic and carcass measurements for the three fat layers taken at the 10th rib and .76, .81 and .87 at the last rib. The correlations ($P < .01$) between estimated l. dorsi depth and actual carcass l. dorsi depth were .67 and .66 for the 10th and the last rib locations, respectively. Correlations between ultrasonic estimates of 1st fat layer, combined 1st and 2nd fat layer depths with percent ham and loin and percent lean cuts were -.67 and -.66, and -.75 and -.73, respectively. Ultrasonic l. dorsi depth estimate at the 10th rib was correlated with percent lean cuts and percent ham and loin (.57 and .50). A multiple regression equation using 10th rib ultrasonic, loin depth, ultrasonic 2nd layer fat depth, and slaughter weight to predict percent lean cuts resulted in a multiple correlation of .81. The addition of ultrasonic l. dorsi depth or actual carcass l. dorsi made no significant contribution to the multiple correlation coefficient.

Ramsey et al. (1972) estimated loin eye area in swine with a single ultrasonic measurement and reported that each centimeter of muscle depth approximated 6.45 cm^2 of muscle area. Measurements of muscle depth from carcass tracings were highly correlated ($r = .91$ and .74) with actual muscle area at the 10th and last rib. Correlations of muscle depth with ham and loin percent ($r = .57$) and lean cuts percentage ($r = .56$) were comparable to those between loin eye area and these two cutout measurements ($r = .59$).

Webb (1975) reported repeatabilities of individual fat depths 6.5 cm off the mid-line at the shoulder, mid-back and loin ranged from .75 to .90. Repeatability of average backfat thickness was .92.

According to Breeden (1972) PSS is moderately heritable, 20 to 40%, is seen more often in gilts than barrows, in confinement operations, in short, squatty, heavily muscled pigs. It appears in almost all breeds of swine in the U.S., but more often in certain strains in given breeds. Poland Chinas, Chester Whites, Yorkshires and Landraces are the most susceptible (Breeden, 1972).

CHAPTER III

MATERIALS AND METHODS

Experimental Animals

Pigs in the base population of purebred Durocs were farrowed in May 1971. Twenty male pigs were randomly selected in July 1971 at the age of ten weeks. The select line was formed in the fall of 1971 by using the four highest indexing boars of this group and 20 of the highest indexing gilts. The index used ($I = \frac{X_{LEA} - \overline{X}_{LEA}}{\sigma_{LEA}} - \frac{X_{BF} - \overline{X}_{BF}}{\sigma_{BF}}$), gave equal emphasis to maximum loin eye area and minimum backfat thickness, estimated by the An/Scan and adjusted to 100 kg live weight. This gave the most efficient estimations of genetic parameters since selection was for two traits (Bruns and Harvey, 1976). In the fall of 1971 four boars and 20 gilts were randomly selected to form the control line. Within line selection was practiced after the lines were formed and closed.

One restriction was that the least desirable animals because of obvious structural unsoundnesses were not considered as potential breeding animals.

Each year breeding animals were farrowed in May, produced litters the following May and were replaced after producing one litter causing generation interval to be one year. Full-sib and half-sib matings were avoided to minimize inbreeding. However, average inbreeding coefficients of parents of the 1975 select and control lines were 10.8% and 15.6%, respectively.

Pigs were self-fed in groups of 20 to 28 in outside pens (15m by 30m) and rations were standardized from year to year. Backfat thickness and loin eye area measurements on live animals at about 100 kg live weight were made from the ultrasonic scanogram resulting from the use of a Polaroid Land camera.

In each generation, a number of barrows at 100 kg live weight were slaughtered in the meat laboratory for carcass analysis. Backfat thickness and loin eye area measurements on the live barrows were not made.

The summary of the number of experimental animals included in the study is shown in Table 1.

The list of the production and carcass traits studied is shown in Table 2.

Live animal backfat thickness was estimated at three locations, shoulder above the elbow, at 10th rib and hip above the stifle joint, about 3.82 cm from the mid-line. Averages of the three measurements were adjusted on a 0.028 cm/kg basis to a 100 kg live weight. Live animal loin eye area was estimated at the 10th rib and adjusted to a 100 kg live weight. The adjustment was 0.213 cm^2/kg live weight. Adjusted age to 100 kg live weight was obtained by adjusting age on a 0.91 kg/day basis.

Carcass backfat thickness was the average of six measurements taken on the mid-line of both sides of the carcass, chilled 24 hr, at the 1st rib, last rib and last vertebra.

Carcass loin eye area at the 10th rib was traced and measured with a planimeter.

Carcass length was the distance from the anterior edge of the aitch bone to the forward edge of the 1st rib immediately ventral to the vertebra.

Chine depth measured at three locations, 10th thoracic, 1st and 5th lumbar vertebra, was the distance from dorsal edge of spinal canal to dorsal

TABLE 1. SUMMARY OF THE OBSERVATIONS INCLUDED IN THE STUDY BY GENERATION

	Generation					Total
	1	2	3	4	5	
Select line						
No. sire groups	4	3	5	5	6	23
No. dam groups	7	15	13	18	18	71
No. observations	47	101	81	99	94	442
Control line						
No. sire groups	4	5	5	4	5	23
No. dam groups	10	13	16	14	16	69
No. observations	95	100	118	91	78	482
Total						
No. sire groups	8	8	10	9	11	46
No. dam groups	17	28	29	32	34	140
No. observations	142	201	199	190	172	904

TABLE 2. MEANS AND STANDARD DEVIATIONS FOR TRAITS INCLUDED IN THE STUDY

Trait	Mean	S.D.
Group I		
Litter size at birth	7.97	2.11
Litter size at 4 weeks	6.13	2.40
Group II		
Body weight at birth, kg	1.35	.25
Body weight at 2 weeks, kg	3.18	.75
Body weight at 4 weeks, kg	5.51	1.44
Teat number	12.48	1.09
Group III (Live data adjusted to 100 kg live weight)		
Adjusted age, day	182.43	12.59
Adjusted loin eye area, cm^2	35.03	2.91
Adjusted backfat thickness, cm	2.54	.37
Group IV (Carcass measurements and yields)		
Carcass loin eye area, cm^2	32.66	3.80
Carcass backfat thickness, cm	3.46	.41
Carcass length, cm	76.66	2.16
Chine depth at 10th rib, cm	5.29	.40
Chine depth at 1st lumbar, cm	4.30	.87
Chine depth at 5th lumbar, cm	6.36	.67
Dressing percentage	71.57	2.34
Ham and loin weight, kg	29.15	1.81
Percent ham and loin	40.11	1.98
Lean cuts weight, kg	42.56	2.53
Percent lean cuts	58.56	2.60

TABLE 2. (Continued) MEANS AND STANDARD DEVIATIONS FOR TRAITS INCLUDED IN THE STUDY

Trait	Mean	S.D.
Group IV (Cont.)		
Primal cuts weight, kg	54.20	2.70
Percent primal cuts	74.56	2.15
Percent high priced cuts	68.48	1.10
Weight total fat trim, kg	9.22	1.58
Percent total fat trim	12.67	2.02
Group V (Carcass quality)		
Ham color	3.16	.48
Ham marbling	13.08	4.41
Ham firmness	3.01	.47
Loin color	3.20	.57
Loin marbling	21.40	6.33
Loin firmness	3.21	.50
Warner-Bratzler shear force, kg	5.58	1.33
Fiber diameter LD, u	47.89	11.10
Fiber diameter red ST, u	50.17	13.81
Percent moisture of _longissimus_	72.44	1.70
Percent ether extract of _longissimus_	5.21	1.72
Percent total cooking loss	36.60	8.22
Percent drip cooking loss	7.96	2.38
Percent volatile cooking loss	28.65	7.15

tip of vertebra or at the muscle-backfat junction.

Dressing percentage was the total chilled carcass weight divided by the live weight of the animal just prior to slaughter.

Total fat trim yield was the sum of clear plate, fat back and other fat trim divided by the chilled carcass weight.

Ham, loin, picnic and Boston butt represented the four lean cuts and these plus the belly were considered the five primal cuts. The percentage of cuts referred to the weight of the cuts divided by the chilled carcass weight (Robison et al., 1960). Percent high priced cuts was found by adding the weights of the ham and loin and dividing by the weight of the lean cuts.

Color, marbling and firmness scores were obtained for the l. dorsi muscle at the 10th rib and ham muscle. Color and firmness were evaluated on the basis of the Wisconsin standard scoring system (Anonymous, 1963). A score of 1 indicated pale, soft, exudative, and a score of 5 represented dark, firm and dry. Marbling scores ranged from 1 (devoid -) to 36 (extremely abundant +) (after U.S.D.A. marbling scores for beef).

Slightly modified A.O.A.C. procedures, from the latest Official Methods of Analysis (A.O.A.C., 1975), were used for determination of percent moisture and ether extract. Warner-Bratzler shear force was evaluated from six 1.27 cm cores per chop of longissimus muscle taken at the 11th thoracic location. Chops were cooked to 76.7 degrees celcius and then roasted to 176.7 degrees celcius. Percent cooking losses was a percent of raw weight. Fiber diameter of longissimus and semitendinosus muscles was measured with a fixed crosshair micrometer.

CPK Stress Syndrome Detection

In 1976, animals in both lines were physically stressed by running them 100 yards six hr before a blood sample was taken from each. The simple test consisted of collecting a drop of blood from the animal's ear on a special filter type paper and sending the paper to the Genetic Information Systems in Elk Grove Village, Illinois, for analysis. Scores of 30 or less indicate stress resistance; those of 30-80 indicate the possibility of stress susceptibility or some other pathological disorder; and a score exceeding 80 indicates the animal is stress prone or has some other pathological disorder affecting the skeleton-muscular system.

Statistical Methods

The statistical technique used was that for the mixed model as described by Harvey (1972). Lines, generations, sex and regression on carcass weight were considered as fixed effects, whereas sires, dams and individuals were random effects. The least-squares model for weight at different ages was,

$$Y_{ijklmn} = U + G_i + L_j + S_{ijk} + D_{ijkl} + A_m + e_{ijklmn}$$

where:

Y_{ijklmn} = the record of the *n*th pig with the *m*th sex of the *l*th dam within the *k*th sire of the *j*th line in the *i*th generation,

U = the population mean,

G_i = the effect of the *i*th generation

L_j = the effect of the *j*th line,

S_{ijk} = the effect of the *k*th sire within the *ij*th generation-line subclass,

D_{ijkl} = the effect of the l̲th dam bred to the i̲j̲k̲th sire,

A_m = the effect of the m̲th sex, and

e_{ijklmn} = the random element associated with the i̲j̲k̲l̲m̲n̲th pig.

In the analyses of variance for litter size at different ages, the least-squares model was,

$Y_{ijkl} = U + G_i + L_j + S_{ijk} + e_{ijkl}$

where:

Y_{ijkl} = the record of the l̲th litter within the k̲th sire of the j̲th line in i̲th generation,

U, G_i, L_j and S_{ijk} = as above, and

e_{ijkl} = the random element associated with the i̲j̲k̲l̲th litter.

The least-squares model for carcass traits was,

$Y_{ijklm} = U + G_i + L_j + S_{ijk} + D_{ijkl} + B(x - \overline{x}) + e_{ijklm}$

where:

Y_{ijklm} = the record of the m̲th pig of the l̲th dam within the k̲th sire of the j̲th line in the i̲th generation,

U, G_i, L_j, S_{ijk} and D_{ijkl} = as above,

$B(x - \overline{x})$ = the effect of regression on carcass weight, and

e_{ijklm} = the random element associated with the i̲j̲k̲l̲m̲th pig.

The results of least-squares analyses of variance, least-squares means and standard errors and all genetic parameters were obtained by using Harvey's LSML76 (Mixed Model Least-Squares and Maximum Likelihood) computer program.

The least-squares analysis of variance scheme used in this study is presented in Table 3.

TABLE 3. LEAST-SQUARES ANALYSIS OF VARIANCE

Source of variation	df	Variance components and coefficients
Sex (fixed)	a-1	
Generations, G (fixed)	g-1	
Lines, L (fixed)	l-1	
Sires / G x L	s-g.l	$E + k_2D + k_3S$
Dams / Sires / G x L	d-s	$E + k_1D$
Regression on carcass wt.	1	
Error	T-a-g-l+g.l-d+1	E

a = number of sexes

g = number of generations

l = number of lines

s = number of sires

d = number of dams

T = total number of records

E = variance due to differences among full-sibs

D = variance due to differences among dams

S = variance due to differences among sires

$k_1 = [1/(d-s)][T - \sum_i \sum_j \sum_k (1/n_{ijk}) \cdot \sum_l n^2_{ijkl}]$

$k_2 = [1/(s-g.l)][\sum_i \sum_j \sum_k (1/n_{ijk}) - (1/T) \sum_i \sum_j \sum_k \sum_l n^2_{ijkl}]$

$k_3 = [1/(s-g.l)][T - \sum_i \sum_j \sum_k (1/n_{ijk})/T]$

CHAPTER IV

EFFECT OF SELECTION ON PERFORMANCE TRAITS

Litter Size at Birth and at 4 Weeks

Estimates of fixed effects. Analyses of variance for litter size at birth and at 4 weeks are presented in Table 4. There were significant differences ($P < .05$) in generation effect for both traits. However, line differences were nonsignificant. Average litter sizes at birth and at 4 weeks were 8.13±.29 and 6.09±.29 for the select line and 7.82±.28 and 6.17±.27 for the control line (Table 5). Differences between select and control lines for litter size at birth and at 4 weeks were 3.96 and -1.30%. Generation comparisons showed that litter size at birth of select line pigs was higher ($P < .01$) than control line pigs in generation 4 and 5 (11.58 and 11.71%), but was lower ($P < .05$) in generation 3 (-6.36%). Litter size at 4 weeks in the select line was higher ($P < .01$) than that of the control line in generation 5 (19.17%), but lower ($P < .01$) in generation 3 (-5.75%). These comparisons indicated an important role of generation effect which is also year effect since there was a new generation each year, upon the two traits. The results confirmed previous studies which indicated that increased fatness failed to affect reproductive traits (Hetzer and Miller, 1970 and Bereskin *et al.*, 1974). However, Berruecos *et al.* (1970) reported that selection for low backfat thickness reduced litter size at birth and weaning.

Estimates of random effect. There were nonsignificant differences among sires for litter size at birth and at 4 weeks.

TABLE 4. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR LITTER SIZE AT DIFFERENT AGES

Source	df	Litter size at birth	Litter size at 4 weeks
Generations (G)	4	14.04*	13.63*
Lines (L)	1	3.56	.23
S / G.L	36	4.88	4.03
Error	103	4.40	5.68

*P $<$ .05

S = Sires

TABLE 5. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR LITTER SIZE BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
	Litter size at birth, no.			
1	8.57±.82	8.27±.58	.30	103.63
2	8.13±.59	8.46±.62	-.33	96.10
3	6.92±.62	7.39±.53	-.47*	93.64
4	9.25±.56	8.29±.60	.96**	111.58
5	7.82±.54	7.00±.55	.82**	111.71
Overall	8.13±.29	7.82±.28	.31	103.96
	Litter size at 4 weeks, no.			
1	6.71±.91	6.40±.62	.31	104.84
2	6.20±.62	7.00±.67	-.80**	88.57
3	6.23±.67	6.61±.57	-.38	94.25
4	6.25±.60	6.50±.64	-.25	96.15
5	5.47±.58	4.59±.58	.88**	119.17
Overall	6.09±.29	6.17±.27	-.08	98.70

* $P < .05$

** $P < .01$

Weight at Birth, 2 Weeks and 4 Weeks, and Teat Number

Estimates of fixed effects. Least-squares analyses of variance for weight at three ages and teat number are presented in Table 6. Sex of pigs was classified as gilts, boars, and barrows. Even though the male pigs were left intact until 8 weeks of age, the fact that they were classified into two categories should give an idea if any differences existed at 4 weeks among these three groups of pigs. Carcass trait observations were obtained only from the barrows. Differences among sexes (Table 6) were significant ($P < .01$) for weight at birth, two weeks and teat number, while those for weights at four weeks were significant ($P < .05$). Comparisons of least-squares means of the three sexes are shown in Table 7. Gilts weighed .05 kg less at birth than boars and .03 kg less than barrows. Boars were .02 kg lighter at birth than barrows, but the only significant difference ($P < .05$) was between gilts and boars. Boars were heaviest at 2 weeks of age; .15 kg heavier ($P < .01$) than gilts and .10 kg heavier ($P < .05$) than barrows. Barrows were heavier than gilts by .05 kg. At 4 weeks boars were .25 kg heavier than gilts and .18 kg heavier than barrows. Barrows were larger than gilts at 4 weeks by .07 kg. Only the difference between boars and gilts was significant ($P < .05$). Gilts, boars and barrows gained 4.09, 4.29 and 4.13 kg, from birth to 4 weeks. These results agreed with those reported by Craig *et al*. (1956) in which boars were significantly heavier than gilts by about five percent at birth and three percent at 8 weeks. Bereskin *et al*. (1973) also reported that boars were .03 kg heavier than gilts at birth ($P < .01$). The heavier boars at birth may be explained by the fact that the male fetus has a higher growth competence before birth than females (Hafez, 1968). Sex differences for teat number were highly significant (Table 6).

TABLE 6. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR WEIGHT AND TEAT NUMBER

Source	df	Weight at birth	Weight at 2 weeks	Weight at 4 weeks	Teat no.
Sex	2	1.22**	7.76**	23.57*	6.71**
Generations (G)	4	4.76**	98.13**	225.52**	6.91*
Lines (L)	1	.23	10.83	75.90	36.27**
S / G.L	37	.90*	7.62	29.23	2.14
D / S / G.L	103	.54**	5.71**	20.29**	1.67**
Error	757	.20	1.53	6.55	.98

*P < .05

**P < .01

S = Sires

D = Dams

TABLE 7. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR WEIGHT AT DIFFERENT AGES AND TEAT NUMBER BY SEX

Item	No.	Weight (kg) at Birth	2 weeks	4 weeks	Teat no.
Female, F	449	1.33±.02	3.12±.05	5.42±.11	12.61±.07
Male, M1[a]	307	1.38±.02	3.27±.06	5.67±.12	12.31±.08
Male, M2[b]	148	1.36±.02	3.17±.07	5.49±.14	12.41±.10
M1-F		.05*	.15**	.25*	-.30**
(M1/F)x100		103.75	104.81	104.61	97.62
M2-F		.03	.05	.07	-.20**
(M2/F)x100		102.26	101.60	101.29	98.41
M2-M1		-.02	-.10*	-.18	.10
(M2/M1)x100		98.55	96.94	95.59	100.81

*P < .05

**P < .01

[a] boars group

[b] barrows group

Comparisons in Table 7 showed that females averaged 12.61±.07 teats, significantly ($P < .01$) more than the average of 12.31±.08 for boars and 12.41±.10 for barrows. Gilts were significantly different from the boar and the barrow groups in all four traits considered. However, boars and barrows differed only for weight at 2 weeks ($P < .05$).

Generation effects were significant ($P < .01$) in the three weights but differences in teat number were only significant ($P < .05$). Line differences were nonsignificant for weight at birth, at 2 weeks and 4 weeks (Table 6) but were significant ($P < .01$) for teat number. Comparisons of the two lines for weight at birth, 2 weeks and 4 weeks, and teat number are shown in Table 8. For weight at birth, pigs in the select line weighed the same as those in the control line in generation 1, and .14 kg more in generation 2, but weighed less than the control in generations 3, 4 and 5 by .07, .07 and .04 kg, respectively. All differences were significant ($P < .01$). Overall mean weight at birth of select line pigs was nonsignificantly lower than that of control line pigs by .01 kg. Pigs in the select line were heavier ($P < .01$) at 2 weeks of age than control line pigs in generation 2 by .14 kg but were smaller by .18 kg ($P < .01$) in generation 4. For all other generations, differences were nonsignificant. Overall mean weight at 2 weeks for select line pigs was .10 kg less than that for the control line ($P > .05$). Pigs in the select line were .32 kg ($P < .01$) heavier, .74 ($P < .01$) and .25 ($P < .05$) lighter than those in control line in generations 1, 4 and 5, respectively, at 4 weeks of age. In generations 2 and 3, the differences between the two lines were nonsignificant. Nonsignificant differences in overall mean weights at 4 weeks between select and control lines was -.26 kg. Pigs in the select line had more teats than

TABLE 8. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR WEIGHT AT DIFFERENT AGES AND TEAT NUMBER BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
	Weight at birth, kg			
1	1.40±.02	1.40±.02	.00	100.00
2	1.51±.02	1.37±.02	.49**	110.22
3	1.33±.02	1.40±.02	-.07**	95.00
4	1.28±.02	1.35±.02	-.07**	94.81
5	1.23±.02	1.27±.02	-.04*	96.85
Overall	1.35±.03	1.36±.03	-.01	99.26
	Weight at 2 weeks, kg			
1	3.46±.10	3.38±.06	.08	102.37
2	3.50±.06	3.36±.06	.14**	104.17
3	3.31±.07	3.28±.06	.03	100.91
4	2.90±.06	3.08±.06	-.18**	94.16
5	2.66±.06	2.69±.07	-.03	98.88
Overall	3.14±.10	3.24±.10	-.10	96.91
	Weight at 4 weeks, kg			
1	5.99±.20	5.67±.12	.32**	105.64
2	5.67±.12	5.75±.12	-.08	98.61
3	6.07±.14	6.05±.11	.02	100.33
4	4.90±.12	5.64±.13	-.74**	86.88
5	4.64±.13	4.89±.14	-.25*	94.89
Overall	5.38±.18	5.64±.16	-.26	95.39
	Teat number			
1	12.31±.15	12.12±.10	.19**	101.57
2	12.52±.10	12.46±.10	.06	100.48
3	12.51±.11	12.10±.09	.41**	103.39
4	12.83±.10	12.38±.11	.45**	103.63
5	12.95±.11	12.25±.07	.70**	105.71
Overall	12.66±.09	12.26±.08	.40**	103.26

---

[*] $P < .05$

[**] $P < .01$

those in the control line in every generation. The differences were .19, .06, .41, .45 and .70 in generations 1 to 5, respectively; only the difference in generation 1 was nonsignificant. Overall, the mean teat number for pigs in the select line was .40 ($P < .01$) more than in the control line.

After five generations of selection for maximum loin eye area and minimum backfat thickness, select and control lines showed no difference in weight at birth, at 2 weeks and at 4 weeks but they differed significantly in number of teats. The results differ from the significant increases in weight at birth and at 21 days reported by Hetzer and Miller (1972).

Estimates of random effects. Effects of sire groups within generation-line subclasses were significant ($P < .05$) only for birth weight, while differences among dams within sires were significant ($P < .01$) for all four traits being considered. Understandably maternal effects greatly affect weight of pigs during the suckling period, but how they affect teat number is more difficult to understand.

Age, Loin Eye Area and Backfat Thickness Adjusted to 100 kg Live Weight

Estimates of fixed effects. Least-squares analyses of variance for age, loin eye area and backfat thickness, estimated by An/Scan and adjusted to 100 kg live weight, are presented in Table 9. Sex differences were significant ($P < .01$) for adjusted age and adjusted backfat thickness but were nonsignificant for adjusted loin eye area. Gilts reached 100 kg live weight 7.53 days later ($P < .01$) than boars (Table 10).

These results agreed with those reported by Craig *et al*. (1956), Cox (1963), Zoellner *et al*. (1963) and Berruecos *et al*. (1970) in which they reported heavier final weights for boars. Boars' adjusted loin eye area was larger than that of gilts' by a nonsignificant .34 cm^2 (Table 10). Boars

TABLE 9. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR AGE, LOIN EYE AREA AND BACKFAT THICKNESS ADJUSTED TO 100 KG LIVE WEIGHT

Source	df	Adj. age	Adj. LEA	Adj. BF
Sex	1	3706.30**	.31	.38**
Generations (G)	4	1555.98**	1.71*	.66**
Lines (L)	1	5976.65**	4.25**	.28**
S / G.L	36	246.64	.45**	.03**
D / S / G.L	94	179.49**	.20	.02**
Error	368	104.07	.16	.01

* $P < .05$

** $P < .01$

LEA = loin eye area

BF = backfat thickness

S = Sires

D = Dams

TABLE 10. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR AGE, LOIN EYE AREA AND BACKFAT THICKNESS ADJUSTED TO 100 KG LIVE WEIGHT BY SEX

Item	no.	Adj. age day	Adj. LEA cm^2	Adj. BF cm
Gilt (Gi)	365	184.93±.92	35.10±.26	2.60±.03
Boar (Bo)	140	177.40±1.14	34.66±.31	2.40±.03
Gi - Bo		7.53**	.34	.20**
(Gi/Bo)x100		104.24	101.27	108.33

$^{**}P < .01$

LEA = loin eye area

BF = backfat thickness

had .20 cm less backfat than gilts ($P < .01$) similar to results reported by Hetzer and Harvey (1967), Berruecos et al. (1970) and Hetzer and Miller (1972) when they found boars had about .20 cm thinner backfat than gilts.

Generation effects were significant ($P < .05$) for age and adjusted backfat thickness and significant ($P < .01$) for adjusted loin eye area. Line differences were highly significant for all three traits (Table 9). Pigs in the select line reached 100 kg later than those in control line in every generation ($P < .01$) except the first when the difference was a nonsignificant -.10 day. Line differences were, from generations 2 to 5 respectively, 5.57, 8.92, 10.27 and 9.27 days. Overall, select line pigs were 6.92 days ($P < .01$) older than those in the control line. The results agreed with an increase in days required to reach 79.4 kg in the low fat line reported by Hetzer and Miller (1972). Pigs in the control line in the present trial ate more but were less efficient than those in the select line (Wheat et al., 1976). Bereskin et al. (1975) also reported that pigs in high-fat lines ate more feed than those in the low-fat lines, but low-fat Durocs out gained high-fat Durocs. Comparison of select and control lines for loin eye area adjusted to 100 kg live weight, in Table 11, showed pigs in the select line had smaller loin eye areas in generation 1 by .71 cm^2 but had larger loin eye areas in later generations by .45, 2.45, 2.00 and 1.29 cm^2 respectively. All differences were significant ($P < .01$) except that in generation 2 which was nonsignificant. Overall mean for estimated loin eye areas of pigs in the select line was larger ($P < .01$) than that in the control line by 1.16 cm^2. The difference of 1.16 cm^2 or 3.37% was less than the 38% reported by Hetzer and Miller (1973) and lower than the 18.3 cm^2 reported by Bereskin et al. (1976) but the latter values were estimated after many more (17)

TABLE 11. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR AGE, LOIN EYE AREA AND BACKFAT THICKNESS ADJUSTED TO 100 KG LIVE WEIGHT BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
Adjusted age, day				
1	187.08±2.81	187.18±2.52	-.10	99.95
2	182.06±2.39	176.49±2.30	5.57**	103.16
3	187.00±2.62	178.08±2.08	8.92**	105.01
4	180.95±2.33	170.68±2.31	10.27**	106.02
5	185.71±2.19	176.44±2.34	9.27**	105.25
Overall	184.41±1.44	177.49±1.42	6.92**	103.90
Adjusted loin eye area, cm^2				
1	33.09±.71	33.80±.71	-.71**	97.90
2	35.54±.71	35.09±.65	.45	101.28
3	37.22±.77	34.77±.58	2.45**	107.05
4	36.06±.65	34.06±.65	2.00**	105.87
5	35.15±.58	33.86±.71	1.29**	103.81
Overall	35.54±.39	34.38±.39	1.16**	103.37
Adjusted backfat thickness, cm				
1	2.49±.08	2.59±.08	-.10**	96.14
2	2.67±.08	2.82±.08	-.15**	94.68
3	2.26±.08	2.26±.06	.00	100.00
4	2.24±.08	2.44±.08	-.20**	91.80
5	2.54±.08	2.69±.08	-.15**	94.42
Overall	2.44±.05	2.54±.05	-.10**	96.06

$^{**}P < .01$

generations of selection than in this study. From Table 11, adjusted backfat thickness in the select line was less ($P < .01$) than that in the control line in all generations except the third in which there was no difference at all. The differences between select and control lines were -.10, -.15, -.20 and -.15 cm in generations 1, 2, 4 and 5 respectively. Overall mean difference in adjusted backfat thickness between select line and control line was -.10 cm ($P < .01$). Selection reduced backfat thickness by 3.94% compared with that of the control line. This value was less than the 16% decrease after five generations of selection (for backfat alone) reported by Zeller and Hetzer (1960). However, the present selection program was relatively effective when compared with reports by Hetzer *et al.* (1956), Zoellner *et al.* (1963), Hetzer and Harvey (1967), Gray *et al.* (1968), Hetzer and Miller (1972), and Bereskin and Darvey (1976).

Estimates of random effects. From least-squares analyses of variance (Table 9), sire differences were significant ($P < .01$) for adjusted loin eye area and backfat thickness but not for age at 100 kg live weight. Dam differences were significant ($P < .01$) for age and backfat thickness adjusted to 100 kg live weight.

Heritability Estimates for Performance Traits

Heritability estimates for performance traits obtained from Harvey's (1977) least-squares mixed model are listed in Table 12. Due to the statistical model used, there were no dam components available for full-sib correlation estimates for litter size at birth and at 4 weeks. Moreover, the negative variance components for litter size at 4 weeks were set to zero by the program. Thus, a heritability estimate was obtained only for litter size at birth. The value of .12±.34 fell in the range of .03 to .17 reported in

TABLE 12. HERITABILITY ESTIMATES FROM FULL-SIB AND HALF-SIB CORRELATIONS FOR CERTAIN PERFORMANCE TRAITS

	h^2 ± S.E.	
Trait	Full-sib	Paternal half-sib
Litter size at birth[a]	....	.12±.34
Litter size at 4 weeks[a]	....	.......[b]
Weight at birth	.57±.08	.26±.10
Weight at 2 weeks	.69±.09	.14±.08
Weight at 4 weeks	.61±.08	.18±.08
Teat number	.25±.06	.08±.07
Adj. age at 100 kg	.45±.10	.16±.12
Adj. loin eye area	.41±.10	.52±.18
Adj. backfat thickness	.51±.10	.38±.16

[a] Calculated from half-sib correlations only.

[b] Negative variance components were set to zero.

the literature (Revelle and Robison, 1973; and Lush and Molln, 1942) and near the .13 reported by Boylan *et al.*(1961). However, many different estimates were reported (.54 by Shelby, 1952; and -.17 by Berruecos *et al.*, 1970). Estimates from full-sib and paternal half-sib correlations for birth weight were .57±.08 and .26±.10. The value obtained from the paternal half-sib correlation was near the .21±.15 reported by Berruecos *et al.* (1970), but was higher than the .05 estimated by Craig *et al.* (1956). The heritability estimate of .57±.08 from the full-sib correlation is larger than that based on paternal half-sibs since the dam component was relatively much larger than the sire component.

Heritability estimates for 2 and 4 week weights from full-sib correlations were .69±.09 and .61±.08. Corresponding estimates from paternal half-sibs were .14±.08 and .18±.08 respectively. No comparable reports of heritability estimates for 2 and 4 weeks weight are available in the literature but estimates for 4 week weights were relatively higher than .01±.03 for weaning weight reported by Berruecos *et al.*, 1970. Heritability estimates for teat number were .25±.06 and .08±.07 from full-sib and paternal half-sib correlations, respectively.

Heritability estimates obtained from full-sib and paternal half-sib correlations for adjusted age at 100 kg live weight were .45±.10 and .16±.12. Although no reports of heritability estimates for this trait are reported in the literature, the value obtained in this study indicates this trait is moderately heritable. Heritability estimates for adjusted loin eye area obtained from the two different methods were .41±.10 and .52±.18. The values were lower than the .70 for carcass loin eye reported by Siers and Thomson (1972). Heritability for adjusted backfat thickness estimated from full-sib and half-sib correlations were .51±.10 and .38±.16. The .38±.16 value was the same as reported by Berruecos *et al.* (1970) for adjusted backfat thickness to 63.6 kg live weight, and near those reported by Gray *et al.* (1968), Hetzer and Miller (1970) and Berruecos *et al.* (1970), but higher than the .25 reported by Siers and Thomson (1972). The higher value of .51±.10 was relatively close to those reported by Stanislaw *et al.* (1967) and Hetzer and Miller (1972).

Genetic, Phenotypic and Environmental Correlations

Since the negative variance components were set to zero by the program, the only phenotypic correlation available was that between litter sizes at birth and at 4 weeks. The value was .61 indicating that litter sizes at birth and at 4 weeks were closely related phenotypically.

Genetic, phenotypic and environmental correlations for weights at birth, 2 weeks and at 4 weeks, and teat number are presented in Table 13. The estimates between weight at birth and at 2 weeks were .51±.11, .53 and .58 for genetic, phenotypic and environmental correlations respectively. Corresponding estimates between weight at birth and weight at 4 weeks were .35±.13, .39 and .44. The highest correlations among weights at three ages were those between weights at 2 and 4 weeks. The values were .66±.08 for genetic, .75 for phenotypic, and .92 for environmental correlations. The large genetic correlations among weights at progressive periods suggested part-whole automaticity and the possibility that the same genes are largely responsible for weight gains made during different periods of development. Genetic correlations between teat number and weight at birth, 2 and 4 weeks were .26±.17, .38±.16 and .19±.18. Phenotypic correlations between teat number and weight at different ages were positive and very low with values

TABLE 13. GENETIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS AMONG WEIGHT AT DIFFERENT AGES AND TEAT NUMBER[a] [b]

Item	Weight at 2 weeks	Weight at 4 weeks	Teat no.
Weight at birth			
genetic	.51±.11	.35±.13	.26±.17
phenotypic	.53	.39	.08
environmental	.58	.44	-.03
Weight at 2 weeks			
genetic		.66±.08	.38±.16
phenotypic		.75	.08
environmental		.92	-.17
Weight at 4 weeks			
genetic			.19±.18
phenotypic			.05
environmental			-.05

[a] Obtained from full-sib correlations.

[b] Standard errors for genetic correlations only.

of .08, .08 and .05 respectively. Low negative environmental correlations of -.03, -.17 and -.05 were found between teat number and weights at birth, 2 weeks and 4 weeks, respectively.

Correlation coefficients between weights at three different ages and age at 100 kg live weight, adjusted loin eye area and adjusted backfat thickness and those among the last three traits are presented in Table 14. Genetic, phenotypic and environmental correlations between adjusted age at 100 kg and weight at birth were -.40±.21 and -.40 and -.40; those between adjusted age and weight at 2 weeks were -.41±.20. -.42 and -.46; and between adjusted age and weight at 4 weeks were -.55±.21, -.45 and -.35. These negative correlations ($P < .01$) indicate that larger pigs during the beginning period of growth needed less time to reach 100 kg live weight. Genetic correlations between adjusted loin eye area and weight at different ages were -.24±.20 for weight at birth and -.09±.19 and .10±.19 for weights at 2 and 4 weeks. Relatively high genetic correlation between adjusted loin eye area and age at 100 kg live weight (.34±.20) indicated that selection for larger loin eye area caused a decrease in growth rate. The phenotypic correlation of .17 between adjusted loin eye area and age at 100 kg live weight showed that older pigs had larger loin eye area than younger ones when compared at the same body weight. All genetic, phenotypic and environmental correlations between adjusted backfat thickness and weights at birth, 2 and 4 weeks shown in Table 14 were relatively low. A positive genetic correlation between adjusted backfat thickness and adjusted age at 100 kg of .34±.20 was contradictory to the results in this study, since pigs in the select line grew more slowly than those in the control line. Moreover, a positive genetic correlation between adjusted backfat thickness and adjusted loin eye area of .27±.21 was a surprise. These phenomena may be caused by the random errors.

TABLE 14. GENETIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS BETWEEN WEIGHT AT DIFFERENT AGES AND TEAT NUMBER AND ADJUSTED AGE, LEA AND BF, AMONG ADJUSTED AGE, LEA AND BF[a,b]

Item	Adj. age	Adj. LEA	Adj. BF
Weight at birth			
genetic	-.40±.21	-.24±.20	-.13±.19
phenotypic	-.40	-.06	-.07
environmental	-.40	.11	.002
Weight at 2 weeks			
genetic	-.41±.20	-.09±.20	.09±.18
phenotypic	-.42	-.03	-.03
environmental	-.46	.05	-.24
Weight at 4 weeks			
genetic	-.55±.21	.10±.19	.09±.18
phenotypic	-.45	.03	-.04
environmental	-.35	-.06	-.23
Adjusted age at 100 kg live weight			
genetic		.34±.20	.34±.20
phenotypic		.17	-.07
environmental		.05	-.46
Adjusted loin eye area			
genetic			.27±.20
phenotypic			-.03
environmental			-.29

LEA = loin eye area; BF = backfat thickness

[a] Obtained from full-sib correlations.

[b] Standard errors for genetic correlations only.

Stress Susceptibility in Pigs Selected for Muscling

Using the CPK test to detect stress proneness has several advantages over using halothane gas, but one real disadvantage is that the CPK test requires that the pigs be physically stressed, which can kill susceptible pigs (Wheat et al., 1977). One select-line gilt died after she had been stressed and before a blood sample was taken. Average CPK score for three of her full sisters was 70.3. One of the sisters later died from ulcers, just prior to farrowing. In the select line, 69% of the pigs scored below 30; 28% between 31 and 80; and 3% above 80. In the control line, 88% scored below 30; 12% between 31 and 80; and none higher than 80. Average CPK scores for boars and gilts within the two lines are shown in Table 15.

TABLE 15. AVERAGE CREATINE PHOSPHOKINASE (CPK) SCORES FOR SERUM OF DUROC SWINE GROUPED BY LINE AND SEX WITHIN LINE[a,b]

Select		Control	
24 boars	37.33	17 boars	28.94
34 gilts	24.94	35 gilts	14.00
58 total	30.07	52 total	18.88

[a] Scores of less than 30 = stress resistance; 30 to 80 = possible stress susceptibility; more than 80 = stress prone.

[b] The line difference was highly significant.

CHAPTER V

EFFECT OF SELECTION ON CARCASS YIELD AND MEASUREMENT TRAITS

Loin Eye Area, Backfat Thickness and Carcass Length

Estimates of fixed effects. The results of least-squares analyses of variance in Table 16 show that generation effects were significant ($P < .01$) for loin eye area, backfat thickness and carcass length. Line effects were also highly significant for all three traits. Line differences were highly significant for most traits both in overall and generation comparisons except in generation 1 in which only the difference for loin eye area was significant ($P < .05$, Table 17). Differences in loin eye area between select and control lines increased from .71 cm^2 (2.27%) in generation 1 to 5.74 cm^2 (17.70%) in the fifth generation with an overall average of 2.74 cm^2 (8.72%). Selection reduced backfat thickness by .32 cm (9.67%) by the end of the fifth generation. Overall average reduction in backfat thickness was .27 cm (7.54%). Differences in carcass length between the two lines increased significantly ($P < .01$) from practically zero (.63%) in generation 1 to 2.11 cm (2.77%) in generation 5 with an average generation difference of .94 cm (1.23%).

In brief, after five generations of selection for maximum loin eye area and minimum backfat thickness estimated by the An/Scan, loin eye area and carcass length increased and backfat thickness decreased highly significantly. The results agreed very well with several previous selection studies (Hetzer and Miller, 1973; Bereskin and Darvey, 1976; and Dickerson *et al*., 1976).

TABLE 16. MEAN SQUARES FROM THE LEAST-SQUARES ANALYSES FOR CARCASS LOIN EYE AREA AND BACKFAT THICKNESS AND CARCASS LENGTH

Source	df	Carcass LEA	Carcass BF	Carcass Length
Generations (G)	4	2.54**	.25**	4.24**
Lines (L)	1	6.27**	.38**	4.80**
Carcass weight[a]	1	1.12*	.05*	3.08**
S / G.L	29	.23	.02	.54
D / S / G.L	56	.28*	.02*	.55
Error	49	.16	.01	.38

* $P < .05$

** $P < .01$

[a] Regression on carcass weight.

S = Sires

D = Dams

TABLE 17. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR CARCASS LOIN EYE AREA, BACKFAT THICKNESS AND CARCASS LENGTH BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
	Carcass loin eye area, cm^2			
1	32.02±1.52	31.31±.81	.17*	102.27
2	32.26±.76	30.79±.78	1.47**	104.77
3	33.72±1.08	30.82±.91	2.90**	109.41
4	36.25±.86	33.78±1.10	2.45**	107.31
5	38.17±1.08	32.43±1.22	5.74**	117.70
Overall	34.17±.59	31.43±.56	2.74**	108.72
	Carcass backfat thickness, cm			
1	3.55±.15	3.53±.09	.02	100.57
2	3.56±.08	3.82±.08	-.26**	93.19
3	3.12±.11	3.44±.10	-.32**	90.70
4	3.10±.09	3.40±.12	-.30**	91.18
5	2.99±.11	3.31±.13	-.32**	90.33
Overall	3.31±.07	3.58±.07	-.27**	92.46
	Carcass length, cm			
1	77.35±.86	77.53±.45	-.18	99.77
2	76.26±.43	74.72±.44	1.54**	102.06
3	77.54±.59	76.78±.50	.76**	100.99
4	77.59±.47	76.59±.60	1.00**	101.31
5	78.42±.59	76.31±.67	2.11**	102.77
Overall	77.18±.36	76.24±.34	.94**	101.23

$^{*}P < .05$ $^{**}P < .01$

Regression of carcass length was significant ($P < .01$), but that of loin eye area and backfat thickness were significant ($P < .05$, Table 16). The regressions of loin eye area, backfat thickness and carcass length on carcass weight were .36±.20 cm^2, .03±.02 cm and .24±.08 cm, per kg, respectively (Table 18). Estimates for loin eye area and backfat thickness were significant ($P < .05$) and that for carcass length was significant ($P < .01$). The results showed loin eye area, backfat thickness and carcass length should be adjusted for carcass weight.

Estimates of random effects. Least-squares analyses of variance in Table 16 showed that differences among sire groups within generation-line subclasses were nonsignificant for all three traits. Differences among dam groups within sires were significant ($P < .05$) for loin eye area and backfat thickness but not for carcass length, indicating real maternal effects for two of these traits.

Depth of Chine at 10th Rib, 1st and 5th Lumbar

Estimates of fixed effects. Generation effects were significant ($P < .01$) for depth of chine at the 5th lumbar but were nonsignificant for the other two chine measurement sites (Table 19). Differences between select and control lines were significant ($P < .05$) for depth of chine at 1st lumbar and at the 5th lumbar only. Differences in the three traits in each generation are shown in Table 20. Depth of chine at 10th rib of select line was higher ($P < .01$) than that of the control line only in generation 1 by .14 cm (2.72%). In generation 2 there was no difference at all. Control line barrows had more ($P < .05$) depth of chine at the 10th rib than select line pigs in the last three generations by .17 (3.09%), .12 (2.15%) and .17 (3.20%), respectively. The two lines had the same overall means for

TABLE 18. LEAST-SQUARES CONSTANT ESTIMATES OF LINEAR REGRESSION COEFFICIENTS FOR CARCASS YIELD AND MEASUREMENT TRAITS ON CARCASS WEIGHT

Trait	Regression coefficient	Standard error
Loin eye area, cm^2	.36	.20
Backfat thickness, cm	.03	.02
Carcass length, cm	.24	.08
Chine depth at 10th rib, cm	.05	.02
Chine depth at 1st lumbar, cm	.03	.02
Chine depth at 5th lumbar, cm	.04	.03
Dressing percentage	.02	.02
Ham and loin weight, kg	.31	.06
Percent ham and loin	-.02	.02
Lean cuts weight, kg	.49	.07
Percent lean cuts	-.03	.02
Primal cuts weight, kg	.67	.06
Percent primal cuts	-.02	.02
Percent high priced cuts	-.01	.01
Total fat trim weight, kg	.16	.06
Percent total fat trim	.01	.02

TABLE 19. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR CHINE DEPTH AT TENTH RIB, FIRST AND FIFTH LUMBAR

		Chine depth at		
Source	df	10th rib	1st lumbar	5th lumbar
Generations (G)	4	.09	.08	.90**
Lines (L)	1	.00	.24*	.35*
Carcass weight[a]	1	.11	.04	.11
S / G.L	29	.54	.05	.06
D / S / G.L	56	.55	.04*	.04
Error	49	.82	.03	.04

* $P < .05$

** $P < .01$

[a] Regression on carcass weight.

S = Sires

D = Dams

TABLE 20. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR CHINE DEPTH AT TENTH RIB, FIRST AND FIFTH LUMBAR BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
Chine depth at 10th rib, cm				
1	5.29±.21	5.15±.13	.14**	102.72
2	5.21±.12	5.21±.12	.00	100.00
3	5.33±.14	5.50±.13	-.17**	96.91
4	5.47±.13	5.59±.15	-.12*	97.85
5	5.15±.14	5.32±.16	-.17**	96.80
Overall	5.29±.07	5.29±.07	.00	100.00
Chine depth at 1st lumbar, cm				
1	4.29±.27	4.05±.16	.24**	105.93
2	4.58±.15	4.16±.15	.42**	110.10
3	4.57±.18	4.35±.16	.22**	105.06
4	4.12±.15	4.33±.19	-.21**	95.15
5	4.36±.18	4.42±.20	-.06	98.64
Overall	4.41±.08	4.20±.08	.21*	105.00
Chine depth at 5th lumbar, cm				
1	5.77±.25	5.58±.15	.19**	103.41
2	6.49±.15	6.49±.14	.00	100.00
3	6.30±.20	6.35±.17	-.05	99.21
4	6.83±.17	6.83±.21	.00	100.00
5	6.80±.21	6.53±.22	.27**	104.13
Overall	6.50±.14	6.24±.13	.26*	104.17

$^{*}P < .05$ $^{**}P < .01$

this trait. Select line pigs had more depth of chine at 1st lumbar than the control line during the first three generations, and all were highly significant (Table 20). The differences were .24 cm (5.93%), .42 cm (10.10%) and .22 cm (5.06%), respectively. Depth of chine at first lumbar for the select line was less ($P < .01$) than that for control line pigs by .21 cm (4.85%) in generation 4. In the fifth generation, there was a nonsignificant difference between the two lines. Overall mean depth of chine at the 1st lumbar for select line pigs was higher ($P < .05$) than that for control line pigs by .21 cm (5.00%). The difference ($P < .05$) of .26 cm (4.17%) was found for chine depth at 5th lumbar in favor of select line when compared over all generations (Table 20). Select line had more ($P < .01$) chine depth at the fifth lumbar than control line by .19 cm (3.41%) in generation 1 and by .27 cm (4.17%) in generation 5. There were nonsignificant differences between the two lines in generations 2, 3 and 4. There were no previous reports concerning chine depth with which to compare the results of this study.

Least-squares analyses of variance (Table 19) showed that regressions of chine depth at the three locations on carcass weight were nonsignificant. The regression values were $.05 \pm .02$ cm for chine depth at 10th rib, $.03 \pm .02$ cm for chine depth at 1st lumbar and $.04 \pm .03$ cm for chine depth at 5th lumbar (Table 18).

Estimates of random effects. Effects among sire groups within generation-line subclasses were nonsignificant for all three traits. Effects of dams within sire group were significant ($P < .05$) only for chine depth at 1st lumbar.

Carcass Yields

Estimates of fixed effects. Least-squares analyses of variance for carcass yield traits are presented in Table 21. Generation effects were significant ($P < .01$) for all the carcass yield traits. Differences between select and control lines were significant ($P < .01$) for ham and loin weights, percent ham and loin, lean cuts weight, percent lean cuts, primal cuts weight, percent primal cuts, total fat trim weight and percent total fat trim. Line differences were non-significant for dressing percentage and percent high-priced cuts.

Comparisons by generation shown in Table 22 indicate that dressing percentage in the select line was higher than that in control line by .89%, 1.09% and 1.10% in generations 1, 4 and 5, respectively, and these differences were significant ($P < .01$). Control line pigs had higher dressing percentage in generations 2 and 3 by .67% and .03%, but only the differences in generation 2 were significant ($P < .01$). Overall difference of dressing percentage was a nonsignificant .15% in favor of the control line. The results agreed with those reported by Hetzer and Miller (1973).

Yields of ham and loin were higher ($P < .01$) in the select line than in the control in all generations except 4 in which the .16 kg (.53%) difference was not significant. Differences in yield of ham and loin between the two lines were .83 (2.88%), .47 (1.65%), 1.34 (4.72%), 1.52 (5.33%) and .86 kg (2.99%), in generations 1, 2, 3 and 5 and all generations together, respectively. Similar results were obtained from comparisons of percent ham and loin. Highly significant differences of 1.04, .67, 1.80, 2.10 and 1.18% were found in generations 1, 2, 3 and 5, and overall generations. Only the difference of .29% in generation 4 was nonsignificant. Overall

TABLE 21. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR CARCASS YIELD TRAITS

Source	df	Dressing %	Ham and loin		Lean cuts	
			wt.	%	wt.	%
Gen. (G)	4	26.30**	50.80**	19.49**	126.14**	49.23**
Lines (L)	1	.82	124.18**	48.18**	206.84**	80.58**
Carc. wt.[a]	1	4.73	169.13**	4.59	405.68**	5.55
S/G.L	29	4.66	11.51	4.72	17.59	7.35
D/S/G.L	56	4.07**	8.00	3.12	13.70**	5.40**
Error	49	2.14	5.16	2.00	7.25	2.81

TABLE 21. (Contd.)

Source	df	Primal cuts		% high priced cuts	Total fat trim	
		wt.	%		wt.	%
Gen. (G)	4	7.77**	33.73**	6.37**	73.94**	29.09**
Lines (L)	1	20.14**	86.52**	1.92	239.12**	94.01**
Carc. wt.[a]	1	174.92**	3.49	0.79	46.49**	0.67
S/G.L	29	1.35	4.76	1.41	6.10	2.45
D/S/G.L	56	1.90**	3.40**	1.12	8.90	3.43**
Error	49	4.34	1.65	0.76	4.79	1.79

**$P < .01$

[a] Regression on carcass weight.

S = Sires

D = Dams

TABLE 22. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR CARCASS YIELDS BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
Dressing percentage				
1	73.89±1.03	73.00±.57	.89**	101.22
2	70.70±.54	71.37±.55	-.67**	99.06
3	70.99±.66	71.02±.58	-.03	99.96
4	71.91±.54	70.82±.68	1.09**	101.54
5	71.47±.66	70.37±.73	1.10**	101.56
Overall	71.48±.38	71.63±.36	-.15	99.79
Ham and loin weight, kg				
1	29.64±.70	28.81±.42	.83**	102.88
2	28.98±.40	28.51±.39	.47**	101.65
3	29.70±.48	28.36±.43	1.34**	104.72
4	30.38±.41	30.22±.50	.16	100.53
5	30.03±.48	28.51±.52	1.52**	105.03
Overall	29.63±.24	28.77±.23	.86**	102.99
Percent ham and loin				
1	40.70±.99	39.66±.60	1.04**	102.62
2	39.89±.57	39.22±.56	.67**	101.71
3	40.85±.67	39.05±.60	1.80**	104.61
4	41.81±.58	41.52±.71	.29	100.70
5	41.34±.67	39.24±.73	2.10**	105.35
Overall	40.76±.34	39.58±.32	1.18**	102.98

TABLE 22. (Contd.) LEAST-SQUARES MEANS AND STANDARD ERRORS FOR CARCASS YIELDS BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
Lean cuts weight, kg				
1	42.94±.88	42.04±.51	.90**	102.14
2	42.06±.48	41.44±.48	.62**	101.50
3	43.62±.59	42.01±.52	1.61**	103.83
4	44.31±.50	44.05±.62	.26	100.59
5	44.07±.59	42.15±.65	1.92**	104.56
Overall	43.18±.33	42.07±.32	1.11**	102.64
Percent lean cuts				
1	58.98±1.25	57.85±.73	1.13**	101.95
2	57.87±.69	56.99±.69	.88**	101.54
3	59.99±.83	57.85±.74	2.14**	103.70
4	60.97±.71	60.52±.88	.45	100.74
5	60.67±.83	57.99±.92	2.68**	104.62
Overall	59.40±.47	57.88±.45	1.52**	102.63
Primal cuts weight, kg				
1	54.46±.67	53.39±.40	1.07**	102.00
2	54.24±.38	53.31±.37	.93**	101.74
3	54.52±.47	53.63±.42	.89**	101.66
4	55.67±.41	55.24±.50	.43*	100.78
5	55.74±.48	54.21±.52	1.53**	102.82
Overall	54.84±.26	53.69±.25	1.15**	102.14

TABLE 22. (Contd.) LEAST-SQUARES MEANS AND STANDARD ERRORS FOR CARCASS YIELDS BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
		Percent primal cuts		
1	74.85±.98	73.47±.58	1.38**	101.88
2	74.61±.56	73.29±.55	1.32**	101.80
3	74.99±.68	73.86±.60	1.13**	101.53
4	76.59±.58	75.96±.72	.63**	100.83
5	76.70±.68	74.57±.75	2.13**	102.86
Overall	75.44±.37	73.86±.35	1.58**	102.14
		Percent high priced cuts		
1	68.99±.53	68.54±.31	.45**	100.66
2	68.91±.29	68.81±.29	.10	100.15
3	68.07±.37	67.47±.33	.60**	100.89
4	68.57±.31	68.60±.39	-.03	99.96
5	68.15±.37	67.66±.41	.49**	100.72
Overall	68.61±.19	68.38±.18	.23	100.34
		Total fat trim weight, kg		
1	8.79±.59	10.01±.31	-1.22**	87.81
2	9.41±.30	10.12±.30	-.71**	92.98
3	8.24±.43	9.45±.36	-1.21**	87.20
4	7.87±.35	8.85±.44	-.98**	88.93
5	7.51±.43	9.22±.49	-1.71**	81.45
Overall	8.56±.21	9.75±.19	-1.19**	87.79

TABLE 22. (Contd.) LEAST-SQUARES MEANS AND STANDARD ERRORS FOR CARCASS YIELDS BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
		Percent total fat trim		
1	12.14±.81	13.74±.43	-1.60**	88.36
2	12.92±.41	13.91±.42	-.99**	92.88
3	11.35±.59	13.01±.50	-1.66**	87.24
4	10.81±.47	12.18±.60	-1.37**	88.75
5	10.28±.59	12.64±.67	-2.36**	81.33
Overall	11.76±.29	13.40±.27	-1.64**	87.76

---

[*] $P < .05$

[**] $P < .01$

mean percent ham and loin in the select line was 102.98% of that in the control line. Reports of previous studies on these traits were not available to compare with the results obtained. However, Hetzer and Miller (1973) reported a significant increase of weight of right ham by 0.3 kg in low-fat line compared to control line.

From Table 22, yields of the lean cuts in the select line were larger ($P < .01$) than those in the control line by .90 (2.14%), .62 (1.50%), 1.61 (3.38%), 1.92 (4.56%) and 1.11 kg (2.64%) in generations 1, 2, 3 and 5, and overall generations. The difference of .26 kg (.59%) in generation 4 in favor of the select line was nonsignificant. Similar results were also found in percent of lean cuts. Select line barrows had higher ($P < .01$) percent lean cuts than those in the control line in all generations except 4 when the difference was not significant. The percentages in the select line compared to the control line followed closely those in yield of lean cuts. Highly significant increases of both yield and percent of four lean-cuts accompanied selection for larger loin eye area and thinner backfat. Hetzer and Miller (1973) and Bereskin and Darvey (1976) also reported similar results.

Selection for maximum loin eye area and minimum backfat thickness was effective in increasing primal cuts (ham, loin, picnic, Boston butt and the belly) yield and percent primal cuts. Results of comparisons by generation of these two traits in Table 22 showed significant differences ($P < .01$) between select and control lines in all generations, except generation 4 during which a smaller difference ($P < .05$) was found. The largest differences between the two lines of 1.53 kg (2.82%) for primal cuts yield and 2.13% for primal cuts percent were found in the fifth generation. Overall mean of primal cuts yield was 1.15 kg (2.14%) higher in select line barrows than in the control line. Percent of primal cuts in the select line was 1.58% higher than that in the control line.

Percent high-priced cuts (weight of ham and loin divided by weight of lean cuts) was nonsignificantly different between the select and control lines. Results in Table 22 showed that the select line was significantly ($P < .01$) superior to the control line in 3 of 5 generations, 1, 3 and 5, but nonsignificantly higher in generation 2 and nonsignificantly lower in generation 4. Overall difference between means of the two lines was .23%. Generation effects played an important role in this trait.

Significant differences ($P < .01$) in total fat trim weights between select and control line barrow carcasses were found in every generation. Yields of total fat trim in the select line were lower than those in the control line by 1.22 (12.19%), .71 (7.02%), 1.21 (12.80%), .98 (11.07%) and 1.71 kg (18.55%) in generations 1 through 5, respectively. Overall mean total fat trim in the select line was significantly ($P < .01$) lower than in the control line by 1.19 kg (12.21%). The lower trend for select line was also found in percent of total fat trim. Differences between the lines shown in Table 22 were significant ($P < .01$) in all generations. Percentages in the select line were lower than those in the control line by 11.64, 7.12, 12.76, 11.25 and 18.67% in generations 1 through 5, respectively. The overall difference was 12.24%. The results agreed very well with those reported by Hetzer and Miller (1973).

In brief, results in Tables 21 and 22 indicated that selection for maximum loin eye area and minimum backfat thickness was effective in increasing carcass meatiness and in decreasing yield of total fat trim. However, dressing percentage was not altered by the selection.

Regressions were highly significant for yields of ham and loin, four lean-cuts, primal cuts and total fat trim on carcass weight (Table 21). However, regression effects were not significant for dressing percentage, percent ham and loin, percent four lean-cuts, percent primal cuts, percent high-priced cuts and percent total fat trim on carcass weight. Regression on carcass weight effects were nonsignificant for the percentage traits because these traits had already been adjusted by carcass weight. Variations in carcass yields due to carcass weight suggested that regression on carcass weight must be included in the analyses of variance for these traits.

Estimates of random effects. Sire within generation-line effects were nonsignificant for all carcass yield traits studied (Table 21). Dam effects within sires were significant ($P < .01$) for dressing percentage, lean cuts weight, percent lean cuts, primal cuts weight, percent primal cuts and percent total fat trim.

Heritability Estimates for Carcass Yield and Measurement Traits

Heritability estimates for carcass yield and measurement traits obtained from Harvey's least-squares mixed model (1977) are listed in Table 23. The estimate of .53±.28 from the full-sib correlation for carcass loin eye area closely agreed with .49 and .47 reported by Smith and Ross (1965) and Jensen *et al.* (1967). However, this estimate was less than the .66, .79 and .70 reported by Fredeen (1953), Enfield and Whatley (1961) and Siers and Thomson (1972). Additive genetic variance in loin eye area apparently made a major contribution to the total phenotypic variance.

Heritability estimates for carcass backfat thickness of .46±.28 and .11±.49 were obtained by the full-sib and paternal half-sib correlation methods. The .46 from the full-sib correlation was close to the .48

TABLE 23. HERITABILITY AND STANDARD ERROR ESTIMATES FROM FULL-SIB AND HALF-SIB CORRELATIONS FOR CARCASS YIELD AND MEASUREMENT TRAITS

	h^2 ± S.E.	
Trait	Full-sibs	Paternal half-sibs
Carcass loin eye area	.53±.28	.........[a]
Carcass backfat thickness	.46±.28	.11±.49
Carcass length	.64±.27	.........[a]
Chine depth at 10th rib	.63±.27	.63±.54
Chine depth at 1st lumbar	.74±.26	.41±.52
Chine depth at 5th lumbar	.18±.30	.35±.52
Dressing percentage	.95±.23	.22±.50
Ham and loin weight	.65±.27	.53±.53
Percent ham and loin	.68±.27	.60±.54
Lean cuts weight	.73±.26	.38±.52
Percent lean cuts	.77±.26	.46±.53
Primal cuts weight	.52±.28	.43±.53
Percent primal cuts	.63±.27	.49±.53
Percent high priced cuts	.60±.27	.33±.52
Total fat trim weight	.43±.29	.........[a]
Percent total fat trim	.45±.28	.........[a]

[a] Negative variance components were set to zero.

reported by Hetzer and Harvey (1967) but higher than several other reports (Lush, 1936; Johansson and Korkman, 1950; Hetzer et al., 1956; Zoellner et al., 1963; Gray et al., 1968; and Berruecos et al., 1970). The .11 estimated from the paternal half-sib correlation agreed quite well with the .12 estimated by Blunn and Baker (1947).

Heritability of carcass length estimated from full-sib correlation was .64±.27. This value fit into a wide, .20 to .87, range but was higher than the .52 average reported by Arganosa et al. (1969). Higher (Dickerson, 1947) and lower (Siers and Thomson, 1972) estimates were also reported.

Heritability estimates of .63±.27 and .63±.54 were calculated for chine depth at 10th rib from full-sib and half-sib correlations. The estimates for chine depth at 1st lumbar obtained from full-sibs and half-sibs were .74±.26 and .41±.52, respectively. Heritability estimates for chine depth at 5th lumbar were .81±.30 and .35±.52 from full-sib and half-sib correlations.

Heritability estimates obtained from full-sib and half-sib correlations for dressing percentage were .95±.23 and .22±.50. These two values were quite different and outside the range of .25 to .35 as reviewed from several sources by Rice et al. (1970). Results from analysis of variance for this trait (Table 21) indicated the very high dam component and very low sire component caused heritability estimated from full-sib correlation to be much higher than that from the half-sib correlation.

High heritability values were estimated for yield of ham and loin and percent ham and loin. For yield of ham and loin, the estimates of .65±.27 and .53±.53 were obtained from full-sib and half-sib correlations. Corresponding estimates for percent ham and loin were .68±.27 and .60±.54.

The estimates were much higher than the value of .35 as reported by Siers and Thomson (1972) for percent ham and loin.

Heritability estimates for yield of lean cuts were .73±.26 and .38±.52, obtained from full-sib and half-sib correlations respectively. The corresponding estimates for percent lean cuts were .77±.26 and .46±.53. The value estimated from full-sib correlation were close to the reports from Jensen et al. (1967), (.40); Omtvedt (1968), (.62); and Arganosa et al. (1969), (.68). The values estimated from half-sib correlation fell within the .14 to .76 range reported by Craft (1958).

Heritability estimates for yield of primal cuts and percent primal cuts were .52±.28 and .63±.27 from full-sib analyses and .43±.53 and .49±.53 from half-sib analyses. The corresponding estimates for percent high-priced cuts of .60±.27 and .33±.52 were obtained from full-sib and half-sib correlations.

Heritability estimated from full-sib correlations for yield of total fat trim and percent total fat trim were .43±.29 and .45±.28. Corresponding estimates from half-sib correlation were not available due to negative variance components.

Genetic, Phenotypic and Environmental Correlations

Genetic, phenotypic and environmental correlations between carcass loin eye area and other carcass yield and measurement traits are presented in Table 24. A high negative genetic correlation of -.70±.64 was found between loin eye area and backfat thickness. This value was higher than the -.06 to -.45 range found in several reports (Hazel and Kline, 1952; Enfield and Whatley, 1961; Jensen et al., 1967; and Arganosa et al., 1969). The value

TABLE 24. GENETIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS BETWEEN CARCASS LOIN EYE AREA AND OTHER CARCASS YIELD AND MEASUREMENT TRAITS[a,b]

Trait	r_G ± S.E.	r_P	r_E
Carcass backfat thickness	-.70±.64	-.26	.18
Carcass length	-.16±.38	.02	.28
Chine depth at 10th rib	.39±.38	.08	-.34
Chine depth at 1st lumbar	.67±.30	.32	-.30
Chine depth at 5th lumbar	2.01±1.58	.34	-.44
Dressing percentage	.28±.32	.05	-.96
Ham and loin weight	.28±.34	.37	.52
Percent ham and loin	.24±.34	.37	.58
Lean cuts weight	.18±.34	.39	.79
Percent lean cuts	.16±.34	.39	.88
Primal cuts weight	.04±.43	.36	.71
Percent primal cuts	.04±.39	.35	.79
Percent high priced cuts	.32±.38	.10	-.19
Total fat trim weight	-.26±.57	-.39	-.51
Percent total fat trim	-.24±.55	-.39	-.54

[a] Obtained from full-sib correlations.

[b] Standard errors for genetic correlations only.

was also higher than the .27±.20 between adjusted loin eye area and adjusted backfat thickness to 100 kg live weight found in this study for boars and gilts. The negative phenotypic correlation of -.26 between carcass loin eye area and backfat thickness was higher than the -.15 reported by Siers (1975) and Bereskin and Darvey (1976), but was consistent with estimates reported by Whiteman and Whatley (1961). Relatively high negative correlations between carcass loin eye area and backfat thickness in this study suggested that both traits are influenced by a closely linked group of genes, but in opposite directions, despite the moderately positive (.18) environmental correlations between the traits.

A negative genetic correlation of -.16±.38 was found between loin eye area and carcass length. This value was the same as that reported by Siers and Thomson (1972). A phenotypic correlation of .02 found here was similar to the .004 reported by Kropf (1962). An environmental correlation of .28 was also found between these two traits. Positive genetic correlations between loin eye area and depth of chine at different sites ranged from .39±.38 for chine depth at 10th rib to an impossible 2.01±1.58 for chine depth at the 5th lumbar. Phenotypic correlations ranged from very low (.08) between loin eye area and chine depth at 10th rib to a moderately high .34 between loin eye area and chine depth at the 5th lumbar. Moderate negative environmental correlations were found in each paring of the traits.

Genetic correlation between loin eye area and dressing percentage was positive (.28±.32). Positive and low (.05) phenotypic and high negative (-.96) environmental correlations were found between the traits. The results showed a high degree of non-genetic effects. Positive genetic, phenotypic and environmental correlations were calculated between loin eye area and ham and loin weight and percent ham and loin. The genetic correlation of .24±.34 estimated between loin eye area and percent ham and loin was very low compared with the .75 reported by Siers and Thomson (1972). Phenotypic correlations between loin eye area and ham and loin weight, and percent ham and loin were the same (.37). Environmental correlations were high (.52 and .58) between loin eye area and weight and percent of ham and loin.

Genetic correlation between loin eye area and yield of lean cuts and percent lean cuts were practically the same with values of .18±.34 and .16±.34. Phenotypic correlations between loin eye area and the two traits were the same. Genetic correlations between loin eye area and primal cuts weight and percent primal cuts were .04±.43 and .04±.39. High and very high phenotypic and environmental correlations suggested that non-additive gene action played an important role in relationships between loin eye area and primal cuts weight and percent. Genetic correlation between loin eye area and percent high-priced cuts was .32±.38. Low phenotypic and environmental correlations (.10 and -.19 respectively) were found between the traits. Moderate negative genetic correlations existed between loin eye area and total fat trim weight, and percent total fat trim. The correlation coefficients were -.26±.57 and -.24±.55. The same phenotypic correlation (-.39) was found between loin eye area and weight and percent total fat trim. Estimates of environmental correlations were also similar (-.51 and -.54).

Genetic, phenotypic and environmental correlations between backfat thickness and other carcass yield and measurement traits, except loin eye area, are presented in Table 25. The genetic correlation of -.96±.80 between carcass backfat thickness and carcass length was much higher than

TABLE 25. GENETIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS BETWEEN CARCASS BACKFAT THICKNESS AND OTHER CARCASS YIELD AND MEASUREMENT TRAITS[a,b]

Trait	$r_G \pm$ S.E.	r_P	r_E
Carcass length	-.96±.80	-.50	-.04
Chine depth at 10th rib	-.52±.50	-.16	.28
Chine depth at 1st lumbar	-.24±.46	-.35	-.36
Chine depth at 5th lumbar	-.84±1.37	-.34	-.13
Dressing percentage	-.47±.41	-.14	.96
Ham and loin weight	-1.13±.90	-.57	.13
Percent ham and loin	-1.14±.89	-.36	.19
Lean cuts weight	-1.04±.86	-.64	-.09
Percent lean cuts	-1.03±.83	-.63	-.04
Primal cuts weight	-.64±.79	-.59	-.53
Percent primal cuts	-.60±.70	-.57	-.53
Percent high priced cuts	-.65±.50	-.05	.63
Total fat trim	.88±.17	.75	.64
Percent total fat trim	.92±.16	.75	.61

[a] Obtained from full-sib correlations.

[b] Standard errors for genetic correlations only.

those found in other reports which ranged from -.19 to -.62 (Enfield and Whatley, 1961; Arganosa et al., 1969; Siers and Thomson, 1972; and Bereskin and Darvey, 1976). The phenotypic correlation of -.50 between these two traits was higher than the -.36 reported by Enfield and Whatley (1961). An environmental correlation (-.04) was found between the traits.

Genetic correlations of -.52±.50, -.24±.46 and -.84±1.37 between backfat thickness and chine depth at three different sites showed very close relationships between backfat thickness and chine depth only at the 10th rib and at the 5th lumbar. Phenotypic correlations between backfat thickness and chine depth at the 10th rib, 1st lumbar and 5th lumbar were -.16, -.35 and -.34, respectively. High environmental correlation between backfat thickness and chine depth at 1st lumbar and low correlations between backfat thickness and chine depth at the other two sites were found.

Genetic, phenotypic and environmental correlations between backfat thickness and dressing percentage were -.47±.41, -.14 and .96. The estimates showed that genes controlling these two traits were either pleiotropic or were linked, but expressed in opposite directions. No previous studies were available to compare with the estimates obtained. The unrealistic estimated genetic correlations of -1.13±.90 and -1.14±.89 between backfat thickness and weight and percent ham and loin were higher than the estimate of -.15 reported by Siers and Thomson (1972). Phenotypic correlations were -.57 and -.56 between backfat thickness and the two traits. Environmental correlations were .13 and .19. Genetic correlations of -1.04±.86 and -1.05±.83 between backfat thickness and weight and percent lean cuts were unrealistically high.

Negative phenotypic correlations of -.64 and -.63 between backfat thickness and weight and percent lean cuts were higher than the -.49

reported by Jensen et al. (1967). Negative environmental correlations of -.09 and -.04 were found between backfat thickness and the traits. Genetic correlations of -.64±.79 and -.60±.70 were calculated between backfat thickness and weight and percent primal cuts. Phenotypic correlations between backfat thickness and weight and percent primal cuts were -.59 and -.57. Environmental correlation between the two traits were both -.55. Genetic and environmental correlations of -.65±.50 and .63 between backfat thickness and percent high-priced cuts were fairly high, but the phenotypic correlation of -.05 was nonsignificant. Genetic correlations of .88±.17 and .92±.16 were calculated between backfat thickness and weight and percent of total fat trim; and the phenotypic correlation was .75 between both backfat thickness and total fat trim weight and backfat thickness and percent total fat trim. Environmental correlations between backfat thickness, and the two traits were also high (.64 and .61).

The above correlations suggested that selection for maximum loin eye area and minimum backfat thickness should improve overall carcass lean yields and reduce carcass fat yield.

CHAPTER VI

EFFECT OF SELECTION ON CARCASS QUALITY TRAITS

Ham and Loin Quality Scores

Estimates of fixed effects. Least-squares analyses of variance for ham and loin color, marbling and firmness scores are presented in Table 26. Generation effects on most traits studied were nonsignificant except for loin marbling scores in which the generation effects were significant ($P < .05$). Line differences and regressions of all traits on carcass weight were nonsignificant. Comparisons of select and control lines for ham and loin quality scores in Table 27 show a similar trend in differences in ham color, and firmness scores from generation to generation. Ham quality scores for the select line barrows had a higher trend than those for the control line though only the differences in generations 1 and 3 for ham color and firmness scores and ham marbling scores in generation 3 were significant ($P < .01$). Negative differences ($P < .01$) for only ham color and firmness existed in generation 4. Generally pigs in the select line had nonsignificantly higher ham color (darker), marbling and firmness scores than those in the control line by .10 (3.22%), .33 (2.55%) and .10 (3.37%), respectively. The results were in contrast with the reports and philosophy that selection for thinner backfat has an undesirable effect on the structure and color of muscle (Jensen et al., 1967; and Dickerson et al., 1976). However, Dickerson et al. (1976) also reported an increase of .3 in muscle color scores for the lean line.

Differences between the select and control lines for loin color, marbling and firmness scores are also presented in Table 27. The overall

TABLE 26. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR HAM AND LOIN QUALITY SCORES

		Ham			Loin		
Source	df	col.	marbl.	firm.	col.	marbl.	firm.
Gen. (G)	3	.57	16.16	.69	.21	90.77*	.39
Lines (L)	1	.02	30.81	.00	.23	2.74	.26
Carc. wt.[a]	1	.67	68.16	.32	.27	1.94	.11
S/G.L	18	.28	51.09	.25	.29	25.50	.31*
D/S/G.L	41	.29	42.72	.21	.20	19.27*	.15
Error	38	.39	35.17	.28	.19	11.24	.22

* $P < .05$

[a] Regression on carcass weight

col. = color

marbl. = marbling

firm. = firmness

S = Sires

D = Dams

TABLE 27. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR HAM AND LOIN QUALITY SCORES BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
		Ham color		
1	3.72±.24	3.03±.14	.69**	122.77
2	3.07±.13	3.05±.14	.02	100.66
3	3.55±.32	3.21±.19	.34**	110.59
4	3.16±.14	3.41±.17	-.25**	92.67
Overall	3.21±.07	3.11±.09	.10	103.22
		Ham marbling		
1	14.15±2.25	13.03±1.28	1.12	108.60
2	11.36±1.24	11.32±1.29	.04	100.35
3	16.48±3.02	13.41±1.75	3.07**	122.89
4	15.29±1.27	16.40±1.59	-1.11	93.23
Overall	13.25±.93	12.92±.82	.33	102.55
		Ham firmness		
1	3.46±.23	2.87±.14	.59**	120.56
2	3.06±.14	2.96±.14	.10	103.38
3	3.78±.33	3.19±.20	.59**	118.50
4	2.81±.15	3.04±.18	-.23**	92.43
Overall	3.07±.10	2.97±.09	.10	103.37

TABLE 27 (Contd.) LEAST-SQUARES MEANS AND STANDARD ERRORS FOR HAM AND LOIN QUALITY SCORES BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
		Loin color		
1	3.68±.23	2.97±.13	.71**	123.91
2	3.20±.12	3.31±.13	-.11	96.68
3	3.51±.41	3.52±.22	-.01	99.72
4	2.89±.15	3.12±.20	-.23**	92.63
Overall	3.18±.10	3.21±.09	-.03	99.07
		Loin marbling		
1	24.00±3.09	20.86±1.74	3.14**	115.05
2	20.96±1.67	22.86±1.76	-1.90	91.69
3	24.00±4.39	21.14±2.38	2.86*	113.53
4	18.64±1.85	22.56±2.35	-3.92**	82.62
Overall	20.77±1.05	21.88±.93	-1.11	94.93
		Loin firmness		
1	3.60±.21	3.18±.11	.42**	113.21
2	3.23±.11	3.24±.12	-.01	99.69
3	3.76±.39	3.45±.20	.31**	108.99
4	2.92±.14	3.09±.18	-.17*	94.50
Overall	3.21±.09	3.22±.08	-.01	99.69

---

[*] $P < .05$

[**] $P < .01$

difference of -.03 in loin color scores between the select and control lines was nonsignificant. However, pigs in the select line had higher loin color scores (darker) than those in the control line by .71 ($P < .01$) in generation 1 but were lower in all later generations by .11, .01 and .23 ($P < .01$), respectively. Overall mean of loin marbling scores for the select line was lower than that for the control line by 1.11 but the difference was nonsignificant. The differences in loin marbling scores between select and control lines were 3.14 ($P < .01$), -1.90, 2.86 ($P < .05$) and -3.92 ($P < .01$) in generations 1 to 4, respectively. The overall difference of -.01 in loin firmness scores between select and control lines was nonsignificant. The differences between lines (S-C) for generations 1 through 4 were .42 ($P < .01$), -.01, .31 ($P < .01$) and -.17 ($P < .05$). The results showed that selection did not adversely affect ham and loin color, marbling or firmness scores.

Regression estimates of ham and loin color, marbling and firmness scores on carcass weight are listed in Table 28. All regressions of ham and loin quality scores on carcass weight were negative and nonsignificant. There is no need to adjust these traits for differences in carcass weight. However, barrows in this study were slaughtered at approximately a constant live weight of 100 kg.

Estimates of random effects. From least-squares analyses of variance in Table 26, sire effects were significant ($P < .05$) only in loin firmness, and dam effects were significant ($P < .05$) only in loin marbling scores. Sire and dam effects were nonsignificant in the remaining ham and loin quality scores.

TABLE 28. LEAST-SQUARES CONSTANT ESTIMATES OF LINEAR REGRESSION COEFFICIENTS FOR CARCASS QUALITY TRAITS ON CARCASS WEIGHT

Trait	Regression coefficient	Standard error
Ham color	-.01	.00
Ham marbling	-.02	.04
Ham firmness	-.00	.01
Loin color	-.01	.01
Loin marbling	-.10	.07
Loin firmness	-.01	.01
Shear force, kg/cm	.01	.01
Fiber diameter LD, micron	-.02	.02
Fiber diameter ST, micron	.01	.02
Percent moisture	.01	.02
Percent ether extract	-.02	.02
Percent total cooking loss	.10	.05
Percent drip cooking loss	.02	.03
Percent volatile cooking loss	.08	.05

Warner-Bratzler Shear Force, Fiber Diameters, Percent Moisture and Percent Ether Extract

Estimates of fixed effects. Least-squares analyses of variance in Warner-Bratzler shear force values, fiber diameters and percent moisture and ether extract are presented in Table 29. Generation effects were significant ($P < .01$) for fiber diameter in *longissimus dorsi* (LD) and *semitendinosus* (ST) and significant ($P < .05$) for shear force value and percent ether extract, but nonsignificant for percent moisture. Line effects were significant ($P < .01$) for fiber diameter LD and ST, but nonsignificant for all other traits. Line differences within generation for shear force, fiber diameter LD and ST and percent moisture and ether extract are presented in Table 30. Differences between select and control lines for shear force were highly significant in generations 2 and 3 and nonsignificant in generations 1 and 4. The overall mean for shear force in the select line was nonsignificantly higher than that in the control line by .41 kg or 7.59%. This value was higher than .2 kg reported by Dickerson *et al.* (1976). Fiber diameter means for the select line were significantly ($P < .01$) higher than those of the control line in generations 1 and 3, but were nonsignificantly different in generation 2 and 4. Overall difference of 4.65 microns (9.78%) was significant ($P < .01$). Differences between the select and control lines for percent moisture and ether extract are also presented in Table 30. Percent moisture in the select line was higher than in the control line in generations 1 ($P > .05$) and 2 ($P < .01$), but lower in generations 3 ($P < .05$) and 4 ($P > .05$). The overall difference was a nonsignificant .27% in favor of the select line. Percent ether extract in the select line was higher than in the control line only in generation 3, but was lower in all other generations. Differences in generations 2, 3 and 4

TABLE 29. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR WARNER-BRATZLER SHEAR FORCE, FIBER DIAMETER LD AND ST, PERCENT MOISTURE AND ETHER EXTRACT

Source	df	Shear force	Fiber diameter		%	%
			LD	ST	moist.	E.E.
Gen. (G)	3	6.25*	260.00**	399.26**	3.28	10.38*
Lines (L)	1	4.27	56.99**	42.66**	6.31	1.78
Carc. wt.[a]	1	.31	1.66	.62	2.41	.47
S/G.L	18	1.28	3.85**	2.84	3.11	2.53
D/S/G.L	41	1.97	1.30*	2.59	3.09	2.68
Error	38	1.41	.73	1.63	2.51	2.81

* $P < .05$

** $P < .01$

[a] Regression on carcass weight

moist. = moisture

E.E. = ether extract

S = Sires

D = Dams

TABLE 30. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR WARNER-BRATZLER SHEAR FORCE, FIBER DIAMETER LD AND ST AND PERCENT MOISTURE AND ETHER EXTRACT BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
		WB shear force, kg/cm		
1	6.25±.63	6.00±.34	.25	104.17
2	5.48±.32	4.60±.35	.88**	119.13
3	7.02±.94	5.88±.51	1.14**	119.39
4	5.92±.36	5.58±.46	.34	106.09
Overall	5.81±.22	5.40±.20	.41	107.59
		Fiber diameter LD, micron		
1	61.39±3.00	55.34±1.89	6.05**	110.93
2	47.46±1.86	48.69±1.80	-1.23	97.47
3	63.92±2.52	55.66±3.85	8.26**	114.83
4	31.98±1.90	31.29±2.30	.69	102.21
Overall	50.24±3.27	44.86±3.83	5.38**	111.98
		Fiber diameter ST, micron		
1	73.06±2.55	66.38±1.41	6.68**	110.06
2	44.00±1.25	41.91±1.43	2.09*	104.99
3	66.74±4.03	62.74±2.22	4.00**	106.38
4	38.84±1.58	36.27±2.02	2.57**	107.09
Overall	52.20±4.02	47.55±4.71	4.65**	109.78

TABLE 30. (Contd.) LEAST-SQUARES MEANS AND STANDARD ERRORS FOR WARNER-BRATZLER SHEAR FORCE, FIBER DIAMETERS LD AND ST AND PERCENT MOISTURE AND ETHER EXTRACT BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
		% moisture		
1	73.40±.68	72.96±.36	.44	100.60
2	73.04±.35	71.87±.37	1.17**	101.63
3	72.21±1.16	72.92±.62	-.71*	99.03
4	71.54±.44	71.56±.57	-.02	99.97
Overall	72.59±.31	72.32±.27	.27	100.37
		% ether extract		
1	5.09±.77	5.34±.41	-.25	95.32
2	4.44±.39	5.47±.43	-1.03**	81.17
3	6.31±1.20	4.59±.64	1.72**	137.47
4	5.43±.45	6.23±.58	-.80**	87.16
Overall	4.93±.28	5.43±.25	-.50	90.79

---

* $P < .05$

** $P < .01$

were significant ($P < .01$). Overall mean percent ether extract in the select line was nonsignificantly lower than in the control line by .50%. Line differences of .27 and -.50% were higher than .1 and -.2 reported by Dickerson et al. (1976) for percent water and fat, respectively. Selection for increased loin eye area and reduced backfat increased fiber diameter significantly ($P < .01$) but did not significantly affect shear value, percent moisture or fat contents.

Effects of regressions of shear force, fiber diameter and percent moisture and ether extract on carcass weight were all nonsignificant (Table 29). That means the effect of carcass weight on these traits can be excluded from the analyses of variance without any significant loss of accuracy. The regression coefficients of shear force, fiber diameters LD and ST and percent moisture and ether extract on carcass weight were .01±.01 kg, -.02±.02 micron, .01±.02% and -.02±.02% per kg, respectively.

Estimates of random effects. Sire and dam differences revealed by least-squares analyses of variance are shown in Table 28. Sire differences were significant ($P < .01$) for fiber diameter in the LD only. Dam differences were also significant ($P < .05$) only for fiber diameter.

Percent Total Drip and Volatile Cooking Losses

Estimates of fixed effects. Least-squares analyses of variance for percent total drip and volatile cooking losses indicated generation effects were significant ($P < .01$) for all traits (Table 31). Line differences were nonsignificant for percent total cooking loss but were significant ($P < .01$) for percent drip and volatile cooking losses. Further comparisons of the select and control lines by generation are presented in Table 32. Percent total cooking loss was higher in the select line than

TABLE 31. MEAN SQUARES, FROM THE LEAST-SQUARES ANALYSES, FOR PERCENT TOTAL DRIP AND VOLATILE COOKING LOSSES

Source	df	% cooking loss		
		total	drip	volatile
Generations (G)	3	1654.73**	69.79**	1132.13**
Lines (L)	1	8.43	27.30**	70.46**
Carcass weight[a]	1	74.43*	2.21	48.37
S / G.L	18	12.04	2.93	9.27
D / S / G.L	41	22.01	3.16	22.38
Error	38	15.32	4.06	14.17

[*] $P < .05$

[**] $P < .01$

[a] Regression on carcass weight.

S = Sires

D = Dams

TABLE 32. LEAST-SQUARES MEANS AND STANDARD ERRORS FOR PERCENT TOTAL DRIP AND VOLATILE COOKING LOSSES BY LINE AND GENERATION

Gen.	Select line (S)	Control line (C)	S - C	(S/C)x100
		% total cooking loss		
1	36.55±2.10	36.15±1.12	.40	101.11
2	44.43±1.07	43.36±1.17	1.07	102.47
3	32.13±3.15	26.38±1.69	5.75**	121.80
4	26.24±1.19	26.91±1.54	-.67	97.51
Overall	36.93±2.70	36.35±2.31	.58	101.60
		% drip cooking loss		
1	8.38±.89	9.33±.48	-.95**	89.82
2	8.36±.46	9.31±.49	-.95**	89.80
3	6.00±1.53	5.47±.82	.53	109.69
4	5.64±.58	6.34±.75	-.70*	88.86
Overall	7.38±.55	8.14±.48	-.77**	90.66
		% volatile cooking loss		
1	28.48±2.13	26.78±1.14	1.70*	106.35
2	36.00±1.08	34.11±1.19	1.89**	105.54
3	26.12±3.16	20.87±1.70	5.25**	125.16
4	20.72±1.20	20.50±1.55	.22	101.07
Overall	29.59±2.22	27.91±1.90	1.68**	106.02

$^{*}P < .05$

$^{**}P < .01$

in the control line in all generations except 4. The differences between select and control lines were .41, 1.07, 5.57 and -.67% in generation 1 to 4, respectively. Only the 5.57% difference in generation 3 was significant ($P < .01$). Mean percent total cooking loss in the select line was nonsignificantly more than that in the control line by .58%. Percent drip cooking loss per generation was less ($P < .01$) in the select line than in the control line, except in generation 3 in which the difference was nonsignificant. Overall, the -.77% less drip cooking loss in the select line was significant ($P < .01$). Percent volatile cooking loss was larger in the select line than in the control line in all generations, but the difference in generation 4 was nonsignificant. The overall difference in volatile cooking loss between the two lines was 1.68% ($P < .01$). Selection for muscling decreased percent drip cooking loss and increased percent volatile cooking loss significantly ($P < .01$), but had no appreciable effect on percent total cooking loss.

Regressions of percent total drip and volatile cooking losses on carcass weight were significant ($P < .05$) for percent chop cooking loss but nonsignificant for the other two traits (Table 31). Regression coefficients listed in Table 28 showed the estimates of .10±.05%, .02±.03% and .08±.05% per kg for percent chop, drip and volatile cooking losses, respectively.

Estimates of random effects. Least-squares analyses of variance for percent total drip and volatile cooking losses (Table 31) showed there were no significant differences among sires or dams for those traits.

Heritability Estimates for Carcass Quality Traits

Heritability estimates obtained from full-sib and paternal half-sib correlations for all carcass quality traits studied are listed in Table 33. Since negative variable components were set to zero by the program,

TABLE 33. HERITABILITY ESTIMATES FROM FULL-SIB AND HALF-SIB CORRELATIONS FOR CERTAIN CARCASS QUALITY TRAITS

	h^2 ± S.E.	
Trait	Full-sibs	Paternal half-sibs
Ham color	.64±.31	.44±.59
Ham marbling	.74±.30	.32±.57
Ham firmness	.32±.33	.64±.61
Loin color	.........[a]	.........[a]
Loin marbling	.38±.33	.20±.55
Loin firmness	.........[a]	.........[a]
Shear force	.50±.32	.........[a]
Fiber diameter LD	.49±.32	.93±.64
Fiber diameter ST	.22±.33	.10±.53
Percent moisture	.03±.33	.........[a]
Percent ether extract	.36±.33	.........[a]
% total cooking loss	.49±.32	.........[a]
% drip cooking loss	.........[a]	.........[a]
% volatile cooking loss	.53±.32	.........[a]

[a] Negative variance components were set to zero.

heritability estimates for loin color, loin firmness and percent drip cooking loss were not available. Estimates for shear force value, percent moisture and ether extract, and percent chop and volatile cooking losses are available only from full-sib correlations.

Heritability estimates from full-sib and paternal half-sib correlations were .64±.31 and .44±.59 for ham color. These values are close to the .49±.23 reported by Aberle *et al*. (1971) but higher than the conclusion of Jonsson (1965), Pease and Smith (1965) and Arganosa *et al*. (1969), that muscle color is only moderately heritable. Heritability estimates of .74±.30 and .32±.57 indicate ham marbling is possibly more heritable than the .02±.20 found by Aberle *et al*. (1971). The two estimates of heritability for ham firmness were .31±.33 and .64±.61. Heritability estimates of .20±.55 for loin marbling obtained from the paternal half-sib correlation was close to the .19±.14 reported by Jensen *et al*. (1967). A higher heritability estimate of .38±.33 for loin marbling was obtained from the full-sib correlation.

Heritability estimated from full-sib correlation for shear force was .50±.32, much higher than the .04±.11 reported by Aberle *et al*. (1971). Fiber diameter LD was highly heritable with estimates of .49±.32 and .93±.64 obtained from full-sib and paternal half-sib correlations respectively. These values were higher than the .22±.33 and .10±.53 obtained from the corresponding correlations for fiber diameter ST. The full-sib correlation estimate for percent moisture was .03±.33 which is lower than the .36±.33 obtained from the same correlation for percent ether extract.

Heritability estimates from full-sib correlations for percent total and volatile cooking losses were .49±.32 and .53±.32. An appreciable amount of additive gene effects are expected to exist in these traits.

Since only a few references pertaining to meat quality were available in the literature, a comparison of the present results with previous results was not possible for most quality traits.

Genetic, Phenotypic and Environmental Correlations

Genetic, phenotypic and environmental correlations from full-sib analyses between carcass loin eye area and carcass quality traits are presented in Table 34. Genetic and environmental correlations between carcass loin eye area and loin color, loin firmness and percent drip cooking loss were not available because of the negative variance components for these traits.

Negative genetic correlations of -.16±.59 and -.28±.58 were found between carcass loin eye area and ham color and marbling along with genetic correlation of .70±.89 between carcass loin eye area and ham firmness. Low phenotypic correlations of -.10 and .04 between carcass loin eye area and ham color, marbling and firmness were found along with environmental correlations of .03 and .08 between carcass loin eye area and ham color and marbling. An environmental correlation of -.26 between carcass loin eye area and ham firmness is fairly high compared with the other correlations. Genetic correlation was .79±.94 between carcass loin eye area and loin marbling. Phenotypic correlations between carcass loin eye area and loin color, marbling and firmness were .07, -.07 and .08. A negative environmental correlation of -.50 existed between carcass loin eye area and loin marbling.

Shear force correlated with carcass loin eye area; gave values of .39±.56, .30 and .25 for genetic, phenotypic and environmental correlations, respectively. The positive genetic correlation of .39±.56 disagreed with

TABLE 34. GENETIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS BETWEEN CARCASS LOIN EYE AREA AND CERTAIN CARCASS QUALITY TRAITS[a]

Trait	r_G	r_P	r_E
Ham color	-.16±.59	-.06	.03
Ham marbling	-.28±.58	-.10	.08
Ham firmness	.70±.89	.04	-.26
Loin color	.........[b]	.07	......[b]
Loin marbling	.78±.94	-.07	-.50
Loin firmness	.........[b]	.08	......[b]
Shear force	.39±.56	.30	.25
Fiber diameter LD	.93±.73	.16	-.33
Fiber diameter ST	.97±1.10	.15	-.13
% moisture	1.04±6.03	.21	.14
% ether extract	.64±1.02	-.20	-.62
% total cooking loss	1.51±1.17	-.02	-.99
% drip cooking loss	.........[b]	-.16	.....[b]
% volatile cooking loss	.52±.65	.07	-.23

---

[a] Obtained from full-sibs correlations.

[b] Negative variance components were set to zero.

the -.28 reported by Aberle et al. (1971). Genetic correlations of .93±.73 and .97±1.10 were calculated between carcass loin eye area and fiber diameters LD and ST. Correlations of .16 and .15 between carcass loin eye area and fiber diameters LD and ST indicate a large loin eye area is accompanied by large fiber diameters. Environmental correlation of -.33 between carcass loin eye area and fiber diameter LD was higher than the -.13 found between carcass loin eye area and fiber diameter ST.

Genetic correlation of 1.04±6.03 between carcass loin eye area and percent moisture are unrealistic. However, phenotypic correlation between the two traits of .21 showed a positive trend of relationship. Environmental correlation between carcass loin eye area and percent moisture was .14. The genetic correlation between loin eye area and percent ether extract had a large standard error, .64±1.02. Negative phenotypic and environmental correlations of -.20 and -.62 were obtained between loin eye area and percent ether extract.

An unrealistic genetic correlation of 1.51±1.17 was calculated between loin eye area and percent total cooking loss. The environmental correlation between these two variables was .99. Phenotypic correlation of -.02 between loin eye area and percent total cooking loss indicates the variables were independent. A phenotypic correlation of -.16 was obtained between loin eye area and percent drip cooking loss. A genetic correlation of .52±.65 and an environmental correlation of -.23 were calculated between loin eye area and percent volatile cooking loss. The phenotypic correlation between the two traits was only .07.

Genetic, phenotypic and environmental correlations between carcass backfat thickness and carcass quality traits are presented in Table 35.

TABLE 35. GENETIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS BETWEEN CARCASS BACKFAT THICKNESS AND CERTAIN CARCASS QUALITY TRAITS[a]

Trait	r_G	r_P	r_E
Ham color	-.18±.41	.20	.79
Ham marbling	.004±.40	.16	.47
Ham firmness	.72±.55	.17	.10
Loin color	.........[b]	.08	.....[b]
Loin marbling	-.61±.57	.07	.70
Loin firmness	.........[b]	.02	.....[b]
Shear force	-.67±.63	-.19	.36
Fiber diameter LD	.20±.47	.09	-.04
Fiber diameter ST	.12±.72	-.11	-.27
% moisture	-1.31±8.07	-.002	.25
% ether extract	.14±.54	.07	.002
% total cooking loss	-.91±.65	-.08	.36
% drip cooking loss	.........[b]	.07	.....[b]
% volatile cooking loss	.57±.56	-.12	.42

---

[a] Obtained from full-sib correlations.

[b] Negative variance components were set to zero.

Again, genetic and phenotypic correlations between carcass backfat thickness and loin color and firmness and percent drip cooking loss were not available due to their negative variance components.

A genetic correlation of -.18±.41 was found between backfat thickness and ham color. Moderate phenotypic correlation (.20) and a high environmental correlation (.79) were obtained between these traits. The genetic correlation between backfat thickness and loin marbling was .004±.40 and the phenotypic and environmental correlations were .06 and .47. The genetic correlation of .72±.55 between backfat thickness and ham firmness was very high compared with the .17 and .10 phenotypic and environmental correlations. Phenotypic correlations between backfat thickness and loin color, marbling and firmness of .08, .07 and .02 were low compared with those between backfat and ham color, marbling and firmness. Genetic and environmental correlations between backfat thickness and loin marbling of -.61±.57 and .70 were very high compared with those between backfat thickness and ham marbling.

Genetic and environmental correlations between backfat thickness and shear force were -.67±.63 and .36. The phenotypic correlation of -.19 between these two traits was almost the same as -.17 reported by Aberle <u>et al</u>. (1971). Genetic correlations between backfat thickness and fiber diameter LD and ST were .20±.47 and .12±.72. Phenotypic and environmental correlations between backfat thickness and fiber diameter LD were .09 and -.04, and lower than the corresponding correlations of -.11 and -.27 between backfat thickness and fiber diameter ST.

An unrealistic genetic correlation of -.31±8.07 was obtained between backfat thickness and percent moisture, along with a very low phenotypic correlation of -.002, and a comparatively low environmental correlation of .25. The genetic correlation between backfat thickness and percent ether extract was .14±.54 and the phenotypic and environmental correlations were .07 and .002.

Genetic and environmental correlations of -.91±.65 and .86 between backfat thickness and percent total cooking loss, compared with their phenotypic correlation of -.08, were very high. The phenotypic correlation between backfat thickness and percent drip cooking loss of .07 was low. High genetic and environmental correlations of .57±.56 and .42 between backfat thickness and percent volatile cooking loss were in contrast to their low phenotypic correlation of -.12.

In summary, carcass loin eye area was positively correlated genetically with ham firmness, loin marbling, shear force, fiber diameter LD and ST, percent moisture, percent ether extract and percent total and volatile cooking losses but was negatively correlated genetically with ham color and marbling. At the same time, positive genetic correlations were found between carcass backfat thickness and ham marbling and firmness, fiber diameter LD and ST, percent ether extract and percent volatile cooking loss, while negative genetic correlations were found between carcass backfat thickness and ham color, loin marbling, shear force, percent moisture and percent total cooking loss.

CHAPTER VII

SUMMARY

Effects of Selection on Performance Traits

After five generations of selection for maximum loin eye area and minimum backfat thickness (estimated by the An/Scan and adjusted to 100 kg live weight), differences were nonsignificant between the select and control lines in litter size at birth and 4 weeks and weight at birth, 2 and 4 weeks. Generation effects were significant for litter size at birth and 4 weeks, and highly significant for weight at birth, 2 and 4 weeks. Pigs in the boar group were heavier than gilts at birth ($P < .05$), 2 weeks ($P < .01$) and 4 weeks ($P < .05$), and were heavier than those in the barrow group at 2 weeks ($P < .05$). Pigs in the barrow group were nonsignificantly heavier than gilts at all three ages.

Select line pigs had more teats ($P < .01$) than those in the control line. Gilts had more teats ($P < .01$) than boars and barrows. Teat number differences between boars and barrows were nonsignificant, but generation differences in teat number were significant ($P < .01$).

Pigs in the select line grew more slowly ($P < .01$), had larger ($P < .01$) adjusted loin eye area and thinner ($P < .01$) adjusted backfat than control line pigs. Gilts grew more slowly ($P < .01$) and had thicker ($P < .01$) adjusted backfat than boars. Adjusted loin eye area of boars was nonsignificantly larger than that of gilts. Generation differences were highly significant for age and backfat thickness adjusted to 100 kg live weight, and were significant for adjusted loin eye area.

Selection for larger loin eye area and against backfat did not change weight and litter size at birth to 4 weeks, but increased teat number and loin eye area, and decreased backfat thickness and growth rate significantly.

Heritability estimated from the paternal half-sib correlation for litter size at birth was .12±.34. Heritability estimates obtained from full-sib and paternal half-sib correlations were .57±.08 and .26±.10 for weight at birth, .69±.09 and .14±.08 for weight at 2 weeks, .61±.08 and .18±.08 for litter size at 4 weeks, and .25±.06 and .08±.07 for teat number. Heritability estimates obtained from the same correlations for age, loin eye area and backfat thickness adjusted to 100 kg live weight were .45±.10 and .16±.12, .41±.10 and .52±.18, and .51±.10 and .38±.16, respectively.

Genetic and environmental correlations obtained from full-sib correlations between weight at birth and weights at 2 and 4 weeks and teat number were .51±.11 and .58, .35±.13 and .44, and .26±.17 and -.03, respectively. Phenotypic correlations between weight at birth and at 2 and 4 weeks and teat number were .53, .39 and .08. Genetic and environmental correlations between weight at 2 weeks and at 4 weeks and teat number were .66±.08 and .92, and .38±.16 and -.17. Phenotypic correlations between weight at 2 weeks and at 4 weeks and teat number were .75 and .08. Genetic, phenotypic and environmental correlations between weight at 4 weeks and teat number were .19±.18, .05 and -.05.

Genetic, phenotypic and environmental correlations between birth weight and adjusted age, between birth weight and loin eye area and between birth weight and backfat thickness were: -.40±.21, -.40 and -.40; -.24±.20,

-.06 and .11; and -.13±.19, -.07 and .002, respectively. The corresponding correlations between weight at 2 weeks and adjusted age, weight at 2 weeks and loin eye area and weight at 2 weeks and backfat thickness were: -.41±.20, -.42 and -.46; -.09±.20, -.03 and .05; and .09±.18, -.03 and -.24. Genetic, phenotypic and environmental correlations between weight at 4 weeks and adjusted age, loin eye area and backfat thickness were: -.55±.21, -.45 and -.35; .10±.19, .03 and -.06; and .09±.18, -.04 and -.23. The corresponding correlations between adjusted age and adjusted loin eye area and backfat thickness were: .34±.20, .17 and .05; and .34±.20, -.07 and -.46. Genetic, phenotypic and environmental correlations between adjusted loin eye area and adjusted backfat thickness were .27±.20, -.03 and -.29.

Effect of Selection on Carcass Yield and Measurements

Pigs in the select line had longer ($P < .01$) carcasses, larger ($P < .01$) loin eye areas and thinner ($P < .01$) backfat than those in the control line. They also had deeper ($P < .05$) chine depths at the 1st and 5th lumbars. Generation affected ($P < .01$) loin eye area, backfat thickness, carcass length and chine depth at the 5th lumbar but nonsignificantly affected chine depths at the 10th rib and the 1st lumbar. Carcass weight affected ($P < .05$) loin eye area and backfat thickness and highly significantly affected carcass length, but had no significant effect on chine depths at the 10th rib, 1st and 5th lumbars.

Select line pigs yielded more ($P < .01$) ham and loin, lean cuts, and primal cuts and less ($P < .01$) total fat trim than the control line pigs. Dressing percentage of the select line pigs was nonsignificantly lower than that in the control line, while percent high priced cuts was nonsignificantly higher in the select line than in the control line.

Generation effects were significant ($P < .01$) for dressing percentage, weight and percentage of ham and loin, weight and percentage of lean cuts, weight and percentage of primal cuts, percent of high priced cuts and weight and percentage of total fat trim. Regressions of ham and loin weight, weight of lean cuts, weight of primal cuts, and weight of total fat trim on carcass weight were highly significant, but regressions of dressing percentage, percent ham and loin, percent lean cuts, percent primal cuts, percent high priced cuts and percent total fat trim on carcass weight were nonsignificant. Weight of carcass yields must be adjusted to carcass weight in order to reduce variations caused by carcass weight.

Heritability estimates from full-sib correlations for carcass loin eye area and carcass length were .53±.28 and .64±.27. Heritability estimated from full-sib and half-sib correlations for carcass backfat thickness were .46±.28 and .11±.49. The corresponding estimates for chine depth at the 10th rib, 1st and 5th lumbar were .63±.27 and .63±.54, .74±.26 and .41±.52, and .18±.30 and .35±.52. Heritability estimates for weight and percentage of ham and loin were .65±.27 and .68±.27 from full-sib, and .53±.53 and .60±.54 from half-sib correlations. Heritability estimates for weight and percentage of lean cuts were .73±.26 and .77±.26 from full-sib, and .38±.52 and .46±.53 from half-sib correlations, respectively. The corresponding heritability estimates for weight and percent primal cuts were .52±.28 and .63±.27, and .43±.53 and .49±.53. Heritability estimated from full-sib and half-sib correlations for percent high priced cuts were .60±.27 and .33±.52. Heritability estimates from full-sib correlations for weight and percent total fat trim were .43±.29 and .45±.28.

Carcass loin eye area was negatively correlated with carcass backfat thickness, carcass length and total fat trim, but was positively correlated with chine depth, dressing percentage, ham and loin yield, lean cuts yield and primal cuts yield. Genetic correlation coefficients ranged from -.70±.64 between loin eye area and backfat thickness to an unrealistic value of 2.01±1.58 between loin eye area and chine depth at the 5th lumbar. Genetic correlations of .04±.43 and .04±.39 between loin eye area and weight and percent primal cuts were the lowest values obtained among loin eye area and other carcass yield and measurement traits.

Carcass backfat thickness was negatively correlated with most carcass yield and measurement traits except total fat trim, when the values were positive. Genetic correlations between backfat thickness and carcass yield and measurement traits ranged from -1.14±.89 between backfat thickness and ham and loin weight to .92±.16 between backfat thickness and percent fat trim.

Effects of Selection on Carcass Quality

Selection for maximum loin eye area and minimum backfat thickness did not alter ham and loin quality significantly. The results disagreed with a report indicating that selection for thinner backfat has an undesirable effect on the structure and color of the muscles (Jensen *et al.*, 1967). Generation effects were significant ($P < .05$) only for loin marbling score. Regressions of ham and loin quality scores on carcass weight were nonsignificant.

Pigs in the select line had thicker ($P < .01$) muscle fibers than those in the control line. But the selection did not change shear value and percent moisture and ether extract significantly. Generation differences were significant for shear value and percent ether extract, and were highly significant for fiber diameter LD and ST. Regressions of shear value, fiber diameter, and percent moisture and ether extract on carcass weight were nonsignificant.

Selection significantly ($P < .01$) decreased percent drip cooking loss and increased percent volatile cooking loss, but percent total cooking loss was not altered. Generation highly significantly affected percent total drip and volatile cooking losses. Only the regression of percent total cooking loss on carcass weight was significant.

The highly significant line difference in serum creatine phosphokinase (CPK) levels (an average of 29.0 compared with 18.7 in the control line pigs) indicates greater susceptibility to stress among pigs selected for increased muscling. Exercise causes CPK levels to be proportionately higher in blood serum of stress-susceptible pigs than in stress-resistant pigs.

Heritability estimates from full-sib and half-sib correlations were .64±.31 and .44±.59 for ham color, .74±.30 and .32±.57 for ham marbling, and .32±.33 and .64±.61 for ham firmness. The corresponding estimates for loin marbling were .38±.33 and .20±.55. Heritability estimated from the full-sib correlation for shear force was .50±.32. Heritability obtained from the full-sib and half-sib correlations for fiber diameter LD and ST were .59±.32 and .93±.64, and .22±.33 and .10±.53, respectively. Heritability values from full-sib correlations were .03±.33 and .36±.33 for percent moisture and ether extract, and .49±.32 and .53±.32 for percent chop and volatile cooking losses.

Carcass loin eye area was positively correlated genetically with most carcass quality traits studied except ham color and marbling.

Phenotypic correlations between loin eye area and ham firmness, loin color and firmness, shear value, fiber diameter, percent moisture, and percent volatile cooking loss were positive, while phenotypic correlations between loin eye area and ham color and marbling, loin marbling, percent ether extract, and percent chop and drip cooking losses were negative.

Carcass backfat thickness was positively correlated genetically with ham marbling and firmness, fiber diameter, percent ether extract and percent volatile cooking loss, but was negatively correlated genetically with the other carcass quality traits studied. Phenotypic correlations between backfat thickness and ham and loin quality, fiber diameter LD, percent ether extract and percent drip cooking loss were positive, whereas phenotypic correlations between backfat thickness and shear value, fiber diameter ST, percent moisture and percent total and volatile cooking losses were negative.

LITERATURE CITED

Aberle, E. D., W. L. Singleton, S. P. Wilson and R. B. Harrington. 1971. Heritability of muscle quality in swine. J. Anim. Sci. 33:1142.

Adams, J. P., I. T. Omtvedt, J. V. Whiteman and L. E. Walters. 1972. Live and carcass measurements as indicators of lean cut yield in swine. J. Anim. Sci. 35:25.

Anonymous. February, 1963. Pork quality standards. Wisconsin Special Bulletin #9.

Arganosa, V. G., I. T. Omtvedt and L. E. Walters. 1969. Phenotypic and genetic parameters of some carcass traits in swine. J. Anim. Sci. 28:168.

Association of Official Agricultural Chemists. 1975. Official methods of analysis of the Association of Official Agricultural Chemists, 12th ed., Washington, D.C.

Bereskin, B. and R. J. Darvey. 1976. Breed, line, sex and diet effects and interactions in swine carcass traits. J. Anim. Sci. 42:43.

Bereskin, B., R. J. Darvey, W. H. Peters and H. O. Hetzer. 1975. Genetic and environmental effects and interactions in swine growth and feed utilization. J. Anim. Sci. 40:53.

Bereskin, B., H. O. Hetzer, W. H. Peters and H. W. Norton. 1974. Genetic and maternal effects on pre-weaning traits in crosses of high- and low-fat lines of swine. J. Anim. Sci. 39:1.

Bereskin, B., C. E. Shelby and D. F. Cox. 1973. Some factors affecting pig survival. J. Anim. Sci. 36:821.

Berruecos, J. M., E. U. Dillard and O. W. Robison. 1970. Selection for low backfat thickness in swine. J. Anim. Sci. 30:844.

Blunn, C. T. and M. L. Baker. 1947. The relation between average daily gain and some carcass measurements. J. Anim. Sci. 6:424.

Boylan, W. J., W. E. Rempel and R. E. Comstock. 1961. Heritability of litter size in swine. J. Anim. Sci. 20:566.

Breeden, L. 1972. PSS - What are we doing about it? Kansas District Swine Seminar 1972.

Bruns, E. and W. R. Harvey. 1976. Effects of varying selection intensity for two traits on estimation of realized genetic parameters. J. Anim. Sci. 42:291.

Christian, L. L. 1973. CPK stress syndrome detection. Mimeograph. Iowa State University, Ames, Iowa.

Cox, D. F. 1963. Breed and sex effects on the relationship between weight and fatness measured at a constant age in swine. J. Anim. Sci. 22:1091.

Craft, W. A. 1958. Fifty years of progress in swine breeding. J. Anim. Sci. 17:960.

Craig, J. V., N. W. Norton and S. W. Terril. 1956. A genetic study of weight at five ages in Hampshire swine. J. Anim. Sci. 15:242.

Dickerson, G. E. 1947. Composition of hog carcasses as influenced by heritable differences in rate of economy of gain. Iowa State College Research Bulletin 354.

Dickerson, G. E., K. L. Neer, D. R. Campion, H. S. Teague and R. W. Mandigo. 1976. Backfat vs. breeder selection in swine. J. Anim. Sci. 43:214.

Enfield, F. D. and J. A. Whatley, Jr. 1961. Heritability of carcass length, carcass backfat thickness and loin eye area in swine. J. Anim. Sci. 20:631.

Freeden, H. T. 1953. Genetic aspects of Canadian Bacon production. Department Agri. Publ. No. 889, Ottawa, Canada.

Gray, R. C., L. F. Tribble, B. N. Day and J. F. Lasley. 1968. Results of five generations of selection for low backfat thickness in swine. J. Anim. Sci. 27:331.

Hafez, E. S. E. 1968. Reproduction in farm animals. Lea and Febiger Publishing Company.

Harvey, W. R. 1972. General outline of computing procedure for six types of mixed models. Presented at NC-1 and NC-103 Annual Meeting, 1973. Oklahoma City, Oklahoma.

Hazel, L. N. and E. A. Kline. 1952. Mechanical measurement of fatness and carcass values on live hogs. J. Anim. Sci. 11:313.

Hetzer, H. O. and W. R. Harvey. 1967. Selection for high and low fatness in swine. J. Anim. Sci. 26:1244.

Hetzer, H. O. and R. H. Miller. 1970. Influence of selection for high and low fatness on reproductive performance of swine. J. Anim. Sci. 30:481.

Hetzer, H. O. and R. H. Miller. 1972. Rate of growth as influenced by selection for high and low fatness in swine. J. Anim. Sci. 35:730.

Hetzer, H. O. and R. H. Miller. 1973. Selection for high and low fatness in swine: correlated responses of various carcass traits. J. Anim. Sci. 37:1289.

Hetzer, H. O., J. H. Zeller and O. G. Hankins. 1956. Carcass yield as related to live hog probes at various weight and locations. J. Anim. Sci. 15:256.

Jensen, P., H. B. Craig and O. W. Robison. 1967. Phenotypic and genetic variations among carcass traits of swine. J. Anim. Sci. 26:1252.

Johansson, I. and N. Korkman. 1950. A study of the variation in production traits of bacon pigs. Acta Agri. Scand. 1:62.

Jones, G., E. R. Lidvall and C. B. Ramsey. 1970. Ultrasonic estimates of pork carcass cutability. J. Anim. Sci. 30:313.

Kropf, D. H. 1962. The relationship between bone and muscle characteristics in pork carcass. South Carolina Agri. Exp. Sta. Tech. Bull. 1005. April 1962.

Lush, J. L. 1936. Genetic aspects of the Danish system of progeny testing swine. Iowa State Res. Bull. 204.

Lush, J. L. and A. E. Molln. 1942. Litter size and weight as permanent characteristics of sows. U.S.D.A. Tech. Bull. 836.

Omtvedt, I. T. 1968. The pork industry: problem and progress. Some heritability characteristics and their importance in a selection program. Iowa State Press.

Ramsey, E. B., E. R. Lidvall and J. R. Conger, Jr. 1972. Estimating loin eye area in swine with a single ultrasonic measurement. J. Anim. Sci. 35:1160.

Revelle, T. J. and O. W. Robison. 1973. An explanation for the low heritability of litter size in swine. J. Anim. Sci. 37:668.

Rice, V. A., F. N. Andrews, E. J. Warwick and J. E. Legates. 1970. Breeding and improvement of farm animals. 6th ed., McGraw-Hill Book Company, New York.

Robison, O. W., J. H. Cooksey, A. B. Chapman and H. L. Self. 1960. Estimation of carcass merit of swine from live animal measurements. J. Anim. Sci. 19:1013.

Schafer, D. E. 1972. Pork quality and swine production. Kansas District Swine Seminars.

Shelby, C. E. 1952. Genetic aspects of the production registry program of the United Duroc Record Association. Ph.D. Thesis. Iowa State University, Ames, Iowa.

Siers, D. G. 1975. Live and carcass traits in individually fed Yorkshire boars, barrows and gilts. J. Anim. Sci. 41:522.

Siers, D. G. and G. M. Thomson. 1972. Heritabilities and genetic correlations of carcass and growth traits in swine. J. Anim. Sci. 35:311.

Smith, C. and G. J. S. Ross. 1965. Genetic parameters of Danish Landrace pigs. Anim. Prod. 7:291.

Stamm, G. W. 1975. Veterinary guide for farmers. Book Division, The Hearst Corp., New York, New York.

Stanislaw, C. M., I. T. Omtvedt, R. L. Willham and J. A. Whatley, Jr. 1967. A study of some genetic parameters in purebred and crossbred populations of swine. J. Anim. Sci. 26:16.

Webb, A. J. 1975. A note on the repeatability of ultrasonic backfat measurements in pigs. Anim. Prod. 20:433.

Wheat, J. D., D. H. Kropf and R. H. Hines. 1976. Comparison of feed consumption of pigs in two lines. Report of Progress 283. November 11, 1976. Agri. Exp. Sta., Kansas State University, Manhattan, Kansas.

Wheat, J. D., D. H. Kropf and R. H. Hines. 1977. Stress susceptibility in pigs selected for muscling. Report of Progress 312. November 10, 1977. Agri. Exp. Sta., Kansas State University, Manhattan, Kansas.

Zeller, J. H. and H. O. Hetzer. 1960. Selection for high and low fatness. U.S.D.A. Regional Swine Breeding Laboratory Record of Proceedings. pp. 61-62.

Zoellner, K. O., J. F. Lasley, L. F. Tribble and B. N. Day. 1963. Selection for thinner backfat in swine. Mo. Agri. Exp. Sta. Res. Bull. 831.

SELECTION FOR MUSCLING IN DUROCS

by

PONGCHAN NA-LAMPANG

B.S., Chiengmai University, 1971

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

ANIMAL SCIENCE

Department of Animal Science and Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

Pigs in the base population of purebred Durocs were farrowed in May, 1971. The select line was formed by using the 20 most desirable gilts and 4 boars based on an index with maximum loin eye area (LEA) and minimum backfat thickness (BF), estimated by the An/Scan and adjusted to 100 kg, receiving equal emphasis. Twenty gilts and 4 boars were randomly selected to form the control line. Pigs were farrowed in May and June and produced litters a year later, for a generation interval of one year. Observations on 904 pigs during 5 generations of selection, including production and carcass traits, were analyzed to evaluate the effects of selection on these traits. Genetic parameters were also calculated from the data.

Selection increased LEA and decreased BF, both from live and carcass measurements ($P < .01$). Gilts had thicker ($P < .01$) adjusted BF than boars but they did not differ significantly in LEA. Selection did not affect weight and litter size at early stages of growth but decreased ($P < .01$) growth rate in the select line in the later stage of growth. Boars were heavier at birth ($P < .05$), 2 weeks ($P < .01$) and 4 weeks ($P < .05$), and reached 100 kg earlier ($P < .01$) but had fewer ($P < .01$) teats than gilts. Pigs in the select line had more ($P < .01$) teats than those in the control line.

Selection increased carcass length ($P < .01$), chine depth ($P < .05$) at 1st and 5th lumbar locations, and yields ($P < .01$) of ham and loin, lean cuts and primal cuts, and decreased total fat trim yield ($P < .01$). Line differences in dressing percentage and percent of ham and loin weight over four lean-cuts weight were nonsignificant.

Among the carcass quality traits studied, selection increased fiber diameter of longissimus and semitendinosus muscles ($P < .01$) and percent volatile cooking loss ($P < .01$), and decreased percent drip cooking loss ($P < .01$).

Pigs in the select line were more ($P < .01$) susceptible to stress than those in the control line.

Significant regressions of carcass LEA and BF, carcass length, ham and loin weight, lean cuts weight, percent chop cooking loss and total fat trim on carcass weight indicated these carcass traits must be adjusted for variation in carcass weight. Regressions of the other carcass traits on carcass weight were nonsignificant.

Heritability estimates from full-sib and half-sib correlations for LEA were .41±.10 and .52±.18 (live), and .53±.28 (carcass, full-sib). Corresponding estimates for BF were .51±.10 and .38±.16 (live), and .46±.28 and .11±.49 (carcass). Heritability estimates for teat number were lower than those for weight at different ages and adjusted age, LEA and BF. Heritability estimates for most carcass yield and measurement traits were higher than those for production traits. Among carcass quality traits studied, heritability estimates ranged from .03±.33 for percent moisture to .74±.30 for ham marbling. In most cases, heritability estimates obtained from full-sib correlations were higher and had smaller standard errors than those obtained from half-sib correlations.

Adjusted LEA was negatively correlated genetically with weight at birth and 2 weeks but was positively correlated genetically with weight at 4 weeks and adjusted age and BF. Adjusted BF was positively correlated genetically with most traits mentioned above except weight at birth.

Phenotypic and environmental correlations among these traits were also estimated.

Carcass LEA was positively correlated genetically with most carcass yield and measurement traits except BF, carcass length and total fat trim. Carcass BF was negatively correlated genetically with most carcass yields and measurements except percent total fat trim.

Genetic correlations between carcass LEA and carcass quality traits were positive except those with ham color and marbling. Carcass BF was negatively correlated genetically with loin color, marbling and firmness, ham color, Warner-Bratzler shear force, percent moisture, percent total and drip cooking losses, and positively correlated with the other carcass quality traits.

Phenotypic and environmental correlations between carcass LEA and BF and several carcass yield, measurement and quality traits were also calculated.