THE INFLUENCE OF GENETIC FACTORS ON PORK QUALITY

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INTRODUCTION

Swine breeders have devoted considerable selection pressure to increase yield of lean meat and to reduce fatness in recent years. As a consequence, the type of hogs has been changed from lard types to the modern meat type. During this period an increased incidence of pale, soft, watery pork has been observed among well muscled swine carcasses.

The increased incidence of low pork quality is becoming a real problem to the swine industry. Many environmental factors have been identified which alter pork quality but the influence of genetic factors on quality traits has not been thoroughly investigated except for the observed differences among breeds of swine. The limited data available today seem inadequate to properly evaluate the probable extensiveness of this condition. Heritability estimates of the traits associated with pork quality and estimates of their relationships with other production and carcass traits are necessary to determine the importance of selecting for or against any quality characteristics. This study was initiated 1) to measure the phenotypic and genotypic variations of traits associated with pork quality and 2) to measure the associations among quality traits and other traits in modern pork carcass populations.

REVIEW OF LITERATURE

Definition of quality. Kauffman (1964) considered quality as the combination of traits that will provide for an edible product that loses a minimum of constituents, free of spoilage during processing, attractive and appetizing, nutritious and palatable. He considered color, firmness, texture and marbling as some of the more important predictive guides in appraising pork quality.

Briskey and Hillier (1963) differentiated quality from quantity in pork. They used quality in connection with processing, retailing and eating attributes of the muscles only. They used quantity to denote backfat thickness and muscling. They further claimed that quantity may be estimated in live animals and in the carcass, whereas, quality can only be estimated after cutting and exposing the muscles.

Kline (1962) considered quality in meats to mean the amount and distribution of marbling, color, texture and firmness of the muscle tissue. These meat characteristics contribute to the satisfaction of the consumers (Breidenstein, 1963). Bray (1963, 1964) stated that quality is related to those factors associated with the palatability of fresh and cured products. In swine he listed color, firmness and marbling as the most important factors which determine quality.

Economic importance of quality in pork. Pork muscles at the time of slaughter appear dark, firm and dry. During the first 24 hours of chilling, they vary widely in quality from an extremely pale, soft and watery appearance to one that is dark, firm and dry (Bray, 1964; Briskey, 1962; Sayre et al., 1963). Pale color, presence of abnormally large amounts of free fluid in the tissue and a soft texture are the characteristics of low pork quality (Bendall and Lawrie, 1964).

Low quality pork has been associated with excessive cooking and curing losses and has been shown to affect the palatability of both the fresh and processed products (Kauffman et al., 1961b). Peterson (1964) considered quality the most important factor which makes pork move in competition with other meats. Furthermore, pork with firm lean had lower shrinkage, lower microbial count, greater color stability and longer shelf life than soft lean (Birmingham and Naumann, 1960). Lu et al. (1958) emphasized that tenderness, flavor and the percentages of fat and lean are the fundamental factors involved in determining meat quality.

Cahill and Bruner (1962) described the desirable features of pork carcasses which include a superior quantity of muscle with a minimum of outside and seam fat; the muscle should be of a color acceptable to the consumer with adequate marbling; and the carcass should have a certain degree of firmness necessary to facilitate processing and to have an attractive display in the meat counter.

Carpenter (1961) reported that palatability ratings increased with an increase in marbling score. Based on published reports, Bray (1964) stated that marbling affected the palatability of fresh pork considerably more than cured pork; marbling of pork chops was more highly related to juciness than either tenderness or flavor; and that palatability of fresh roast pork was influenced less by marbling than pork chops.

Henry et al. (1963) studied 79 pork carcasses to evaluate the relationships between physical observations and physical and chemical analyses. In this study, the taste panel score indicated that tenderness was highly correlated with marbling and juiciness. Marbling was significantly associated with flavor and the shear value. Murphy and Carlin (1961) also reported that marbling had a significant positive effect on both tenderness and juiciness of pork chops. However, they reported that marbling did not have any effect on flavor. Harrington and Pearson (1962) reported that the two measures of marbling, visual scores and intramuscular fat content, were significantly related with tenderness. Carpenter and King (1964) reported that both marbling and backfat thickness were significantly associated with tenderness of pork chops.

Naumann et al. (1960) found that carcasses with less backfat yielded loins with less marbling, softer lean but larger loin eye area. The laboratory taste panel did not show a clear preference for pork chops of different degrees of marbling but the consumer panel heavily preferred marbled over sparsely marbled chops. They also found that firmness of the lean had little effect upon the organoleptic and sheer value of pork chops.

Cole et al. (1954) selected 59 swine carcasses from a packing plant based on five levels of firmness as measured by a penetrometer and grouped into four according to the amount of finish. They found no significant differences in cooking losses which could be attributed to differences in firmness of fat. There was no consistent preference for any roast of any one degree of finish or firmness of fat. The degree of finish or firmness had no effect on cooler shrinkage and curing losses.

Saffle (1962) concluded that neither taste nor consumer panel was able to distinguish between firm and soft loins; that marbling was more highly related to juiciness than to tenderness or flavor; that marbling accounted for only about 25 percent of the total variation in juiciness; and that consumers at the purchasing counter discounted pork which had abundant marbling. Kauffman et al. (1961a) found that a definite preference for unmarbled chops existed among the buyers studied. However, the taste panel reaction indicated a preference for marbled chops over the unmarbled ones.

Birmingham et al. (1953) conducted a study to determine consumers' preference for pork of different degrees of fatness. Loin chops, ham slices and sliced bacon divided into Groups A and B were used. Group A had an average backfat thickness of 41.5 mm. with no appreciable deficiency in firmness or color; group B had an average backfat thickness of 35 mm. but were appreciably deficient in firmness or color or both. They found that a higher percentage of the 361 households which participated preferred the group B meats before and after cooking.

Carpenter (1961) studied two weight groups of light and dark colored loins and found no significant differences in tenderness or flavor due to color but there was a significantly higher cooking loss in the light colored loins. Juiciness score for the dark colored loins were significantly higher than the scores for the light colored loins.

Breeds and breeding. No attention was given to carcass quality during the process of developing the meat type hogs. Hoges (1965) studied 1002 German Improved Landrace pigs. He gave a score of zero to five for meat quality which included meat structure, color and juiciness. The area of the longissimus dorsi muscle was less than 34 sq. cm. in 67.7 percent of the pigs scoring five and more than 34 sq. cm. in pigs scoring zero to two. Pigs with low scores had an unfavorable fat to lean ratio but with a better ham conformation than pigs with high score.

Ludvigsen (1963) found that short, fairly compact, meaty types of hogs with heavily muscled hams were more susceptible to pale, soft and watery condition than pigs with fairly long carcasses and relatively less muscled hams. Wismer-Pedersen (1964) reported that pigs with higher proportion of ham and loin in the carcass had a higher incidence of soft and pale muscle.

Whiteman et al. (1951) studied carcasses of 136 hogs to determine differences in carcass traits due to breeding. The study included inbred lines, two-line and three-line crosses and outbred Duroc; crossbreds; and an inbred line of the Landrace-Poland breeding. They noted that all the carcasses of the Landrace-Poland line were too soft to be highly desirable. Judge et al. (1959) found that certain breeds tended to produce dark, marbled and firm loin muscles at comparatively higher rates than other breeds.

Briskey (1962) stated that at least the sensitivity of the animal to conditions which develop pale, soft and watery pork are heritable. He cited the National Barrow show where about 18.3 percent of the 150 carcasses entered in the contest were extremely pale, soft and watery. Sayre et al. (1963) found that at three hours post slaughter, the longissimus dorsi muscle of the Chester White was significantly darker than the muscles of either the Hampshire or Poland and remained darker through 24 hours post mortem. The Hampshire and Poland muscles were similar in color intensity at three hours post mortem but at 24 hours, the muscles of the Poland were significantly lighter in color than those from the Hampshire.

Ludvigsen (1963) compared the Pietran breed of swine imported to Denmark with the Danish Landrace. The Pietran had shorter carcasses with higher percent lean than the Landrace. However, the average color score of the loin eye muscle at the last rib was only 1.44 for the Pietran with 80 percent of the carcasses having 0.5 to 1.5 scores indicative of watery pork. The Landrace average score for color was 2.06 with only 20 percent of the carcasses within the watery category. Otto (1963) found that the German Yorkshire meat was darker than the meat from the German Improved Landrace in two of the six muscles he studied.

Hedrick et al. (1965) reported that the loins and hams of the Duroc barrows were significantly firmer and darker in color than those from the Hampshire barrows. The incidence of pale, soft and watery muscle was greater in the Hampshire than in the Duroc. Marbling was significantly greater in the Duroc than in the Hampshire.

Jensen et al. (1967) reported significant differences among five breeds of swine they studied involving carcass traits associated with meat quality. Bray (1967) presented a rather comprehensive review on the influence of breeds of swine on the variation of pork quality and quantity factors.

The influence of sex. Many studies had been conducted to determine the influence of sex on production and carcass traits in swine but only a few had been reported on the effect of sex on pork quality. Anderson (1955) using 550 pigs mainly Landrace, Poland and crossbreds reported that the males were 8.3 pounds heavier at 154 days old, 0.2 inch shorter, had 0.2 inch more backfat, 1.2 percent more fat cuts and 1.4 percent less lean cuts than the females. Herbert and Crown (1956) reported that gilt carcasses yielded higher percentages of ham and loin, had larger loin eye areas and higher percentages of separable lean in the ham than the barrows. The thickness of lean in the ham was greater in the gilts than in the barrows. The barrows had thicker backfat than the gilts.

Self et al. (1957) studied 322 gilts and 262 barrows of unknown history. They divided these hogs into six weight groups and four carcass grades for each group. They reported no significant differences between barrows and gilts in average backfat thickness, carcass length and percent lean cut yields. The gilts had larger loin eye areas. They also reported 46.9 percent of the hams to be two-toned, 47.5 percent for the gilts and 46.2 percent for the barrows. Two-toning did not appear to be associated with weight, sex, carcass length and loin grade.

Bruner et al. (1958) studied 385 littermate gilts and barrows from about 40 pounds until they reached 210 pounds slaughter weight. They found that barrows were significantly younger at slaughter. The gilts had significantly less backfat, larger loin eye areas, longer carcasses, heavier trimmed loins and higher percentages of lean cuts.

Osinska et al. (1959) reported that gilt carcasses were longer with less backfat and had more lean meat than the barrow carcasses. Charrette (1959) likewise, reported that gilt carcasses were longer than barrow carcasses and that the gilts required more days to attain the slaughter weight. Jonsson (1962) reported that the gilts had longer carcasses and had darker colored muscle and the females had an advantage over the males in carcass traits related to lean production.

Zobrisky et al. (1961) found that gilts yielded a significantly more lean, and had a larger loin eye area than barrows. Hams from the gilts contained significantly more lean and less fat than hams from the littermate barrows.

Magee et al. (1964) used 461 Yorkshire pigs to study the interaction between the effects of sex and inbreeding on the 154-day weight. They reported that among non-inbred pigs, the difference in the 154-day weight was 17.1 pounds in favor of the barrows. This difference narrowed as the degree of inbreeding increased. The effect of inbreeding appeared to be greater for the barrows than for the gilts.

Kolaczyk and Kotik (1966) used 32 barrows and 32 gilts of the Chester White breed to determine the effect of sex on the properties of the longissimus dorsi muscle. They reported significant differences in favor of the gilts in percent moisture, percent myoglobin and lower light reflectance, meaning darker color. The barrows had higher percent fat.

In most nutrition studies, the carcasses from gilts were found to be either slightly or significantly superior to carcasses from barrows in terms of less backfat, greater length, larger loin eye areas, higher percent lean cuts and less fat cuts (Beacon, 1965; Bowland, 1962; Carpenter and King, 1964; Cahill et al., 1960; Cahilly et al., 1963; Clark et al., 1961; Crum et al., 1964; Hale and Southwell, 1966;

Kropf *et al.*, 1959; McCamphell *et al.*, 1961; Meade *et al.*, 1966; Merker *et al.*, 1958). These researchers used two or more of the traits mentioned above and their findings showed the same trend.

Heritability estimates. The data presented in Table I is an attempt to bring together available heritability estimates of production and carcass traits in swine. The heritability estimate for age at slaughter ranged from -.07 (Sviken, 1966) to 0.57 (Johansson and Korkman, 1951). The other two estimates available were both 0.45 (Nowichi, 1961; Broderick, 1961). All reports were in abstract forms and details were not available. An approximate average heritability estimate for age at slaughter would be 0.49.

The heritability estimates for probe backfat ranged from 0.09 (Dillard *et al.*, 1962) to >1.00 (Cox, 1959). One source of variation in the estimates of heritability for probe backfat may be attributed to the way in which this trait was measured in the live animals. This review included average backfat from one to six readings using either a metal ruler or a lean meter taken at different sites. The average weight of the animals ranged from 198 to 225 pounds at the time of measurements. Based on 25 reports, the approximate heritability estimate for probe backfat would be approximately 0.43.

Craft (1958) reported in his review article, heritability estimates for carcass backfat ranging from 0.12 to 0.80 with an average of 0.49. Other studies reported thereafter

TABLE I

A REVIEW OF HERITABILITY ESTIMATES OF SOME TRAITS IN SWINE

Traits	Range of estimates	Number of estimates[a]	Approximate average[b]	Reference[c]
Age at slaughter	-.07 - 0.57	4	0.49	25, 68, 104, 133
Probe backfat	0.09 - 1.00	25	0.43	39, 45, 53, 54, 64, 87, 88, 119, 131, 147
Carcass backfat	0.12 - 0.84	21	0.50	4, 16, 25, 40, 44, 47, 57, 67, 68, 78, 87, 93, 104, 116, 128, 132, 138
Carcass length	0.20 - 0.87	20	0.52	4, 25, 40, 44, 47, 48, 49, 68, 78, 87, 104, 116, 128, 133, 138
Loin eye area	0.16 - 0.79	13	0.47	40, 47, 48, 49, 57, 67, 128, 132

[a]Some authors gave more than one estimate. Every estimate was counted.

[b]Average is the simple arithmetic mean.

[c]The references are listed under the same number in the literature cited section.

were within this range except for 0.84 reported by Enfield and Whatley (1961) using the maternal half-sib correlation analysis. With the same data but using paternal half-sib and full-sib correlation analyses, the estimates for carcass backfat thickness were found to be 0.42 and 0.63, respectively. Hazel (1963) gave an average estimate for carcass backfat of 0.50 which is the average for the 21 articles included in this review.

Craft (1958) and Fredeen (1958) in their reviews reported a range of 0.40 to 0.81 for the heritability estimates of carcass length. Craft (1958) estimated 0.59 as an approximate average, but his review did not include the 0.20 reported by Locniskar (1963) or the 0.87 reported by Smith and Ross (1965). The approximate average estimate for this trait based on 19 reports would be approximately 0.52.

Craft (1958) and Hazel (1963) reported the heritability estimate for loin eye area to be approximately 0.50. Fredeen (1958) reported a range from 0.16 to 0.79. Enfield and Whatley (1961) not only reported the highest heritability estimate for loin eye area of 0.79 using the paternal half-sib correlation but also the lowest estimate of 0.10 from the same data using the maternal half-sib correlation analysis.

Part of the discrepancies between reports may be due to the way the loin eye area was measured. Earlier studies measured the area by multiplying the length by the width while later studies used the compensating polar planimeter to measure the loin eye area. Another possible source of variation is the site where the loin eye area tracings were taken. Some were measured at the last rib, while others were at the 7th rib and more recently, the measurements were being taken at the tenth rib. Judge (1964), Kline and Goll (1964) and Kropf (1962) reported significant differences in area of the longissimus dorsi muscle at different locations along the loin. The average of the heritability estimates for loin eye area included in this review is 0.47. Essentially the same value was reported by Jensen et al. (1967) and Smith and Ross (1965).

Craft (1958) reported heritability estimates ranging from 0.14 to 0.76 for lean cut yield as percent of carcass weight with an approximate average of 0.31. Anderson (1955) reported a 0.15 as an estimate of heritability for carcass lean yield. Jensen et al. (1967) and Dickerson (1947) reported 0.40 and 0.29, respectively, as heritability estimates for this trait.

Hazel (1963) emphasized the importance of color, firmness and taste in appraising quality in pork. However, he stated that no one really knows how these traits are related to meatiness or the extent to which hereditary variations can influence quality in pork. Allen et al. (1963) reported that the heritability estimates for color and firmness scores of the longissimus dorsi muscle of both Yorkshire and Duroc pigs were essentially zero. Bray (1964) cited the Danish workers who reported heritability estimates for loin color and firmness to be 0.43 for the gilts and 0.23 for the barrows. Jensen et al. (1967) reported that color, firmness and marbling scores were moderately heritable.

Pease and Smith (1965) analyzed the data from the progeny of 100 Landrace and 149 Large White sires all with four litters of four pigs each. They used color of the longissimus dorsi muscle cut at the last rib. Color score was determined by comparing the muscle color with a series of seven colored discs prepared especially for the purpose. For the Landrace, the heritability estimate for color was 0.41 for the males and 0.55 for the females. The corresponding values for the Large White were 0.34 and 0.17. They also reported that the Large White breed had darker color than the Landrace and the gilts of both breeds had darker muscle than the males.

Minkema et al. (1961) used the refraction index to determine firmness of the backfat of 3300 pigs from seven stations. A comparison of the variances between and within litters revealed that the variation in backfat firmness was largely genetic in origin. Minkema et al. (1963) reported the heritability of backfat firmness as measured by the refraction index to be 0.07 for the castrates and 0.60 for the gilts. They also reported that the genetic and total variations were greater in the female than in the males.

Duniec et al. (1961) used the data from carcasses of 352 Large White "baconers" by 44 sires to calculate the heritability estimate of chemical fat of the loin muscle and fatty tissue content of the carcass. Chemical fat was determined by a modified Gerber method and the fatty tissue content was estimated using a regression equation. They found the heritability estimate for chemical fat to be 0.50 and 0.69 for the fatty tissue. The genetic correlation between these two traits was 0.11 and their phenotypic correlation was 0.20.

Genetic correlations. Very few genetic correlations among the economically important traits in swine have been reported. The available results (Enfield and Whatley, 1961; Fredeen and Jonsson, 1958; Jensen *et al.*, 1967; Locniskar, 1963; Smith and Ross, 1965; Stanislaw *et al.*, 1967) are discussed in the Results and Discussion section of this thesis and will not be repeated in this section.

Phenotypic correlations. Many phenotypic correlation coefficients have been published concerning various production and carcass traits in swine. Correlation coefficients were presented to support the discussion of the results based on the objectives of a particular study. Many of these studies were results of feeding trials using rather limited number of animals. More often than not, simple correlations were computed without removing the variations due to the treatments imposed as planned in their experiments.

The correlation coefficients are summarized in Table II. No attempt will be made to discuss each report. The average estimate of the correlation was arrived at by getting the simple average if there was more than one estimate available.

TABLE II

A REVIEW OF PHENOTYPIC CORRELATIONS AMONG SOME TRAITS IN SWINE

Traits	Range of estimates		Number of estimates[a]	Approximate average[b]	Reference[c]
Probe backfat and:					
Carcass backfat	0.59	0.90	8	0.73	94, 106, 109, 111, 117, 124, 136
Carcass length	-.65	0.33	6	-.24	43, 106, 109, 117, 124
Loin eye area	-.58	-.08	10	-.37	43, 58, 66, 106, 109, 117, 118, 124
Carcass lean yield	-.83	-.36	13	-.64	7, 66, 106, 109, 110, 117, 118, 124 135, 144, 147
Live lean yield	-.80	-.36	9	-.61	106, 109, 110, 117, 118, 124, 136, 145
Ether extract		0.73	1	0.73	124
Total moisture	-.82		1	-.82	124
Carcass backfat and:					
Carcass length	-.66	0.32	27	-.25	6, 26, 28, 33, 43, 47, 51, 62, 79, 81, 91, 103, 106, 117, 126, 128, 129, 134, 138
Loin eye area	-.66	0.11	24	-.26	10, 28, 43, 47, 51, 58, 66, 74, 81, 106, 112, 117, 128, 129, 134, 138, 139, 141
Carcass lean yield	-.72	-.26	21	-.65	27, 43, 51, 60, 62, 110, 111, 112, 117, 118, 135, 139, 143
Live lean yield	-.72	-.26	6	-.49	106, 110, 111, 117, 118, 136
Lean cut weight	-.51	-.38	2	-.44	85, 134
Ether extract	-.06	0.72	4	0.32	7, 27, 74, 137
Total moisture	-.68	-.45	2	-.57	7, 27

TABLE II (Continued)

Carcass length and:					
Loin eye area	-.29	0.38	25	0.08	6, 10, 12, 26, 28, 47, 51, 62, 66, 74, 81, 103, 106, 112, 117, 128, 134, 138
Carcass lean yield	-.08	0.64	19	0.32	27, 28, 32, 51, 60, 62, 66, 103, 106, 109, 110, 112, 117, 135
Live lean yield	-.18	0.42	7	0.14	106, 109, 117, 134, 136, 145
Lean cut weight	0.21	0.46	3	0.35	85, 103, 134
Age at slaughter	-.51	0.37	6	-.12	12, 42, 103, 106
Loin eye area and:					
Carcass lean yield	0.25	0.78	19	0.54	27, 28, 32, 34, 51, 62, 66, 82, 106, 118, 139, 145
Live lean yield	0.53	0.71	3	0.60	106, 117, 118
Lean cut weight	0.54	0.69	2	0.61	85, 134
Ether extract	-.18	-.60	3	-.40	7, 27, 74
Total moisture	0.41	0.54	2	0.48	7, 27

[a]Some authors gave more than one estimate. Every estimate was counted.

[b]Average is the simple arithmetic mean.

[c]The references are listed under the same number in the literature cited section.

Most of these correlations will be referred to in the Results and Discussion section of this thesis.

MATERIALS AND METHODS

The animals used in this study were obtained from the experimental swine breeding herds maintained at Stillwater and Fort Reno in the Oklahoma project of the Regional Swine Breeding Laboratory. The data were collected from fall, 1964 through fall, 1966 involving 650 pigs out of 280 dams, 89 sire groups and seven lines of breeding. The breed comsition of the lines evaluated is given in Table III. Not all lines of breeding were available in all seasons because the same herds were concurrently being used for a reciprocal recurrent selection experiment. The number of sire groups, dams, and pigs by litter line of breeding used in each season are given in Appendix Tables XXIII and XXIV. Only litters with at least two test pigs and at least two litters per sire group were included in the statistical analyses of the data. All pigs were self-fed in confinement in groups of six pigs from approximately eight weeks of age until they weighed 200 pounds liveweight at weekly weighing intervals. A few pigs raised on pasture were also included to replace some pigs which were removed from the test lots for various reasons.

During the fall of 1964, the Stillwater pigs were slaughtered at the Oklahoma State University Meat Laboratory and the Fort Reno pigs were slaughtered at Harris Meat Com-

TABLE III

BREED COMPOSITION OF THE LINES OF BREEDING OF THE ANIMALS USED IN THIS STUDY

Line of breeding of: Sire	Dam	Line of litter designation[a]
Duroc	Duroc	8
Beltsville No. 1	Beltsville No. 1	9
Hampshire	Hampshire	14
Duroc	Beltsville No. 1	89
Beltsville No. 1	Duroc	98
Hampshire	Line 89 or 98	99
Poland	Beltsville No. 1	30
Poland	Line 32	30
Landrace	Beltsville No. 1	31
Landrace	Line 30	31
Landrace	Line 32	31
Line 30	Line 31	32
Line 30	Line 32	32
Line 32	Line 32	32

[a]Lines 30, 31 and 32 were grouped into one and was designated Line 33 or backcrosses in the statistical analyses.

pany, Oklahoma City. Starting in the spring of 1965, all pigs from both stations were slaughtered at Harris Meat Company. Carcass measurements were taken 48 hours after slaughter. The right loin of each carcass was brought to the University Meat Laboratory for further analyses.

The traits studied were:

Age at slaughter represented the number of days from birth to reach the slaughter weight of approximately 200 pounds.

Probe backfat was an average of six readings taken on both sides of the animal about $1\frac{1}{2}$ inches from the midline approximately over the first rib, last rib and the last lumbar vertebra using a lean meter. Probing was done as the pigs reached slaughter weight.

Carcass length was the distance from the anterior edge of the aitch bone to the forward edge of the first rib. The average length of the two sides was used in the analysis.

Carcass backfat thickness was measured approximately over the first rib, last rib and last lumbar vertebra on both sides of the carcass at the midline. The average of six readings was used.

Lean cut yield was composed of combined weights of closely trimmed hams, loins and shoulders. The lean cut weight was also analyzed as a percentage of slaughter weight and chilled carcass weight.

Loin eye area was the measurement of the cross section of the longissimus dorsi muscle at the tenth rib. The area was determined with a compensating polar planimeter from the tracings made from the individual loins.

The exposed surface of the longissimus dorsi muscle at the tenth rib was subjectively evaluated for marbling, color and firmness using the score card presented in Table IV. A committee of at least two persons scored each time and their average was used in the analysis.

A two-inch sample of each loin, including the ninth and tenth ribs, was used for firmness determinations. Three penetrometer readings (dorsal, medial and lateral) were taken on the surface of the longissimus dorsi muscle at the tenth rib. The instrument and procedures used were previously described by Pilkington (1960). These three readings and their average were used in the statistical analyses.

After taking the penetrometer readings, the longissimus dorsi muscle was separated from the chop, placed in a plastic bag and frozen. At a later period, ether extract and total moisture determinations were made following the procedures reported by the A.O.A.C. (1955).

During the last two seasons of the study, an additional one-inch chop (at the eighth rib) was taken following the two-inch section and used for tenderness evaluation. These chops were individually wrapped and frozen until all samples for the season had been accumulated. The chops were then thawed for at least twelve hours prior to cooking. They were deep-fried to an internal temperature of 160° F. in a 270° F. cooking oil. A 3/4-inch meat borer was used to take the

TABLE IV

SCORE CARD USED IN THE EVALUATION OF THE QUALITY OF THE LONGISSIMUS DORSI MUSCLE

Numerical value	Description of the score		
	Marbling	Color	Firmness
1	Devoid	Extremely pale	Very soft
2	Scantily	Pale	Soft
3	Slightly	Slightly pink	Slightly soft
4	Average	Moderately pink	Average
5	Moderately	Bright pink	Slightly firm
6	Well	Slightly dark	Firm
7	Abundant	Dark	Very firm

samples. Two to three meat cores were taken per chop depending on the size and shape of the longissimus dorsi muscle. One reading per meat core was recorded for tenderness using the Warner-Bratzler shear machine. The average value was used for the statistical analysis.

The first statistical analyses included all 650 animals analyzed separately by sex using the following statistical model:

$$Y_{ijklm} = \mu + r_i + l_{ij} + s_{ijk} + d_{ijkl} + e_{ijklm}$$

where:

Y_{ijklm} = the phenotypic observation on one of the traits from the mth pig, lth dam, kth sire, jth line and ith season

μ = mean common to each trait

r_i = the effect of the ith season and i = 1, 2,...5.

l_{ij} = the effect of the jth line in the ith season and j = 1, 2,...n; where n is the number of lines per season

s_{ijk} = the effect of kth sire in the jth line in the ith season and k = 1, 2,...p; where p is the number of sires per line within season

d_{ijkl} = the effect of the lth dam in the kth sire, in the jth line in the ith season and l = 1, 2,... q; where q is the number of dams mated to each sire

e_{ijklm} = random error unique for each pig.

From the first analysis, the means, standard deviations, coefficients of variation and correction factors were computed and tests for homogeneity of variances between barrows and gilts were conducted. Since there were no large differences in the error variances for the two sexes, the data were adjusted for sex, to a barrow equivalent basis, by either adding or subtracting the average differences between the barrows and gilts for a particular trait. The corrections are given in Appendix Table XXV.

The adjusted data were then analyzed on a within line of breeding basis. The same statistical model was used except the line was removed as a source of variation. The means, standard deviations and coefficients of variation were computed to determine the level of performance of the different lines of breeding. The variances for each line were also closely examined to determine if any line was greatly different from the others.

The magnitude of the error mean squares indicated that all lines studied were relatively uniform. The data from all seven lines were pooled and analyzed using the same model with line of breeding as a source of variation put back into the model.

Data from 210 barrow-gilt littermate pairs were also analyzed on a within sex basis. Only one pair per litter and at least two litters per sire were included in this analysis. The same statistical model was used except dam was removed as a source of variation.

All models were constructed with the assumption that no interaction existed among the effects and that all errors were normally and independently distributed about a mean of zero and a common variance σ^2.

The analysis of variance for a nested classification with unequal number of subclasses (Snedecor, 1956) was used. Each line of breeding and each sire was considered as being different each season. The analysis of variance and the expected mean squares are given in Tables V and VI.

TABLE V

ANALYSIS OF VARIANCE FOR THE BARROW-GILT PAIRS[a]

Source of variation	Degrees of freedom	Mean squares	Expected mean squares
Between seasons	R - 1	MS_R	
Between lines within seasons	L - R	MS_L	
Between sires within lines	S - L	MS_S	$\sigma_W^2 + k_1\sigma_S^2$
Between pigs within sires	W - S	MS_W	σ^2_W

[a]R = number of seasons
L = number of lines, each line considered as being different each season
S = number of sire groups used
W = total number of observations
k_1 = average number of observations per sire group

TABLE VI

ANALYSIS OF VARIANCE FOR A SINGLE VARIABLE[a]

Source of variation	Degrees of freedom	Mean squares	Expected mean squares
Between seasons	R - 1	MS_R	
Between lines within seasons	L - R	MS_L	
Between sires within lines	S - L	MS_S	$\sigma_W^2 + k_2\sigma_D^2 + k_3\sigma_S^2$
Between dams within sires	D - S	MS_D	$\sigma_W^2 + k_1\sigma_D^2$
Between pigs within dams	W - D	MS_W	σ_W^2

[a]R = number of seasons
L = number of lines, each line considered as being different each season
S = number of sire groups used
D = number of dams used
W = total number of observations
k_1, k_2, k_3 are values that approximate the average number of observations in each subgroup.

From Table V, the sire component of variance was computed using the following equation:

$$\sigma_s^2 = \frac{MS_S - MS_W}{k_1}$$

where:

σ_S^2 = between sire component of variance,

MS_S = mean squares between sire in line and in season,

MS_W = error mean squares, and

k_1 = average number of pigs per sire.

Heritability estimate for each trait was computed within sex by the following equation (Becker, 1964):

$$h^2 = \frac{4\ \sigma_S^2}{\sigma_S^2 + \sigma_W^2}$$

where:

h^2 = heritability estimate

σ_S^2 = between sire component of variance which is assumed to contain $\frac{1}{4}$ of the additive genetic variance

σ_W^2 = error mean square

From Table VI, the sire component of variance was calculated by first computing the dam component of variance (σ_D^2) using the equation:

$$\sigma_D^2 = \frac{MS_D - MS_W}{k_1}$$

where:

σ_D^2 = between dam within sire component of variance

MS_D = mean squares between dams within sire

MS_W = error mean square

k_1 = average number of pigs per dam within sire.

then:

$$\sigma_S^2 = \frac{MS_S - (MS_W + k_2\sigma_D^2)}{k_3}$$

where:

σ_S^2 = between sire component of variance

MS_S = mean squares between sires in lines

MS_W = error mean squares

σ_D^2 = between dam component of variance

k_3 = average number of pigs per sire in lines, and

k_2 = average number of pigs per dam within sire.

Heritability estimate for each trait was computed by the following equation (Becker, 1964):

$$h^2 = \frac{4\ \sigma_S^2}{\sigma_S^2 + \sigma_D^2 + \sigma_W^2}$$

where:

h^2 = heritability estimate

σ_S^2 = between sire component of variance assumed to contain only $\frac{1}{4}$ of the additive genetic variance

σ_D^2 = between dam within sire component of variance

σ_W^2 = error mean squares

The standard error of each heritability estimate was obtained by the method described by Robertson (1959):

$$\text{S.E. of } h^2 = \left(h^2 + \frac{4}{n}\right)\sqrt{\frac{2}{N}}$$

where:

h^2 = heritability estimate

n = average number of pigs per sire group (k_3), and

N = number of sire groups used in computing the estimate.

Phenotypic and genetic correlations between any two traits were calculated. To obtain the components of covariance between two traits, a and b, the mean cross products were estimated from the analysis of variance of the sums of traits a and b using the expected mean squares as given in

TABLE VII

ANALYSIS OF VARIANCE FOR THE SUMS OF TWO VARIABLES a AND b[a]

Source of variation	Degrees of freedom	Mean square	Expected mean squares
Between seasons	$R - 1$	MS_R	
Between lines within seasons	$L - R$	MS_L	
Between sires within lines	$S - L$	MS_S	$\sigma^2_{W(a+b)} + k_2\sigma^2_{D(a+b)} + k_3\sigma^2_{S(a+b)}$
Between dams within sires	$D - S$	MS_D	$\sigma^2_{W(a+b)} + k_2\sigma^2_{D(a+b)}$
Between pigs within dams	$W - D$	MS_W	$\sigma^2_{W(a+b)}$

[a]R = number of seasons
L = number of lines, each line considered as being different each season
S = number of sire groups used
D = number of dams used
W = total number of observations
k_1, k_2, k_3 are values that approximate the average number of observations in each subgroup

Table VII.

Since $\sigma^2_{(a+b)} = \sigma^2_a + \sigma^2_b + 2\sigma_{ab}$, σ_{ab} was obtained by rearranging the equation into:

$$\sigma_{ab} = \frac{\sigma^2_{(a+b)} - \sigma^2_a - \sigma^2_b}{2}$$

where:

σ_{ab} = covariance of traits a and b

$\sigma^2_{(a+b)}$ = variance of trait a plus trait b

σ^2_a = variance of trait a, and

σ^2_b = variance of trait b.

The above outline was used in calculating the components of covariance of two traits between pigs in dam ($\sigma_{W_{ab}}$), between dams in sire ($\sigma_{D_{ab}}$), and between sires in lines ($\sigma_{S_{ab}}$).

The phenotypic correlation coefficient (r_P) between two traits was calculated by the following equation:

$$r_P = \frac{\sigma_{W_{ab}} + \sigma_{D_{ab}} + \sigma_{S_{ab}}}{\sqrt{\left(\sigma^2_{W_a} + \sigma^2_{D_a} + \sigma^2_{S_a}\right)\left(\sigma^2_{W_b} + \sigma^2_{D_b} + \sigma^2_{S_b}\right)}}$$

where:

r_P = phenotypic correlation coefficient

$\sigma^2_{W_a}$, $\sigma^2_{W_b}$, $\sigma_{W_{ab}}$ = variance and covariance of traits a and b between pigs within dam,

$\sigma^2_{D_a}$, $\sigma^2_{D_b}$, $\sigma_{D_{ab}}$ = variances and covariance of traits a and b between dams within sire, and

$\sigma^2_{S_a}$, $\sigma^2_{S_b}$, $\sigma_{S_{ab}}$ = variances and covariance of traits a and b between sires within lines.

Genetic correlation coefficient (r_G) between any two traits was calculated from between sire components of variance and covariance by the following equation:

$$r_G = \frac{\sigma_{S_{ab}}}{\sqrt{\sigma^2_{S_a} \cdot \sigma^2_{S_b}}}$$

The standard error of each genetic correlation was calculated using the equation given by Reeve (1955):

$$\text{S.E. of } r_G = \frac{1 - r_G^2}{\sqrt{2}} \sqrt{\frac{\text{S.E. } h_a^2 \cdot \text{S.E. } h_b^2}{h_a^2 \cdot h_b^2}}$$

where:

r_G^2 = genetic correlation coefficient square,

S.E. of h_a^2 = standard error of heritability estimate of trait a

S.E. of h_b^2 = standard error of heritability estimate of trait b,

h_a^2 = heritability estimate of trait a, and

h_b^2 = heritability estimate of trait b.

RESULTS AND DISCUSSION

The means, standard deviations and coefficients of variation for each line of breeding are presented in Appendix Table XXVI. This table was included merely to indicate the level of performance of the different lines of breeding and to show that all lines studied were comparatively uniform as indicated by the magnitude of their standard deviations. The means were unadjusted for season but the standard deviations were computed from the error mean square.

The Hampshire pigs appeared to have an advantage over all other lines in measures of meatiness except for carcass length and carcass backfat. However, the Hampshire and line 33 pigs had the least desirable, although acceptable, carcasses regarding quality characteristics as measured by marbling, color and firmness scores and ether extract. The crossbred pigs appeared somewhat intermediate in all carcass quality traits except for color score where they registered the darkest colored loins.

The Duroc pigs had the least desirable measures of carcass meatiness. They had the most backfat, smallest loin eye areas, and lowest yield of lean cuts. However, they appeared to have the advantages over all other lines in measures of carcass quality characteristics except for color score.

These observations tend to support earlier reports by Ludvigsen (1963), Wismer-Pedersen (1964) and Hedrick *et al.* (1965) who concluded that meatier types of hogs tended to produce lower pork quality.

The Influence of Sex

The means, standard deviations and coefficients of variation for each sex are presented in Table VIII. The means were unadjusted but the standard deviations were computed from the error mean squares of the analyses of variance. No statistical analysis was conducted to determine the level of significance of the differences between sexes.

Production and carcass quantity traits. The barrows were younger at slaughter than were gilts. This result agrees with most published reports (Broderick, 1961; Bruner *et al.*, 1958; Omtvedt *et al.*, 1965, 1967).

The barrows had 0.12 inch thicker probe backfat and 0.11 inch more carcass backfat than the gilts. These results were in general agreement with many workers who reported similar findings (Beacom, 1965; Carpenter and King, 1964; McCamphell *et al.*, 1961; Omtvedt *et al.*, 1965, 1967; Reddy *et al.*, 1959).

The carcass length of the gilts was 0.5 inch longer than the barrows. Published reports showed a similar pattern (Fredeen *et al.*, 1964; Beacom, 1965; McCamphell *et al.*, 1961; Omtvedt *et al.*, 1965, 1967).

The average loin eye area of the gilts was 0.64 square

TABLE VIII

MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION FOR THE TRAITS STUDIED

Trait	MALES				FEMALES			
	No.	Mean	Standard deviation[a]	Coefficient of variation	No.	Mean	Standard deviation[a]	Coefficient of variation
				Percent				Percent
Age at slaughter, days	375	147.7	8.91	6.03	275	160.4	8.12	5.06
Probe backfat, in.	279	1.40	0.13	9.35	275	1.28	0.12	9.62
Carcass backfat, in.	375	1.37	0.12	8.76	275	1.26	0.15	12.26
Carcass length, in.	375	29.6	0.55	1.87	275	30.1	0.50	1.68
Loin eye area, sq. in.	375	4.02	0.40	9.90	275	4.66	0.33	7.09
Lean cut weight, lb.	375	76.0	2.46	3.24	275	80.3	2.56	3.19
Liveweight lean yield, %	375	37.0	1.13	3.06	275	39.3	1.30	3.29
Carcass lean yield, %	375	52.5	1.36	2.58	275	55.6	1.70	3.06
Marbling score	375	3.8	1.07	28.19	275	3.3	1.16	35.03
Ether extract, %	286	5.12	1.76	34.54	239	3.94	1.56	39.59
Color score	375	3.9	0.92	23.47	275	3.9	0.55	14.19
Firmness score	375	4.4	0.91	20.57	275	3.9	1.30	33.32
Dorsal penetrometer reading, mm.	286	4.05	0.95	23.39	239	4.81	1.28	26.67
Medial penetrometer reading, mm.	286	4.47	0.87	19.50	239	5.26	1.17	22.33
Lateral penetrometer reading, mm.	286	3.73	0.85	22.74	239	4.26	1.10	25.82
Average penetrometer reading, mm.	286	4.08	0.81	19.76	239	4.77	1.10	23.03
Total moisture, %	269	70.7	1.49	2.11	224	71.2	1.49	2.10
Shear value, lb.	180	11.9	1.94	16.27	178	12.4	1.29	10.37

[a]Computed from the error mean squares of the analysis of variance.

inch larger than the barrows. Most workers agree that gilts have larger loin eye areas than barrows but the magnitude of the difference differs from one report to another (Bruner et al., 1958; Judge, 1964; Omtvedt et al., 1965, 1967; Meade et al., 1966; Zobrisky et al., 1961).

The gilts yielded 4.3 pounds or 5.66 percent more lean cuts than did the barrows. Expressing the yield as percentages of slaughter weight and chilled carcass weight, the gilts had 2.3 and 3.1 percent, respectively, higher yield than the barrows. Studies conducted to compare lean yield and carcass characteristics of barrows and gilts are numerous. Omtvedt et al. (1965) found gilts to have a 3.0 percent higher yield of lean cuts on a carcass weight basis than barrows. Anderson (1955), Bruner et al. (1958), Carpenter and King (1964), Herbert and Crown (1956), McCamphell and Baird (1965), Osinska et al. (1959) and Zobrisky et al. (1961) all showed that gilts were leaner than barrows.

The results of the present study along with previous findings by other researchers present strong evidence that barrows reach slaughter weight at an earlier age than gilts. However, gilt carcasses are longer and meatier as measured by less backfat, larger loin eye area, and higher yield of lean cuts than barrows.

Carcass quality traits. The longissimus dorsi muscles of barrows were more abundantly marbled than those of gilts. Similar results were reported by Omtvedt et al. (1965) using the same scoring system. Crum et al. (1964), Clark et al.

(1961), Judge et al. (1959) and Lidvall et al. (1964) also noted more marbling in the longissimus dorsi muscle of barrows than of gilts.

There was no difference in color score of the longissimus dorsi muscle found between barrows and gilts. Similar results were earlier reported by Omtvedt et al. (1965) and Judge et al. (1959). Foreign investigators found that the loins from gilt carcasses were darker than the loins from barrows (Jonsson, 1962; Kolaczyk and Kotik, 1966; Otto, 1963; Pease and Smith, 1965). The differences in the results obtained by American workers and by the investigators from other countries may be attributed to the ways color of the muscle were determined. Local workers used the highly subjective scoring system while Pease and Smith (1965) used colored discs for comparison and Kolaczyk and Kotik (1966) used a color reflectance method in determining color.

Using the score card, the loins from the barrow carcasses were 11.36 percent firmer than the loins from the gilt carcasses. This difference was also detected using the penetrometer reading which showed that the loins from the barrows were 16.91 percent firmer on the average than the loins from the gilts. The dorsal penetrometer reading showed as much as 18.77 percent advantage of the barrows over the gilts in the firmness of the longissimus dorsi muscle. Judge et al. (1959), using only three categories of firmness, observed no difference in firmness of the longissimus dorsi muscle due to sex. Bradley *et al*. (1966) working on beef, found that steers had slightly firmer longissimus dorsi muscles than the heifers. They used four firmness classes.

The gilts had 1.18 percent less ether extract and 0.5 percent more total moisture than the barrows. Kolaczyk and Kotik (1966) reported that the barrows had significantly higher percent fat and lower total moisture than the gilts using the longissimus dorsi muscle for the analysis.

The loins from the gilts required 4.20 percent more force to cut a 3/4-inch meat core than the loins from the barrows indicating the longissimus dorsi muscle from the barrows was more tender than those from the gilts as measured by the Warner-Bratzler shear machine. Bradley *et al*. (1966) found no difference in tenderness of the longissimus dorsi muscle between steers and heifers using a taste panel.

While all measures of carcass meatiness favored the gilts, all measures of carcass quality favored the barrows except in color where both sexes had the same ratings. These results are in general agreement with most published reports.

Heritability Estimates

Three heritability estimates for each trait were calculated by the paternal half-sib correlation analysis. Using the data from 210 barrow-gilt littermates, heritability estimates within sex were computed and presented in Table IX. The estimates of the sire variance and the error mean squares for each of the barrows and the gilts are given in the Appen-

TABLE IX

HERITABILITY ESTIMATES FOR ALL TRAITS STUDIED BASED ON BARROW-GILT LITTERMATE ONLY

Trait	MALES			FEMALES		
	Degrees of freedom for sire	Heritability estimate	Standard error[a]	Degrees of freedom for sire	Heritability estimate	Standard error[a]
Age at slaughter	51	0.26	.26	51	0.15	.24
Probe backfat	43	0.88	.40	51	0.17	.24
Carcass backfat	51	0.34	.27	51	0.51	.30
Carcass length	51	0.46	.30	51	1.51	.48
Loin eye area	51	-.09	.20	51	0.63	.33
Lean cut weight	51	0.89	.37	51	0.61	.32
Liveweight lean yield	51	0.79	.35	51	0.34	.27
Carcass lean yield	51	0.56	.31	51	0.67	.33
Marbling score	51	0.34	.27	51	0.83	.36
Ether extract	46	0.15	.25	46	0.64	.34
Color score	51	0.17	.24	51	0.45	.29
Firmness score	51	0.47	.30	51	0.33	.27
Dorsal penetrometer reading	46	0.34	.28	46	-.09	.20
Medial penetrometer reading	46	0.63	.34	46	0.64	.34
Lateral penetrometer reading	46	0.52	.32	46	0.61	.33
Average penetrometer reading	46	0.57	.33	46	0.41	.30
Total moisture	43	0.39	.30	43	0.62	.34
Shear value	35	1.08	.47	35	0.23	.28

[a]Standard error (Robertson, 1959).

dix Table XXVII. Heritability estimates using the sex corrected data from 650 animals are given in Table X. The estimates of the sire and dam components of variance and error mean squares are presented in the Appendix Table XXVIII.

Age at slaughter. The estimates of heritability for age at slaughter were low with large standard errors suggesting that this trait is not highly heritable. In an abstract by Sviken (1966), a heritability estimate of -.07 for age at slaughter was reported, but no detail regarding the data was available. Other reports of heritability estimate for age ranged from 0.45 (Broderick, 1961 and Nowicki, 1961) to 0.57 (Johansson and Korkman, 1951).

Probe backfat. The barrows had a higher heritability estimate for probe backfat than gilts but the standard error was larger. The sex corrected heritability estimate for probe backfat was 0.62 compared to the 0.55 and 0.47 reported by Stanislaw *et al*. (1967) for the purebreds and crossbreds, respectively. Zoellner *et al*. (1963) and Cox (1959) reported heritability estimates of 0.83 and 1.00, respectively. The estimate of 0.17 found for the gilts was lower than most estimates reported but similar to 0.16 and 0.18 reported by Reddy *et al*. (1959) for the spring and fall born pigs, respectively.

No estimates are available where analyses were done on a within sex basis. The genetic variance was higher and the error variance was lower for the barrows than the gilts resulting in the higher heritability estimate for the barrows.

TABLE X

COMBINED HERITABILITY ESTIMATES USING DATA ADJUSTED TO A BARROW EQUIVALENT BASIS

Trait	Degree of freedom for sire	Heritability estimate	Standard error[a]
Age at slaughter	72	0.11	0.10
Probe backfat	69	0.62	0.19
Carcass backfat	72	0.53	0.16
Carcass length	72	0.96	0.23
Loin eye area	72	0.47	0.15
Lean cut weight	72	0.68	0.18
Liveweight lean yield	72	0.62	0.18
Carcass lean yield	72	0.64	0.18
Marbling score	72	0.28	0.12
Ether extract	55	0.42	0.16
Color score	72	0.10	0.10
Firmness score	72	0.30	0.13
Dorsal penetrometer reading	55	0.12	0.11
Medial penetrometer reading	55	0.36	0.15
Lateral penetrometer reading	55	0.27	0.13
Average penetrometer reading	55	0.30	0.14
Total moisture	51	0.52	0.18
Shear value	36	0.33	0.18

[a]Standard error (Robertson, 1959).

This may partly be explained by the fact that these estimates were taken from 210 gilts out of 63 sire groups compared with only 181 barrows out of 53 sire groups. The small number of pigs and sires used resulted in large standard errors of the heritability estimate. The higher error variance for the gilts may also be attributed to the fact the gilts were more temperamental than the barrows (Jonsson, 1967) which might have caused considerable error in determining probe backfat.

Carcass backfat. Gilts had higher heritability estimates for carcass backfat than barrows. The average heritability estimate of 0.50 obtained from the review of 21 previous studies was similar to the 0.53 found in this study for the sex corrected estimate. Craft (1958) reported 0.59 as an approximate average heritability estimate for this trait.

Carcass length. The heritable portions of the total variance in carcass length were estimated to be 0.46, 1.51 and 0.96 for the barrows, gilts and sex corrected data, respectively. Both the genetic and phenotypic variation were much higher in the gilts than in the barrows. The heritability estimates for the gilts and for the sex corrected data in this study were probably overestimates. A review of published estimates for carcass length ranged from 0.20 (Locniskar, 1963) to 0.87 (Smith and Ross, 1965), the average of 20 estimates being only 0.52.

Loin eye area. The heritability estimates for loin eye area were -.09 for the barrows and 0.63 for the gilts. Both the genetic and phenotypic variances were higher in the gilts than were in the barrows. These results indicated that selection for loin eye area through the females may bring about greater improvement in loin eye area. Direct comparison of these estimates with others are not available since most of the heritability estimates have been computed on a between sex basis.

The sex corrected heritability estimate for loin eye area was 0.47, the same as the average of 13 estimates available in published literature. Jensen et al. (1967) found 0.47 and Smith and Ross (1965), 0.49 as heritability estimates for loin eye area. Craft (1958) reported an approximate average heritability estimate of 0.48 for this trait.

Lean cut weight. The heritability estimates for lean cut weight were 0.89 for the barrows and 0.61 for the gilts. The barrows had greater genetic variance but the phenotypic variance was somewhat smaller than those found in the gilts. Larger proportion of the variance between gilts must be getting into the within sire variance taken into consideration that there were equal numbers of barrows and gilts per sire group. Larger barrow variance was found in between sire variance, thus increasing the ratio of the genetic variance to the total variance for the barrows.

A heritability estimate of 0.68 was obtained from the sex corrected analysis for lean cut weight. This estimate and the small standard error indicate that this was a highly heritable trait.

Liveweight lean yield. The heritability estimates for percent lean of liveweight were 0.79 for the barrows and 0.34 for the gilts. These estimates were much lower than those found in total lean weight estimates but the trend was the same for both traits. The heritability estimate from the combined sex analysis for percent lean of liveweight was 0.62, slightly lower than the value for total lean weight. Likewise, this value and the standard error associated with the estimate indicate that percent lean of liveweight was also a highly heritable trait.

Adjusting the yield of lean cuts to a percent lean of liveweight basis not only lowered the estimates of heritability but the observed genetic and phenotypic variations were also considerably decreased for the barrows, gilts and for the combined sex. Analyzing the data on a percentage basis removed some variation due to differences in slaughter weight. However, since the slaughter weight of the animals in this study had a very narrow range, the adjustments apparently did not change the ratio between the genetic and phenotypic variances in the combined sex analysis.

Carcass lean yield. The heritability estimates for yield of lean cuts as a percent of chilled carcass weight were 0.56 for the barrows and 0.67 for the gilts. Adjusting the yield of lean cuts to percent lean of carcass weight basis slightly improved the heritability estimate for the gilts but considerably lowered the estimate for the barrows for this trait.

The sex corrected heritability estimate for percent lean of carcass weight was 0.64. This value was within the range reviewed by Craft (1958) who reported an approximate average of 0.31 and considered this to be probably low. Jensen et al. (1967) found 0.40 as heritability estimate for percent carcass lean yield.

Marbling score and ether extract. These two traits appeared to be moderate to highly heritable. Ether extract had a lower genetic variation than marbling score for both barrows and gilts. The heritable portion of the total variation in marbling score for the sex corrected data was 0.28. This value is in agreement with the estimates of 0.29 reported by Smith and Ross (1965) and 0.19 reported by Jensen et al. (1967). The heritability estimate for ether extract of 0.42 was considerably lower than the 0.78 and 1.00 reported by Allen et al. (1966) for the Yorkshire and Duroc breeds, respectively. Duniec et al. (1961) found heritability estimate of 0.50 for chemical fat which was closer to the 0.42 found in this study.

Color score. The genetic variation for color score was much higher in the gilts than in the barrows. Pease and Smith (1965) found similar results for Landrace but not for Large White carcasses. The heritability estimates for the barrows, gilts and sex corrected data indicated that color score was not a heritable trait. Allen et al. (1966) found essentially zero heritability estimate for color. Jensen et al. (1967) found heritability estimate of 0.28 ± 0.15 for color score.

Firmness. Firmness score appeared to be moderate to highly heritable as shown by the heritability estimates of 0.47 for the barrows and 0.33 for the gilts. The sex corrected heritability estimate was 0.30 for firmness score. Firmness of the longissimus dorsi muscle as measured by the penetrometer readings appeared to be low to highly heritable. The rather low estimates for the dorsal readings were attributed to the relatively large error variances for the barrows, gilts and sex corrected data compared with the other readings. The estimates from the medial and average penetrometer readings indicated that firmness of the longissimus dorsi muscle was moderately heritable which confirmed the estimates found in firmness score. Jensen et al. (1967) found 0.21 as heritability estimate for firmness score.

Total moisture. The heritability estimates for total moisture were 0.39 for the barrows and 0.61 for the gilts. The sex corrected estimate of 0.52 for the total moisture was considerably lower than the 0.81 reported by Jensen et al. (1967). Allen et al. (1966) reported heritability estimates of 1.00 for the Duroc and 0.70 for the Yorkshire.

Shear value. The heritable portions of the total variation in shear value were 1.08 for the barrows and only 0.23 for the gilts. The sex corrected estimate for shear value was 0.33 which was close to the 0.25 reported by Jensen et al. (1967). There is no explanation for the 1.08 heritability estimate found in the barrows but is likely due to chance.

Genetic Correlations

The genetic correlation coefficients are presented in Tables XI through XVI and the corresponding genetic variances and covariances used in calculating the genetic correlations are presented in Appendix Table XXIX.

Age at slaughter. Age at slaughter had a low genetic relationship (-.20) with probe backfat but was genetically related with carcass backfat (-.60). Age at slaughter had highly significant correlations with carcass length, ether extract and total moisture. These results indicate that selection for older animals at slaughter would increase carcass length and total moisture but would decrease carcass backfat and ether extract.

Age at slaughter was not significantly correlated with marbling and color scores, loin eye area or measures of lean yield. A highly significant correlation was obtained between age at slaughter and lateral penetrometer reading but not with the other three penetrometer readings or firmness score.

Age at slaughter had a negative sire variance (for 358 observations) which prevented the estimation of genetic correlation with shear value.

The genetic correlations of age at slaughter with some carcass traits have been presented but not too much emphasis should be placed on them. No estimates are available in the literature which can be used for comparison. The results were very inconsistent. Age at slaughter having significant genetic correlation with carcass backfat and almost zero

TABLE XI

GENETIC CORRELATION COEFFICIENTS OF AGE AT SLAUGHTER WITH SOME CARCASS TRAITS

	Genetic Correlation	Standard Error[a]
Probe backfat	-.20	0.48
Carcass backfat	-.60	0.23
Carcass length	0.97	0.02
Loin eye area	-.45	0.30
Lean cut weight	0.45	0.27
Liveweight lean yield	-.17	0.34
Carcass lean yield	0.27	0.24
Marbling score	-.14	0.43
Ether extract	-.84	0.14
Color score	-.36	0.57
Firmness score	0.10	0.43
Dorsal penetrometer reading	0.40	0.61
Medial penetrometer reading	0.50	0.37
Lateral penetrometer reading	1.03	0.04
Average penetrometer reading	0.56	0.35
Total moisture	0.84	0.14
Shear value	Negative sire variance	

[a]Standard error (Reeve, 1955).

correlation with probe backfat could not be explained. The very high and positive genetic correlation of age at slaughter with carcass length was probably an overestimate. Age did not show any appreciable genetic relationships with firmness score, dorsal, medial and average penetrometer readings, yet a highly significant genetic correlation of 1.03 was obtained between age and the lateral penetrometer reading. The inconsistent results found may be partly attributed to the fact that the sire variance component for age at slaughter was less than three percent of the total variation compared with over 35 percent for the dam variance component.

<u>Probe and carcass backfat</u>. A positive genetic correlation of 0.83 was found between probe and carcass backfat (Table XII). This was expected since both traits were used to estimate the same parameter.

Probe and carcass backfat had highly significantly negative genetic correlations with carcass length. The results were intermediate between the -.47 reported by Fredeen and Jonsson (1958) and the -.72 found by Locniskar (1963) between carcass backfat and carcass length.

Probe and carcass backfat had very low genetic correlations with loin eye area which were in general agreement with the findings of Enfield and Whatley (1961) and Jensen <u>et</u> <u>al</u>. (1967).

Probe and carcass backfat measurements had essentially the same magnitude of genetic correlations with the three measures of lean yield. Both backfat measurements had highly significant correlations with percent lean of carcass weight and lean cut weight, but slightly lower correlations were obtained between the backfat measurements and the percent lean of slaughter weight. The genetic and total variations of percent lean of slaughter weight were lower than those for either lean cut weight or percent lean of carcass weight. Jensen <u>et</u> <u>al</u>. (1967) found a genetic correlation of -.81 between carcass backfat and percent lean cuts. The highly negative genetic correlations between the two measures of backfat thickness and the three measures of yield of lean cuts indicate that some genes with opposite effects influ-

TABLE XII

GENETIC CORRELATION COEFFICIENTS OF PROBE AND CARCASS BACKFAT THICKNESS WITH SOME CARCASS TRAITS

	Probe backfat		Carcass backfat	
	Correlation	SE[a]	Correlation	SE[a]
Carcass backfat	0.83	0.06		
Carcass length	-.53	0.14	-.62	0.12
Loin eye area	-.24	0.21	-.22	0.21
Lean cut weight	-.58	0.14	-.60	0.13
Liveweight lean yield	-.50	0.16	-.44	0.17
Carcass lean yield	-.58	0.14	-.58	0.14
Marbling score	-.48	0.19	-.56	0.18
Ether extract	-.14	0.26	-.18	0.26
Color score	-.08	0.31	-.05	0.39
Firmness score	-.08	0.24	-.16	0.25
Dorsal penetrometer reading	-.32	0.34	-.18	0.40
Medial penetrometer reading	-.37	0.23	-.27	0.26
Lateral penetrometer reading	-.40	0.25	-.14	0.30
Average penetrometer reading	-.37	0.24	-.20	0.28
Total moisture	0.04	0.28	0.33	0.24
Shear value	-.53	0.21	-.17	0.31

[a]Standard error (Reeve, 1955).

ence backfat thickness and yield of lean cut.

Probe and carcass backfat measurements had high genetic correlations with marbling score but essentially zero genetic correlations with color and firmness scores. These results were not in agreement with the findings of Jensen et al. (1967) who reported genetic correlations of 0.84 between carcass backfat and firmness score and almost significant correlation between carcass backfat and color score. The differences may be partly attributed to the differences in scoring systems used. Further study on this subject is needed before drawing any conclusion.

Probe backfat had moderate genetic correlations with the four penetrometer readings but the magnitude of the standard errors suggests these correlations were not significant. Carcass backfat had much lower correlations with the penetrometer readings than was with the probe backfat. Carcass backfat correlations with the penetrometer readings were obtained from 525 observations while the probe backfat, from only 430 observations. These results further indicate that carcass backfat thickness and firmness were not genetically related.

Both measures of backfat thickness had very low genetic correlations with ether extract and total moisture. These results are in general agreement with the findings of Jensen et al. (1967).

Both measures of backfat thickness had negative genetic correlations with carcass length, marbling score, shear value and the three measures of yield of lean cuts. Probe backfat showed higher genetic relationships with some traits than carcass backfat but there was no consistent pattern observed. Selection for less backfat thickness may bring about some changes in carcass length, yield of lean cuts and marbling score without apparent effects on color and firmness of the longissimus dorsi muscle.

Carcass length. Carcass length had a significant genetic correlation of -.51 with loin eye area (Table XIII). Enfield and Whatley (1961) and Smith and Ross (1965) also found negative genetic correlations between these two traits but the magnitude of their correlations was somewhat lower than what was found in this study. This high negative genetic correlation was attributed to a rather high genetic variation in carcass length (24 percent of the total variation) and relatively small genetic variation in loin eye area (12 percent of the total variation). Error variance, when expressed as a percentage of the total variance, was essentially the same for both traits. The dam variance for loin eye area was about twice as much as for carcass length. These differences in the variance distribution must have resulted in a high negative covariance between these two traits and hence, the high negative correlation.

Carcass length was not genetically correlated with any of the three measures of yield of lean cuts; the highest correlation being 0.30 with percent lean of carcass weight. The three measures of yield of lean cuts had similar genetic

TABLE XIII

GENETIC CORRELATION COEFFICIENTS OF CARCASS LENGTH AND LOIN EYE AREA WITH SOME CARCASS TRAITS

	Carcass length		Loin eye area	
	Correlation	SE[a]	Correlation	SE[a]
Loin eye area	-.51	0.14		
Lean cut weight	0.05	0.18	0.78	0.08
Liveweight lean yield	0.02	0.18	0.92	0.03
Carcass lean yield	0.30	0.16	0.77	0.09
Marbling score	0.41	0.19	-.01	0.27
Ether extract	0.10	0.23	0.37	0.23
Color score	0.45	0.27	-.73	0.19
Firmness score	0.47	0.17	-.39	0.22
Dorsal penetrometer reading	-.23	0.34	0.44	0.33
Medial penetrometer reading	-.05	0.24	0.60	0.18
Lateral penetrometer reading	-.02	0.26	0.62	0.19
Average penetrometer reading	-.08	0.25	0.55	0.20
Total moisture	-.06	0.23	-.14	0.28
Shear value	0.28	0.27	0.41	0.28

[a]Standard error (Reeve, 1955).

variation. However, percent lean of carcass weight had a much smaller dam variance which might have resulted in a slightly higher genetic covariation and eventually higher genetic correlation with carcass length than either percent lean of liveweight or lean cut weight.

Carcass length had a high genetic correlation with marbling score suggesting that the genes which determine carcass length also have some effect on marbling score.

The high genetic correlation between carcass length and firmness score and the very low correlation between carcass length and the penetrometer readings could not be explained. The correlation between carcass length and firmness score was obtained from 650 observations while the correlations between length and penetrometer reading were based on only 525 observations. This inconsistency suggests that further study is needed to determine the magnitude of the genetic relationships of carcass length with firmness.

Carcass length did not show any appreciable genetic relationships with ether extract, total moisture or shear value. No estimates are available in the literature for comparison with the present results. Carcass length was negatively correlated with loin eye area and positively correlated with marbling and firmness scores. Therefore, based on these data, it can be concluded that selection for longer animals may be expected to decrease the size but increase the quality attributes of the longissimus dorsi muscle.

Loin eye area. Loin eye area showed highly significant genetic correlations with all three measures of yield of lean cuts (Table XIII). Jensen et al. (1967) found a significant genetic correlation of 0.47 between loin eye area and percent lean cuts. The genetic correlations between loin eye area and the three measures of meatiness found in this study should be carefully interpreted. The possibility of chance correlation this high cannot be totally excluded. The genetic variance of the traits involved were also rather high. These results indicate that the genes responsible for larger loin eye area also contribute to high yield of lean cuts.

Loin eye area was not genetically related to marbling score. This result could be expected since the phenotypic correlations showed that loin eye area was not closely related to backfat thickness measurements, but marbling was, and loin eye area was closely related with yield of lean cuts while marbling was not. The genetic correlation of -.01 found between loin eye area and marbling score in this study was somewhat intermediate between the -.82 reported by Jensen et al. (1967) and the 0.48 found by Smith and Ross (1965). The latter workers used fat distribution interpreted here to be marbling.

The significant genetic correlation between loin eye area and color score indicates that both traits have some genes in common with antagonistic effects. Selection for larger loin eye area would result in lighter color of the longissimus dorsi muscle.

Loin eye area was not correlated with the dorsal penetrometer reading but was significantly correlated with the other penetrometer readings. These differences may be attributed to the larger error variance associated with the dorsal reading compared with the other readings. The magnitude of the correlations and standard errors indicate that real genetic relationships exist between loin eye area and firmness as measured by the medial and lateral penetrometer readings. However, the genetic relationship of loin eye area and firmness score only approached significance. Jensen et al. (1967) found that loin eye area was not genetically related with either color or firmness score.

The genetic relationship between loin eye area and either ether extract or total moisture was low. Jensen et al. (1967) reported a significant correlation between loin eye area and ether extract but found no relationship between loin eye area and total moisture. No other reports are available in the literature which can be used for comparison.

Loin eye area was moderately associated with shear value but the large standard error associated with the estimate indicates that no real genetic relationship exists between these two traits.

These results indicate that loin eye area had a highly significant genetic relationship with yield of lean cuts and color score. There were some observable genetic relationships between loin eye area and the medial and lateral penetrometer readings but lower genetic relationship existed between loin eye area and firmness score. Because of conflicting results found in this study and those from North Carolina (Jensen et al., 1967), further study is needed to determine the genetic relationship of loin eye area to the quality attributes of the meat.

Lean cut yield. The genetic correlations between any two of the three measures of yield of lean cuts were essentially 1.00 (Table XIV). This was expected since this is merely one variable expressed in three different ways. However, the three measures of meatiness did not have the same magnitude of genetic relationships with pork quality attributes.

Marbling score did not have any appreciable genetic correlations with either lean cut weight or percent lean of liveweight but showed a significant correlation with percent lean of carcass weight. Color score had a highly significant genetic correlation with lean cut weight but had lower genetic relationships with either percent lean of liveweight or carcass weight. Firmness score had high genetic correlations with either lean cut weight or percent lean of liveweight but showed very small genetic relationship with percent lean of carcass weight. Adjusting the lean cut weight to percent lean of carcass weight improved the genetic relationship with marbling score but considerably lowered its relationship with color and firmness scores. Adjusting the lean cut weight to percent lean of liveweight did not change the magnitude of its genetic relationship with quality traits. Jensen et al. (1967) reported genetic correlations close to zero

TABLE XIV

GENETIC CORRELATION COEFFICIENTS OF YIELD OF LEAN CUTS WITH SOME CARCASS TRAITS

	Lean cut Weight		Liveweight Lean yield		Carcass Lean yield	
	Correlation	SE[a]	Correlation	SE[a]	Correlation	SE[a]
Liveweight lean yield	1.00	0.00				
Carcass lean yield	1.04	0.02	0.99	0.00		
Marbling score	0.13	0.24	0.18	0.24	0.48	0.19
Ether extract	0.18	0.22	0.29	0.22	0.36	0.21
Color score	-.79	0.14	-.63	0.22	-.54	0.26
Firmness score	-.54	0.17	-.48	0.19	-.11	0.24
Dorsal penetrometer reading	0.38	0.30	0.42	0.30	0.14	0.37
Medial penetrometer reading	0.60	0.16	0.56	0.17	0.36	0.38
Lateral penetrometer reading	0.58	0.17	0.48	0.21	0.38	0.24
Average penetrometer reading	0.52	0.18	0.49	0.20	0.30	0.24
Total moisture	0.03	0.23	-.08	0.25	-.23	0.25
Shear value	0.36	0.26	0.43	0.26	0.41	0.28

[a]Standard error (Reeve, 1955).

between percent lean cuts and marbling, color and firmness scores. Differences in scoring system for quality traits may help explain the differences of the results found in this study and those by Jensen et al. (1967).

The high genetic correlation between yield of lean cuts and firmness score was verified by even higher genetic correlations of the yield of lean cuts with firmness as measured by the penetrometer. The dorsal reading had low genetic correlations with the three measures of meatiness. However, lean cut weight had genetic correlations of 0.60 and 0.58 with the medial and lateral readings, respectively. The corresponding genetic correlations for percent lean of liveweight were 0.56 and 0.48 with the medial and lateral readings, respectively. Percent lean of carcass weight had much lower genetic correlations with the penetrometer readings than either lean cut weight or percent lean of liveweight.

The discrepancies in the results may be attributed to the great differences in the distribution of the variances of the three penetrometer readings and three measures of meatiness. The genetic variations of the penetrometer readings were much lower for the dorsal than either the medial or lateral reading. About 81 percent of the total variance in the dorsal reading was associated with the error variance compared to only 74 and 71 percent for the medial and lateral readings, respectively. On the other hand, percent lean of carcass weight had a much greater error variance, 75 percent of the total variance compared to only about 70 and 65 percent for the lean cut weight and percent lean of liveweight, respectively. These differences must have resulted in lower covariances between percent lean of carcass weight and the penetrometer readings and between the dorsal reading and the three measures of meatiness.

The three measures of meatiness did not show any significant genetic correlations with ether extract, total moisture and shear value. These results were in general agreement with the findings of Jensen *et al.* (1967).

The measures of meatiness had different magnitudes of genetic relationship with carcass quality characteristics of pork. Lean cut weight appeared to have better relationships with color and firmness than either percent lean of liveweight or carcass weight. Marbling score was not related with either lean cut weight or percent lean of liveweight but was related with percent lean of carcass weight. The three measures of meatiness were not genetically related with ether extract, total moisture and shear value.

Marbling score and ether extract. Marbling score and ether extract had a genetic correlation of 0.94 (Table XV). This was expected since both variables were used to estimate the amount of fat in the muscle. Jensen *et al.* (1967) reported a genetic correlation of 1.11 between these two traits.

Color score had genetic correlations of 0.53 and 0.07 with marbling score and ether extract, respectively. The large standard errors associated with these estimates suggest

TABLE XV

GENETIC CORRELATION COEFFICIENTS OF MARBLING SCORE AND ETHER EXTRACT WITH SOME CARCASS TRAITS

	Marbling score		Ether extract	
	Correlation	SE[a]	Correlation	SE[a]
Ether extract	0.94	0.05	-	
Color score	0.53	0.34	0.07	0.42
Firmness score	0.75	0.14	0.58	0.20
Dorsal penetrometer reading	-1.47	0.72	-1.09	0.08
Medial penetrometer reading	-1.21	0.20	-.73	0.13
Lateral penetrometer reading	-1.23	0.24	-1.00	0.00
Average penetrometer reading	-1.24	0.23	-.87	0.07
Total moisture	-.71	0.18	-.97	0.01
Shear value	0.36	0.33	0.16	0.32

[a]Standard error (Reeve, 1955).

that these relationships were not significant. These estimates were in general agreement with Jensen *et al.* (1967) who reported very low genetic correlations between marbling score and color score and between ether extract and color score.

Firmness score was significantly correlated with marbling score and ether extract, and therefore suggest that marbling score, ether extract and firmness score have some genes in common. Selection for more marbling would result in an increase in ether extract as well as firmness of the longissimus dorsi muscle. Jensen *et al.* (1967) found a genetic correlation of 0.72 between marbling and color scores but noted a zero correlation between color score and ether extract.

Both marbling score and ether extract had real high genetic correlations with firmness as measured by the penetrometer. Marbling score had a genetic correlation of -1.21 with the medial reading and -1.47 with the dorsal reading. Large standard error was associated with the last estimate. Ether extract had genetic correlations of -.73 with the medial reading and -1.09 with the dorsal reading. These results further confirm the high genetic relationship found between marbling and firmness score and between ether extract and firmness score.

Marbling score had a genetic correlation of -.71 with total moisture. This is somewhat lower than the -.96 reported by Jensen *et al.* (1967). However, the small standard error associated with the estimate indicates that a high observable genetic relationship exists between these two traits.

In this study ether extract had a genetic correlation of -.97 with total moisture as compared to a -.95 reported by Jensen *et al.* (1967). Apparently no genetic relationship exists between marbling and shear value, or between ether extract and shear value. Essentially zero genetic correlations between these traits were found in this study and by Jensen *et al.* (1967).

These results indicate that marbling score and ether extract are both genetically related to firmness and total moisture of the muscle. Marbling score and ether extract failed to show any significant genetic relationships with shear value or color score.

Color score. Color score had moderate to high genetic correlations with firmness score and penetrometer readings (Table XVI). However, the large standard errors associated with these estimates indicate that no real genetic relationships exist between color score and firmness. These results seem to contradict all views about the pale, soft and watery pork condition. Jensen *et al.* (1967) found a genetic correlation of 1.30 between color and firmness scores. The seemingly favorable results found in this study may be attributed to the failure of the judges to properly distinguish color of the longissimus dorsi muscle by subjective scoring. More accurate color determination is needed to properly eval-

TABLE XVI

GENETIC CORRELATION COEFFICIENTS AMONG OTHER CARCASS TRAITS INCLUDED IN THE STUDY

	Correlation	SE[a]	Correlation	SE[a]
	Color score		Firmness score	
Firmness score	0.35	0.40		
Dorsal penetrometer reading	-.33	0.58	-1.47	0.54
Medial penetrometer reading	-.52	0.32	-1.18	0.12
Lateral penetrometer reading	-.46	0.39	-.81	0.12
Average penetrometer reading	-.42	0.38	-1.09	0.06
Total moisture	-.24	0.54	-.60	0.18
Shear value	0.00	0.63	0.13	0.33
	Dorsal		Medial	
Medial penetrometer reading	1.17	0.16		
Lateral penetrometer reading	1.04	0.04	1.00	0.00
Average penetrometer reading	1.06	0.06	1.02	0.01
Total moisture	0.84	0.09	0.70	0.13
Shear value	-.16	0.37	0.12	0.31
	Lateral		Average	
Average penetrometer reading	0.99	0.01		
Total moisture	1.03	0.02	0.81	0.07
Shear value	0.19	0.31	0.07	0.21
	Total moisture			
Shear value	0.18	0.31		

[a]Standard error (Reeve, 1955).

uate color differences.

Color score also failed to show any genetic relationship with total moisture or shear value. Jensen _et al._ (1967) reported moderate genetic correlations between color score and total moisture and between color score and shear value but the magnitude of the standard errors associated with their estimates suggest that no real genetic relationships exist between these traits.

Firmness score. Firmness score was significantly correlated with all penetrometer readings (Table XVI). This was anticipated since the score and the penetrometer were used to determine firmness of the longissimus dorsi muscle. The dorsal penetrometer had a higher genetic correlation with firmness score than either the medial or lateral readings. It has been discussed earlier that the greater error variance associated with the dorsal penetrometer reading caused the relationship of this variable to be somewhat different from those of the medial and lateral readings.

Firmness score had a highly negative genetic correlation with total moisture. The magnitude of this correlation and its standard error indicate that these two traits have some common genes with antagonistic effects. Jensen _et al._ (1967) reported a zero genetic correlation between these two traits. Again, differences in the scoring systems used may be partly responsible for the differences of the results.

Penetrometer reading. The four penetrometer readings were all highly correlated to each other genetically (Table

XVI). All penetrometer readings had highly significant genetic correlations with total moisture, much higher than the genetic correlation found between firmness score and total moisture. No significant genetic relationships were found between any of the four penetrometer readings and shear value.

The relationships of the dorsal penetrometer reading with most of the other traits studied were either too high or too low compared with the other two penetrometer readings. It should be pointed out that a large error variance was associated with the dorsal reading. This error could be accounted for by the way the loins were cut at the tenth rib since the surface of the loin eye muscle was somewhat slanting towards the median. This was more clearly evident when the ribs were not intact in the loins.

Shear value. Tenderness as measured by the Warner-Bratzler shear machine did not show any appreciable genetic relationships with the other traits studied except probe backfat. This is in general agreement with the findings of Jensen *et al.* (1967). This may be due to the small number of sire groups used in this study which caused large standard errors of the heritability estimates and consequently large standard errors associated with the estimate of the genetic correlations. In the formula, standard error of the genetic correlations is a function of the heritability estimates and their standard errors.

Phenotypic Correlations

Estimate of the correlation among eighteen traits were obtained after removing the variations due to the line of breeding and season-year effects. The phenotypic correlation coefficients are given in Tables XVII through XXII. The corresponding phenotypic variances and covariances used in calculating the correlations are presented in Appendix Table XXIX.

Age at slaughter. Older pigs at slaughter had less backfat and higher yield of lean cuts, but no close relationships were obtained between age at slaughter and carcass quality measurements. The correlations with marbling score and total moisture were significant but accounted for only one and two percent, respectively, of the variations in age at slaughter (Table XVII). Omtvedt et al. (1967) found higher correlations between age at 200 pounds and measures of lean cut yield than were found in this study. Their data were adjusted to 200-pound basis while in this study, actual age of the animals at slaughter was used. Variable results have been reported in literature concerning the relationships of age with carcass length. Omtvedt et al. (1967) found a -.16, Bennett and Coles (1946) reported a 0.37 for the males and -.11 for the females, and Cummings and Winters (1951) found a -.51 correlation between age and carcass length. The correlation coefficient between these two traits in the present study was only 0.09.

TABLE XVII

PHENOTYPIC CORRELATION COEFFICIENTS OF AGE AT SLAUGHTER WITH SOME CARCASS TRAITS

	Age at slaughter
Probe backfat	-.15**
Carcass backfat	-.16**
Carcass length	0.09*
Loin eye area	0.11*
Lean cut weight	0.31**
Liveweight lean yield	0.34**
Carcass lean yield	0.31**
Marbling score	0.11*
Ether extract	0.09
Color score	-.03
Firmness score	0.02
Dorsal penetrometer reading	0.03
Medial penetrometer reading	0.02
Lateral penetrometer reading	0.04
Average penetrometer reading	0.03
Total moisture	-.15**
Shear value	0.07

*Significant at 5 percent level.
**Significant at one percent level.

Probe and carcass backfat. These two measures are believed to be estimating the same thing. The correlation coefficient between these two measures was 0.58 (Table XVIII) about the same magnitude as reported earlier by Omtvedt *et al.* (1967). This was considerably lower than those reported from other stations (Pearson *et al.*, 1956, 1957; Price *et al.*, 1957). These workers used rather small numbers of animals and variations due to breed and nutritional background of the animals were not adjusted for in the analysis.

TABLE XVIII

PHENOTYPIC CORRELATION COEFFICIENTS OF PROBE AND CARCASS BACKFAT WITH SOME CARCASS TRAITS

	Probe backfat	Carcass backfat
Carcass backfat	0.58**	
Carcass length	-.45**	-.33**
Loin eye area	-.21**	-.05
Lean cut weight	-.39**	-.27**
Liveweight lean yield	-.44**	-.36**
Carcass lean yield	-.53**	-.49**
Marbling score	0.02	-.04
Ether extract	0.09	-.02
Color score	0.05	0.04
Firmness score	0.16**	0.06
Dorsal penetrometer reading	-.15**	-.10*
Medial penetrometer reading	-.20**	-.09
Lateral penetrometer reading	-.19**	-.06
Average penetrometer reading	-.20**	-.09
Total moisture	-.10	-.01
Shear value	-.15**	-.17**

*Significant at 5 percent level.
**Significant at one percent level.

Probe and carcass backfat showed the same trends in their relationships with the other traits but probe backfat was more closely associated with carcass length, loin eye area and yield of lean cuts than was carcass backfat. Fatter animals tended to have shorter carcasses, smaller loin eye area and less lean cut yields. Both backfat thickness measurements were more closely correlated with lean cut yield expressed as a percentage of carcass weight than when expressed on a total weight basis or as a percentage of slaughter weight. Probe backfat accounted for about 28 percent of the variation in percent lean of carcass weight. These results were in close agreement with the report of Omtvedt et al. (1967). Lasley et al. (1956) reported that the weight of lean cuts had a correlation coefficient of -.51 with carcass backfat and -.57 with probe backfat. Pearson et al. (1958) found correlation coefficients of -.61 and -.47 between carcass lean yield and probe backfat and between carcass lean yield and carcass backfat, respectively. Pearson et al. (1957) reported a correlation coefficient of -.28 between probe backfat and loin eye area at the tenth rib.

Probe and carcass backfat had low but significant correlations with all measures of firmness. They accounted for only about four percent of the variation in average penetrometer reading and for only about three percent of the variation in firmness score. Carcass backfat had no association with firmness of the lean. Judge et al. (1959) reported a low, significant correlation between carcass backfat and firmness but the correlations between carcass backfat and marbling score, and between carcass backfat and color score were essentially zero. Jurgens et al. (1967) reported a correlation of 0.25 between firmness and carcass backfat.

Neither probe nor carcass backfat were associated with either ether extract or total moisture. Both backfat measurements were correlated with shear value. Henry et al. (1963) and Jurgens et al. (1967) found very low correlations between carcass backfat and percent fat.

Carcass length. Longer carcasses tended to have smaller loin eye area and higher yield of lean cuts than shorter carcasses, but the magnitude of these correlations were too small to be very important (Table XIX). Lasley et al. (1956), Nelson and Sumption (1962) and Topel et al. (1965) found that longer carcasses had higher lean yields than shorter carcasses. The reported correlation coefficients between carcass length and loin eye area varied from -.29 (Omtvedt et al., 1967) to 0.38 (Pearson et al., 1959). The average for 25 estimates included in the literature review was 0.08. Based on the data from the present study and the average estimate from published reports, carcass length accounted for only about one percent of the variation in loin eye area.

TABLE XIX

PHENOTYPIC CORRELATION COEFFICIENTS OF CARCASS LENGTH AND LOIN EYE AREA WITH SOME CARCASS TRAITS

	Carcass length	Loin eye area
Loin eye area	-.12**	
Lean cut weight	0.21**	0.54**
Liveweight lean yield	0.11*	0.56**
Carcass lean yield	0.19**	0.47**
Marbling score	0.07	-.18**
Ether extract	0.06	-.23**
Color score	0.01	-.08
Firmness score	0.01	-.25**
Dorsal penetrometer reading	0.04	0.28**
Medial penetrometer reading	0.06	0.33**
Lateral penetrometer reading	0.02	0.29**
Average penetrometer reading	0.05	0.32**
Total moisture	-.01	0.12*
Shear value	0.00	0.16**

*Significant at 5 percent level.
**Significant at one percent level.

Carcass length was not correlated with any measures of carcass quality. Smith and Ross (1965) reported a correlation coefficient of 0.21 between carcass length and fat distribution. No other report is available correlating carcass length with any measures of quality. All the correlation coefficients of carcass length with quality measures were essentially zero and between carcass length and measures of meatiness were very low although positive. Carcass length, therefore, cannot be a good indicator of carcass muscling or quality.

Loin eye area. The correlation coefficient of loin eye area and lean cut yield as a percentage of carcass weight was 0.47 (Table XIX). This is within the range of correlation coefficients reported by other workers. The correlation coefficients between these two traits ranged from 0.25 (Fredeen et al., 1964) to 0.78 (Brown et al., 1951) with an average estimate of 0.54 out of nineteen reports.

The correlation coefficient between loin eye area and lean yield as a percentage of slaughter weight was found to be 0.56, much higher than when yield was expressed on a carcass weight basis. Correlation coefficients of 0.53 and 0.57 between these two traits have been reported by Omtvedt et al. (1967) and Price et al. (1957), respectively. The same workers also reported lower estimates of relationships between loin eye area and lean yield expressed as a percentage of carcass weight.

Carcasses with larger loin eye areas tended to have lower marbling score, color score and tended to be softer as measured by the firmness score and by the penetrometer readings (Table XIX). A larger loin eye area was associated with less ether extract, more total moisture and decreased tenderness as measured by the shear value. Judge _et al_. (1959) found very low associations between loin eye area and marbling, color or firmness scores. Jurgens _et al_. (1967) also found no relationship between loin eye area and firmness of the lean.

The results of this study indicate that larger loin eye area was related to higher lean cut yield and lower meat quality. Loin eye area accounted for less than one-third of the phenotypic variation in lean cut production either expressed as total weight, or as percentages of carcass or slaughter weights. Therefore, loin eye area should not be overemphasized when used as a guide in estimating meatiness in carcass evaluation.

Lean cut yield. The correlations between any two of the three measures of meatiness were very high (Table XX). However, since weight of lean cuts is part of either slaughter or carcass weight, the magnitudes of their relationships may be understood. Total weight of lean cuts accounted for about 72 percent of the variation in lean cut yield when expressed as a percentage of slaughter weight and for only about 52 percent of the variation when expressed as percentage of lean of carcass weight. The correlation between percent lean of liveweight and percent lean of carcass weight

TABLE XX

PHENOTYPIC CORRELATION COEFFICIENTS OF YIELD OF LEAN CUTS WITH SOME CARCASS TRAITS

	Lean cut weight	Liveweight lean yield	Carcass lean yield
Liveweight lean yield	0.85**		
Carcass lean yield	0.72**	0.83**	
Marbling score	-.10*	-.10*	-.08
Ether extract	-.05	-.08	-.08
Color score	-.17**	-.17**	-.14**
Firmness score	-.21**	-.27**	-.22**
Dorsal penetrometer reading	0.28**	0.32**	0.28**
Medial penetrometer reading	0.34**	0.37**	0.33**
Lateral penetrometer reading	0.28**	0.30**	0.30**
Average penetrometer reading	0.32**	0.35**	0.33**
Total moisture	0.00	0.00	0.03
Shear value	0.07	0.13*	0.19**

*Significant at 5 percent level.
**Significant at one percent level.

was 0.83, essentially the same as reported by Omtvedt et al. (1967).

The phenotypic correlation coefficients of any of the three measures of meatiness with all carcass quality traits were, for all practical purposes, of the same magnitude except for shear value which had a correlation of 0.07 with total lean weight and 0.19 with carcass lean yield. Carcass lean yield was not correlated with marbling score, ether extract and total moisture. It accounted for only about two percent of the variation in color score, for less than five percent of the variation in firmness score and for less than 11 percent in the variation of the medial or average penetrometer reading. The magnitude of the correlations of carcass lean yields with the five measures of firmness may be of considerable importance. The firmer the lean tissue of the longissimus dorsi muscle, the lower the yield of lean cuts. Cole *et al.* (1954) stated that the degree of firmness of fat had no influence on the percentage of primal cuts or percentage fat. They did not mention the degree of relationship and they used only 59 carcasses.

Correlation coefficients based on rather limited data of -.73 and 0.84 between carcass lean yield and percent moisture were reported by Brown *et al.* (1951) and Babatunde *et al.* (1966), respectively. The correlation between these two traits in the present study was essentially zero. Correlation coefficients of -.67 and -.84 were also reported between carcass lean yield and carcass fat by Brown *et al.* (1951) and Babatunde *et al.* (1966), respectively. These two traits had a correlation coefficient of only -.08 in the present study. Babatunde *et al.* (1966) used only 30 animals and Brown *et al.* (1951) used 32 animals. Neither group of workers removed the variations due to the treatments imposed in their experiments.

Marbling score and ether extract. Marbling score accounted for about 44 percent of the variation in ether extract (Table XXI). This was expected since both traits were used to estimate the amount of fat in the muscle. Based on rather limited number of observations, correlation coefficients of 0.74, 0.76 and 0.85 between marbling and ether extract were reported by Birmingham *et al.* (1966), Judge *et al.*

TABLE XXI

PHENOTYPIC CORRELATION COEFFICIENTS OF MARBLING SCORE AND ETHER EXTRACT WITH SOME CARCASS TRAITS

	Marbling score	Ether extract
Ether extract	0.66**	
Color score	0.29**	0.04
Firmness score	0.48**	0.36**
Dorsal penetrometer reading	-.41**	-.39**
Medial penetrometer reading	-.41**	-.40**
Lateral penetrometer reading	-.40**	-.39**
Average penetrometer reading	-.44**	-.43**
Total moisture	-.48**	-.80**
Shear value	-.12*	-.11*

*Significant at 5 percent level.
**Significant at one percent level.

(1960), and Harrington and Pearson (1962), respectively.

Marbling score was moderately correlated with color score but the correlation between ether extract and color score was essentially zero. Allen *et al.* (1966) and Judge *et al.* (1960) found similar phenotypic relationships between ether extract and color score.

Marbling score and ether extract were moderately correlated with all measures of firmness. The higher the marbling score or ether extract, the firmer the lean of the longissimus dorsi muscle. The magnitudes of association of marbling score with the penetrometer readings were as high as the association of ether extract with the penetrometer readings. Marbling score appeared to be a better indicator of firmness than was ether extract. Marbling score and ether extract accounted for about 23 and 13 percent of the variations in firmness score, respectively. These results were in general agreement with published reports. Judge *et al.* (1960) reported a correlation coefficient of 0.37 between ether extract and firmness score. Birmingham *et al.* (1966) reported a -.32 correlation coefficient between penetrometer reading and subjective marbling score for pork and -.33 for beef longissimus dorsi muscle. In this study the correlation between marbling score and medial penetrometer reading was -.41.

Ether extract and marbling score accounted for about 64 and 23 percent of the variation in total moisture, respectively. Correlation coefficients of -.84 and -.88 between percent fat and percent moisture have been reported by Judge *et al.* (1960) and Henry and Bratzler (1960), respectively.

Both marbling and ether extract had low, negative, but significant correlations with shear value indicating that the higher the fat content, the more tender the longissimus dorsi muscle. These results agree with most reports (Harrington and Pearson, 1962; Henry *et al.*, 1963 and Murphy and Carlin, 1961).

Color score. Color score accounted for only about 12 percent of the variation in firmness score (Table XXII). This relationship was considerably higher than the association of color score with any of the penetrometer readings, the highest being -.21 with the dorsal reading. Addis *et al.* (1965) reported a phenotypic correlation of 0.57 between color and firmness of the gluteus medius muscle. Color

TABLE XXII

PHENOTYPIC CORRELATION COEFFICIENTS AMONG OTHER TRAITS INCLUDED IN THE STUDY

	Color score	Firmness score
Firmness score	0.35**	
Dorsal penetrometer reading	-.21**	-.60**
Medial penetrometer reading	-.18**	-.63**
Lateral penetrometer reading	-.16**	-.56**
Average penetrometer reading	-.20**	-.65**
Total moisture	0.02	-.27**
Shear value	0.06	0.00
	Penetrometer readings	
	Dorsal	Medial
Medial penetrometer reading	0.81**	
Lateral penetrometer reading	0.69**	0.82**
Average penetrometer reading	0.91**	0.95**
Total moisture	0.33**	0.35**
Shear value	-.12*	-.10
	Penetrometer readings	
	Lateral	Average
Average penetrometer reading	0.90**	
Total moisture	0.36**	0.38**
Shear value	-.12*	-.12*
	Total Moisture	
Shear value	0.05	

*Significant at 5 percent level.
**Significant at one percent level.

score was not related to total moisture and shear value. Carpenter (1961) reported no significant differences in tenderness which could be attributed to differences in color of the loins. Carpenter and King (1965) found a zero correlation between muscle color and shear value in lamb carcasses. Judge _et al_. (1960) obtained a nonsignificant correlation between total moisture and color score but reported a -.30 correlation between total moisture and tenderness using a 10-point scale for tenderness.

Firmness of the lean. Firmness score was highly correlated with all penetrometer readings (Table XXII). The average penetrometer reading had the highest relationships with firmness followed by the medial reading. Either of the two penetrometer readings accounted for at least 40 percent of the variation in firmness score. The correlation between the average of the three readings and the medial readings was 0.95. Gannaway (1955) found a -.81 correlation coefficient between penetrometer reading and firmness score of the ham. These results indicate that the scoring system for firmness used in this study adequately measured the firmness of the lean. The medial penetrometer reading would be sufficient to measure firmness. The medial penetrometer reading also showed the best associations with most of the other carcass traits studied than either the dorsal or lateral readings. This was attributed to the fact the middle portion of the muscle has relatively less connective tissues than the area closer to the perimeter of the muscle.

Firmness score accounted for about seven percent of the variation in total moisture (Table XXII). The four penetrometer readings had about the same degree of relationships with total moisture and the medial reading accounted for about 12 percent of the variation in total moisture. Judge et al. (1960) found a correlation coefficient of -.20 between total moisture and firmness score.

Firmness score had zero correlation with shear value while all penetrometer readings account for only about one percent of the variation in shear value. These results agreed with Naumann et al. (1960) who stated that firmness of the lean had little effect upon the organoleptic and shear characteristics of pork chops. However, Judge et al. (1960) reported a correlation coefficient of -.55 between firmness of the lean and tenderness as scored by a taste panel. They used three categories of firmness and 10-point scale for tenderness.

Total moisture content and shear value were not correlated. Judge et al. (1960) found the same relationship between these two traits.

Based on these results, it can be concluded that most quality traits have favorable relationships among themselves.

SUMMARY

The objectives of this study were to measure the phenotypic and genotypic variation of traits associated with pork quality and to determine the associations among quality traits and other economically important traits. For these objectives, data were collected over a period of five seasons from 1964 fall through 1966 fall involving 650 pigs out of 280 dams, 89 sires and seven lines of breeding. The animals were from the experimental swine breeding herds at Stillwater and Fort Reno. Heritability estimates and genetic correlations among traits were calculated from the sire components of variance and covariance. Phenotypic correlations among traits were also calculated. All parameter estimates were done on a within year-season-line of breeding basis using the analyses of variance for a nested classification with unequal number of subclasses.

Eighteen traits were investigated. The production traits included age at slaughter and probe backfat. Carcass "quantity" traits included carcass backfat, loin eye area, carcass length, weights of closely trimmed hams, loins and shoulders, percent lean of slaughter weight and percent lean of chilled carcass weight. Carcass "quality" traits included marbling, color and firmness scores of the longissimus dorsi muscle at the 10th rib, three penetrometer readings and

their averages, also ether extract, and total moisture for the longissimus dorsi muscle at the 10th rib. Shear values for the longissimus dorsi muscle at the 8th rib were also determined. Carcass evaluation was done 48 hours after slaughter.

The results of this study verified most reports in the literature that the barrows reached market weight at an earlier age and were fatter than gilts, but that gilt carcasses were longer, had higher yield of lean cuts and larger loin eye area. The longissimus dorsi muscle from the barrows were scored higher for marbling and firmness, had higher ether extract content and lower total moisture. No appreciable differences were noted between barrows and gilts in color score of the longissimus dorsi muscle and shear value. The gilts also had considerably larger genetic variances than the barrows as shown by higher heritability estimates in most traits studied. These preliminary results were indications that barrows and gilts may have some differences in their ability to inherit certain traits from their parents.

The sex corrected heritability estimates indicated that probe and carcass backfat thickness, carcass length, loin eye area, weight of lean cuts, percent lean of slaughter weight, percent lean of carcass weight, ether extract, and total moisture were highly heritable traits ($h^2 \geq 0.40$). Marbling and firmness scores, the medial, lateral and average penetrometer readings and shear value were moderately heritable ($0.20 \leq h^2 \leq 0.40$). Age at slaughter, color score and dorsal penetrometer reading were lowly heritable ($h^2 \leq 0.20$). Based on these estimates, it was concluded that except for color score, traits associated with pork quality are moderately to highly heritable and could be improved through direct selection for the desired traits.

The genetic correlations among the traits indicated that selection for less backfat would increase carcass length and yield of lean cuts, without significant effects on loin eye area, color and firmness of the longissimus dorsi muscle or total moisture. Selection for larger loin eye area would increase yield of lean cuts without much change in the quality attributes except color score. The genetic correlations among quality traits were moderate and compatible. Selection for increased marbling score would also increase ether extract and firmness of the longissimus dorsi muscle and also percent lean of carcass weight and reduce backfat thickness and total moisture. It appeared that the amount of lean can be increased and the amount of backfat decreased and still have acceptable degrees of marbling and firmness of the muscle through proper selection procedures.

Probe and carcass backfat had a correlation coefficient of 0.58. The variation in backfat thickness accounted for approximately 15 to 28 percent of the variation in the yield of lean cuts but for only zero to 4 percent of the variation in traits associated with quality. Carcass length could explain only one to 4 percent of the variation in yield of lean cuts. Carcass length was not correlated with any measures of carcass quality. Variation in loin eye area accounted for about 26 percent of the variation in yield of lean cuts but for a maximum of 11 percent of the variation in measures of carcass quality. The variation in any one quality trait accounted for zero to 14 percent of the variation in yield of lean cuts. The three measures of yield of lean cuts were highly correlated to each other and revealed essentially the same trends of relationships with the other traits investigated. It was concluded that any one of the three measures would give about the same results. The correlation between marbling score and ether extract was 0.66. It appeared that the scoring system for marbling used in this study quite adequately measured the amount of fat in the muscle. Both ether extract and marbling score were highly correlated with firmness and total moisture. Firmness score and the penetrometer readings were highly correlated. The results indicated that the scoring system for firmness used in this study adequately measured the firmness of the lean. Based on the results, it was concluded that most quality traits have favorable relationships among themselves.

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APPENDIX

TABLE XXIII

NUMBER OF SIRES, DAMS AND PIGS BY LITTER LINE OF BREEDING INCLUDED IN THE ANALYSIS OF DATA FOR ALL TRAITS EXCEPT PROBE BACKFAT

Line of litter		Season and Year					Total
		Fall 1964[a]	Spring 1965[a]	Fall 1965[b]	Spring 1966[c]	Fall 1966[c]	
8	Sire			4			4
	Dam			11			11
	Pig			26			26
9	Sire			5			5
	Dam			14			14
	Pig			33			33
14	Sire	4	4	6	6	7	27
	Dam	9	9	16	22	30	86
	Pig	24	18	44	47	62	195
33	Sire	2		4	4	5	15
	Dam	4		10	13	18	45
	Pig	8		32	33	36	109
89	Sire		4			6	10
	Dam		11			22	33
	Pig		25			50	75
98	Sire		5			5	10
	Dam		12			14	26
	Pig		27			32	59
99	Sire	8			10		18
	Dam	21			44		65
	Pig	55			98		153
Total	Sire	14	13	19	20	23	89
	Dam	34	32	51	79	84	280
	Pig	87	70	135	178	180	650

[a]No penetrometer reading and chemical analyses done during the spring of 1965 season and also for line 99 during the fall, 1964.

[b]Total moisture determination started from 1965 fall.

[c]Warner-Bratzler shear values were taken only during the last two seasons.

TABLE XXIV

NUMBER OF SIRES, DAMS AND PIGS BY LITTER LINE OF BREEDING INCLUDED IN THE ANALYSIS OF PROBE BACKFAT

Line of		Season and Year					Total
		Fall 1964	Spring 1965	Fall 1965	Spring 1966	Fall 1966	
8	Sire			3			3
	Dam			4			4
	Pig			4			4
9	Sire			3			3
	Dam			4			4
	Pig			6			6
14	Sire	4	4	6	6	7	27
	Dam	9	9	16	22	30	86
	Pig	24	18	20	45	62	169
33	Sire	2		4	4	5	15
	Dam	4		10	13	18	45
	Pig	8		16	30	36	90
89	Sire		4			6	10
	Dam		10			22	32
	Pig		23			50	73
98	Sire		5			5	10
	Dam		12			14	26
	Pig		27			32	59
99	Sire	8			10		18
	Dam	21			44		65
	Pig	55			98		153
Total	Sire	14	13	16	20	23	86
	Dam	34	31	34	79	84	262
	Pig	87	68	46	173	180	554

TABLE XXV

CORRECTION FACTORS USED TO ADJUST THE DATA TO A BARROW EQUIVALENT BASIS

Trait	Factor[a]
Age at slaughter, days	-13.0
Probed backfat, in.	+ 0.12
Carcass backfat, in.	+ 0.11
Carcass length, in.	- 0.5
Loin eye area, sq. in.	- 0.64
Lean cut weight, lb.	- 4.3
Liveweight lean yield, %	- 2.4
Carcass lean yield, %	- 3.1
Marbling score	+ 0.5
Color score	0.0
Firmness score	+ 0.5
Penetrometer readings:	
Dorsal, mm.	- 8.0
Medial, mm.	- 8.0
Lateral, mm.	- 6.0
Average, mm.	- 7.0
Ether extract, %	+ 1.18
Total moisture, %	- 0.5
Average shear value, lb.	- 0.6

[a]Added or subtracted to the values recorded for the females as indicated by the + or - sign.

TABLE XXVI

MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATIONS FOR THE DIFFERENT LINES OF BREEDING[a]

TRAIT LINE OF BREEDING	No.	Mean	Standard deviation[b]	Coefficient of Variation
Age at slaughter, days				
Line 8	26	143.6	11.91	8.29
Line 9	33	148.7	6.89	4.63
Line 14	195	154.0	8.94	5.80
Line 33	109	146.6	9.49	6.47
Line 89	75	145.6	9.14	6.28
Line 98	59	147.7	8.08	5.47
Line 99	153	143.2	7.78	5.43
All lines	650	148.0	8.77	5.93
Live probe, in.				
Line 14	169	1.38	0.12	8.93
Line 33	90	1.43	0.13	9.32
Line 89	73	1.38	0.14	10.24
Line 98	59	1.46	0.09	6.06
Line 99	153	1.40	0.12	8.38
All lines[c]	554	1.40	0.12	8.73
Carcass backfat, in.				
Line 8	26	1.56	0.14	9.25
Line 9	33	1.33	0.09	6.87
Line 14	195	1.34	0.12	8.69
Line 33	109	1.41	0.13	9.19
Line 89	75	1.38	0.13	9.26
Line 98	59	1.42	0.09	6.51
Line 99	153	1.33	0.13	9.63
All lines	650	1.37	0.12	8.85
Carcass length, in.				
Line 8	26	28.9	0.56	1.92
Line 9	33	30.0	0.67	2.22
Line 14	195	29.1	0.55	1.90
Line 33	109	29.4	0.55	1.85
Line 89	75	30.0	0.59	1.97
Line 98	59	30.0	0.55	1.82
Line 99	153	30.2	0.55	1.82
All lines	650	29.6	0.56	1.89

TABLE XXVI (Continued)

Loin eye area, sq. in.				
Line 8	26	3.44	0.45	12.96
Line 9	33	3.83	0.39	10.28
Line 14	195	4.32	0.41	9.47
Line 33	109	4.27	0.38	8.94
Line 89	75	4.00	0.38	9.49
Line 98	59	3.67	0.33	8.88
Line 99	153	3.75	0.39	10.46
All lines	650	4.02	0.39	9.72
Lean cut weight, lb.				
Line 8	26	70.7	2.36	3.34
Line 9	33	72.6	2.71	3.74
Line 14	195	78.3	3.12	3.99
Line 33	109	76.3	2.80	3.67
Line 89	75	75.1	2.74	3.65
Line 98	59	74.4	2.60	3.50
Line 99	153	75.5	2.96	3.92
All lines	650	76.0	2.89	3.81
Slaughter lean yield, %				
Line 8	26	34.3	1.32	3.86
Line 9	33	35.4	1.23	3.47
Line 14	195	38.1	1.34	3.52
Line 33	109	37.0	1.49	4.02
Line 89	75	36.5	1.17	3.21
Line 98	59	36.2	1.04	2.87
Line 99	153	36.8	1.25	3.39
All lines	650	37.0	1.30	3.51
Carcass lean yield, %				
Line 8	26	48.8	1.38	2.82
Line 9	33	50.8	1.39	2.73
Line 14	195	54.0	1.81	3.36
Line 33	109	52.4	1.76	3.37
Line 89	75	51.7	1.37	2.65
Line 98	59	51.1	1.37	2.68
Line 99	153	52.6	1.83	3.48
All lines	650	52.5	1.69	3.32
Marbling score				
Line 8	26	5.23	0.71	13.64
Line 9	33	3.25	0.87	26.86
Line 14	195	3.09	0.83	26.85
Line 33	109	3.07	1.00	32.64
Line 89	75	4.36	1.10	25.25
Line 98	59	4.08	1.16	28.53
Line 99	153	4.62	1.32	28.68
All lines	650	3.78	1.05	27.92

TABLE XXVI (Continued)

Ether extract, %				
Line 8	26	8.70	1.97	22.62
Line 9	33	4.42	1.15	26.06
Line 14	177	4.10	1.16	28.29
Line 33	109	4.26	1.16	27.24
Line 89	50	6.15	2.44	39.65
Line 98	32	6.02	1.88	31.16
Line 99	98	6.37	2.30	36.10
All lines	525	5.12	1.66	32.40
Color score				
Line 8	26	4.16	0.78	18.84
Line 9	33	3.85	1.23	32.05
Line 14	195	3.75	0.55	14.73
Line 33	109	3.52	0.94	26.65
Line 89	75	4.24	0.91	21.52
Line 98	59	4.31	0.82	18.98
Line 99	153	4.01	0.80	20.01
All lines	650	3.90	0.81	20.70
Firmness score				
Line 8	26	5.63	0.65	11.55
Line 9	33	3.98	1.08	27.09
Line 14	195	4.11	1.01	24.66
Line 33	109	3.60	1.18	32.68
Line 89	75	4.63	1.18	25.44
Line 98	59	4.65	1.21	26.00
Line 99	153	5.05	1.00	19.86
All lines	650	4.41	1.07	24.28
Dorsal penetrometer reading, mm.				
Line 8	26	2.45	0.59	24.04
Line 9	33	3.75	0.96	25.58
Line 14	177	4.61	1.16	25.07
Line 33	109	4.38	1.03	23.55
Line 89	50	3.25	1.06	32.61
Line 98	32	3.38	1.16	34.21
Line 99	98	3.72	1.03	27.63
All lines	525	4.03	1.06	26.38
Medial penetrometer reading, mm.				
Line 8	26	2.85	0.61	21.40
Line 9	33	4.21	0.94	22.33
Line 14	177	5.12	1.05	20.53
Line 33	109	4.80	1.04	21.74
Line 89	50	3.53	0.93	26.44
Line 98	32	3.38	1.06	31.35
Line 99	98	4.24	0.94	22.20
All lines	525	4.46	1.00	22.30

TABLE XXVI (Continued)

Lateral penetrometer reading, mm.				
Line 8	26	2.23	0.76	33.94
Line 9	33	3.45	0.89	25.77
Line 14	177	4.31	0.93	21.81
Line 33	109	3.86	0.96	24.80
Line 89	50	2.89	0.83	28.83
Line 98	32	2.72	0.94	34.60
Line 99	98	3.61	0.75	20.85
All lines	525	3.70	0.89	24.10
Average penetrometer reading, mm.				
Line 8	26	2.51	0.54	21.62
Line 9	33	3.80	0.83	21.68
Line 14	177	4.69	0.96	20.64
Line 33	109	4.36	0.91	20.67
Line 89	50	3.24	0.84	25.82
Line 98	32	3.18	0.98	30.85
Line 99	98	3.87	0.83	21.51
All lines	525	4.08	0.89	21.90
Total moisture, %				
Line 8	26	68.9	1.77	2.57
Line 9	33	71.4	1.54	2.16
Line 14	153	71.6	1.23	1.72
Line 33	101	71.0	1.24	1.74
Line 89	50	70.1	2.02	2.88
Line 98	32	69.5	1.47	2.11
Line 99	98	69.8	1.68	2.41
All lines	493	70.7	1.49	2.11
Shear value, lb.				
Line 14	109	11.4	1.40	12.36
Line 33	69	13.5	1.97	14.63
Line 89	50	11.2	2.54	22.49
Line 98	32	12.2	1.79	14.70
Line 99	98	11.6	2.19	18.92
All lines	358	11.9	1.97	16.57

[a]Computed after adjusting the data to barrow equivalent basis.

[b]Computed from the error mean square of the analysis of variance.

[c]Ten pigs from lines 8 and 9 included in the last item.

TABLE XXVII

COMPONENTS OF VARIANCE USED FOR CALCULATING HERITABILITY ESTIMATES FROM BARROW-GILT LITTERMATE DATA ONLY

	Gilt				Barrow			
	Sire		Individual		Sire		Individual	
	d.f.	Component[a]	d.f.	Component[b]	d.f.	Component[a]	d.f.	Component[b]
Age at slaughter	51	5.360931	147	136.134354	51	8.417206	147	123.587159
Live probe	51	0.000977	147	0.021619	43	0.018473	128	0.016385
Carcass backfat	51	0.002781	147	0.019186	51	0.001129	147	0.012337
Carcass length	51	0.191240	147	0.314456	51	0.049963	147	0.381429
Loin eye area	51	0.040234	147	0.215480	51	-0.004479	147	0.208920
Lean cut weight	51	1.936366	147	10.628435	51	2.542166	147	8.897823
Liveweight lean yield	51	0.231060	147	2.508520	51	0.458117	147	1.854201
Carcass lean yield	51	0.762904	147	3.799694	51	0.436730	147	2.649286
Marbling score	51	0.297511	147	1.134531	51	0.115892	147	1.231091
Ether extract	46	0.492456	137	2.598047	46	0.144202	137	3.643297
Color score	51	0.077171	147	0.597425	51	0.032756	147	0.690446
Firmness score	51	0.134391	147	1.472414	51	0.185294	147	1.398656
Dorsal penetrometer reading	46	-0.040216	137	1.801782	46	0.101393	137	1.102940
Medial penetrometer reading	46	0.266225	137	1.408680	46	0.190502	137	1.012274
Lateral penetrometer reading	46	0.199443	137	1.115313	46	0.133678	137	0.896463
Average penetrometer reading	46	0.142048	137	1.240878	46	0.136780	137	0.815698
Total moisture	43	0.439797	131	2.420610	43	0.295221	131	2.759618
Shear force value	35	0.246182	115	4.120791	35	1.270893	115	3.415418

[a]Between sire mean square - within error mean square/average number of pigs per sire group.

[b]Within error mean square.

TABLE XXVIII

COMPONENTS OF VARIANCE USED FOR CALCULATING HERITABILITY ESTIMATES FROM ALL DATA

Trait	Sire			Dam			Individual		
	d.f.	Component[a]	Percent	d.f.	Component[b]	Percent	d.f.	Component[c]	Percent
Age at slaughter	72	3.562773	2.86	191	44.141151	35.40	370	76.994595	61.74
Live probe	69	0.003380	15.37	176	0.003600	16.38	292	0.015005	68.25
Carcass backfat	72	0.002486	13.18	191	0.001649	8.74	370	0.014727	78.08
Carcass length	72	0.118959	24.08	191	0.059165	11.98	370	0.315851	63.94
Loin eye area	72	0.029228	11.81	191	0.065376	26.41	370	0.152962	61.78
Lean cut weight	72	1.993887	16.95	191	1.401645	11.92	370	8.367351	71.13
Liveweight lean yield	72	0.398859	15.62	191	0.468811	18.36	370	1.686108	66.02
Carcass lean yield	72	0.608123	15.98	191	0.340226	8.94	370	2.858108	75.09
Marbling score	72	0.097410	7.01	191	0.179367	12.91	370	1.112843	80.08
Ether extract	55	0.380046	10.44	159	0.510011	14.01	298	2.750776	75.55
Color score	72	0.018045	2.44	191	0.070657	9.55	370	0.651280	88.01
Firmness score	72	0.109787	7.38	191	0.232592	15.63	370	1.145604	76.99
Dorsal penetrometer reading	55	0.041599	2.98	159	0.223596	16.03	298	1.129678	80.99
Medial penetrometer reading	55	0.120590	8.99	159	0.229879	17.14	298	0.990621	73.87
Lateral penetrometer reading	55	0.074474	6.65	159	0.252058	22.51	298	0.793169	70.84
Average penetrometer reading	55	0.082349	7.52	159	0.215486	19.69	298	0.796817	72.79
Total moisture	51	0.384510	12.94	152	0.369204	12.42	279	2.218710	74.64
Shear value	36	0.392987	8.32	120	0.449611	9.52	195	3.880288	82.16

[a]Between sire mean square - (Dam component X average number of pigs per dam in sire + Individual error mean square)/Average number of pigs per sire.

[b]Between dam mean square - Individual error mean square/average number of pigs per dam in sire.

[c]Within error mean square.

TABLE XXIX

PHENOTYPIC AND GENOTYPIC VARIANCE AND COVARIANCE USED FOR CALCULATING CORRELATIONS BETWEEN ANY TWO TRAITS

	Number of	Variance		Covariance	
	Observations	Sire	Total[a]	Sire	Total[a]
Age at slaughter and:	650	3.562772	124.698518		
Carcass length	650	.118959	.493976	.633409	.686414
Carcass backfat	650	.002486	.018862	- .056049	- .245485
Loin eye area	650	.029282	.247565	- .145458	.625311
Lean cut weight	650	1.993887	11.762883	.119765	11.784882
Liveweight lean yield	650	.398859	2.553778	- .200976	6.085838
Carcass lean yield	650	.608123	3.806487	.409860	6.853736
Marbling score	650	.097410	1.389620	- .080578	1.413208
Color score	650	.018045	.739983	- .091248	- .289308
Firmness score	650	.109787	1.487983	.065623	.276846
Carcass length and:	650	.118959	.493976		
Carcass length	650	.002486	.018862	- .010611	- .032195
Loin eye area	650	.029228	.247565	- .030308	- .042277
Lean cut weight	650	1.993887	11.762883	.022220	.511534
Liveweight lean yield	650	.398859	2.553778	.005325	.119560
Carcass lean yield	650	.608123	3.806487	.080158	.263789
Marbling score	650	.097410	1.389620	.043894	.057323
Color score	650	.018045	.739983	.020640	.007834
Firmness score	650	.109787	1.487983	.053818	.012130

TABLE XXIX (Continued)

Carcass backfat and:	650	.002486	.018862		
Loin eye area	650	.029228	.247565	- .001854	- .003605
Lean cut weight	650	1.993887	11.762883	- .042487	- .125159
Liveweight lean yield	650	.398859	2.553778	- .013987	- .078172
Carcass lean yield	650	.608123	3.806487	- .022493	- .132382
Marbling score	650	.097410	1.389620	- .008762	- .007116
Color score	650	.018045	.739983	- .000367	.004900
Firmness score	650	.109787	1.487983	- .002683	.009727
Loin eye area and:	650	.029228	.247565		
Lean cut weight	650	1.993887	11.762883	.188256	.924211
Liveweight lean yield	650	.398859	2.553778	.099051	.444620
Carcass lean yield	650	.608123	3.806487	.106911	.451515
Marbling score	650	.097410	1.389620	- .000541	- .104984
Color score	650	.018045	.739983	- .016672	- .034467
Firmness score	650	.109787	1.487983	- .021962	- .149259
Lean cut weight and:	650	1.993887	11.762883		
Liveweight lean yield	650	.398859	2.553778	.892045	4.654276
Carcass lean yield	650	.608123	3.806487	1.148689	4.808102
Marbling score	650	.097410	1.389620	.057984	- .409300
Color score	650	.018045	.739983	- .150335	- .503504
Firmness score	650	.109787	1.487983	- .252153	- .884319
Liveweight lean yield and:	650	.398859	2.553778		
Carcass lean yield	650	.608123	3.806487	.486868	2.578740
Marbling score	650	.097410	1.389620	.036177	- .194922
Color score	650	.018045	.739983	- .052749	- .232689
Firmness score	650	.109787	1.487983	- .101749	- .522186

TABLE XXIX (Continued)

Carcass lean yield and:	650	.608123	3.806487		
Marbling score	650	.097410	1.389620	.115944	- .190888
Color score	650	.018045	.739983	- .056529	- .236736
Firmness score	650	.109787	1.487983	- .027478	- .528829
Marbling score and:	650	.097410	1.389620		
Color score	650	.018045	.739983	.022256	.290349
Firmness score	650	.109787	1.487983	.077408	.696427
Color score and:	650	.018045	.739983		
Firmness score	650	.109787	1.487983	.023763	.367125
Live probe and:	554	.003380	.021985		
Age at slaughter	554	1.900621	121.620013	- .015632	- .238369
Carcass length	554	.128486	.479904	- .011055	- .046203
Carcass backfat	554	.321304	.018812	.002744	.011767
Loin eye area	554	.033433	.247179	- .002504	- .015194
Lean cut weight	554	2.013822	12.025660	- .047668	0 .201127
Liveweight lean yield	554	.431829	.025817	- .019215	- .105524
Carcass lean yield	554	.635572	4.014947	- .026756	- .153591
Marbling score	554	.139095	1.435462	- .010365	.003201
Color score	554	.036011	.718989	- .000880	.005883
Firmness score	554	.148652	1.549571	- .001842	.030109
Live probe and:	430	.002768	.020564		
Dorsal penetrometer reading	430	.064691	.014791	- .004346	- .026870
Medial penetrometer reading	430	.162521	1.399514	- .007833	- .034610
Lateral penetrometer reading	430	.101954	1.156360	- .006774	- .029110
Average penetrometer reading	430	.115015	1.143424	- .006610	- .030343
Ether extract	430	.451801	3.690880	- .004932	.025584

TABLE XXIX (Continued)

Live probe and:	399	.002068	0.019251		
Total moisture	399	.427920	2.991515	.001146	- .023197
Live probe and:	353	.002564	.019337		
Shear value	353	.433147	4.750311	- .017785	- .046741
Dorsal penetrometer reading and:	525	.041600	1.394874		
Age at slaughter	525	3.078635	136.957857	.141586	.370738
Carcass backfat	525	.001968	.018194	- .001653	- .015350
Carcass length	525	.101386	.480710	- .014728	.032103
Loin eye area	525	.027551	.246366	.014940	.166095
Lean cut weight	525	2.622755	12.430886	.125812	1.182353
Liveweight lean yield	525	.470489	2.724827	.059362	.627291
Carcass lean yield	525	.635483	3.955928	.022834	.667481
Marbling score	525	.044384	1.331040	- .063125	- .565088
Color score	525	.021086	.733110	- .009848	- .214204
Firmness score	525	.120431	1.602711	- .104490	- .903819
Medial penetrometer reading	525	.120590	1.341090	.083102	1.111936
Lateral penetrometer reading	525	.074474	1.119701	.057718	.858433
Average penetrometer reading	525	.082349	1.094651	.062034	1.123647
Ether extract	525	.380046	3.640834	- .137279	- .872345

TABLE XXIX (Continued)

Medial penetrometer reading and:	525	.120590	1.341090		
Age at slaughter	525	3.078635	136.957857	.305118	13.410903
Carcass backfat	525	.001968	.018194	- .004087	- .014429
Carcass length	525	.101386	.480710	- .005775	.051865
Loin eye area	525	.027551	.246366	.034525	.188113
Lean cut weight	525	2.627455	12.430886	.334811	1.401660
Liveweight lean yield	525	.470489	2.724827	.133699	.699165
Carcass lean yield	525	.635483	3.955928	.099952	.762256
Marbling score	525	.044384	1.331040	- .088625	- .549209
Color score	525	.021086	.733110	- .026087	- .176431
Firmness score	525	.120431	1.602711	- .142279	- .921186
Lateral penetrometer reading	525	.074474	1.119701	.095073	1.008160
Average penetrometer reading	525	.082349	1.094651	.101810	1.155973
Ether extract	525	.380046	3.640834	- .155230	- .883794
Lateral penetrometer reading and:	525	.074474	1.119701		
Age at slaughter	525	3.078635	136.957857	.494355	.445629
Carcass backfat	525	.001968	.018194	- .001654	- .008839
Carcass length	525	.101386	.480710	- .001673	.016921
Loin eye area	525	.027551	.246366	.028265	.154330
Lean cut weight	525	2.627455	12.430886	.257899	1.051686
Liveweight lean yield	525	.470489	2.724827	.090416	.519417
Carcass lean yield	525	.635483	3.955928	.081940	.628186
Marbling score	525	.044384	1.331040	- .070742	- .485626
Color score	525	.021085	.733110	- .018219	- .148527
Firmness score	525	.120431	1.602711	- .076665	- .753657
Average penetrometer reading	525	.082349	1.094651	.077563	.995133
Ether extract	525	.380046	3.640834	- .168115	- .797144

TABLE XXIX (Continued)

Average penetrometer reading and:	525	.082349	1.094651		
Age at slaughter	525	3.078635	136.957857	.288892	.354432
Carcass backfat	525	.001968	.018194	- .002556	- .012799
Carcass length	525	.101386	.480710	- .006874	.033219
Loin eye area	525	.027551	.246366	.026169	.168377
Lean cut weight	525	2.627455	12.430886	.242430	1.204031
Liveweight lean yield	525	.470489	2.724827	.096470	.611494
Carcass lean yield	525	.635483	3.955928	.069039	.679373
Marbling score	525	.044384	1.331040	- .074680	- .532416
Color score	525	.021086	.733110	- .017685	- .017938
Firmness score	525	.120431	1.602711	- .108918	- .862011
Ether extract	525	.380046	3.640834	- .153629	- .849198
Ether extract and:	525	.380046	3.640834		
Age at slaughter	525	3.078635	136.957857	- .903745	1.901700
Carcass backfat	525	.001968	.018194	- .005038	- .038820
Carcass length	525	.101386	.480710	.018874	.077455
Loin eye area	525	.027551	.246366	.038282	- .218715
Lean cut weight	525	2.627455	12.430886	.177680	- .358659
Liveweight lean yield	525	.470489	2.724827	.123522	- .251152
Carcass lean yield	525	.635483	3.955928	.174509	- .298123
Marbling score	525	.044384	1.331040	.121481	1.443810
Color score	525	.021086	.733110	.006540	.069991
Firmness score	525	.120431	1.602711	.123542	.877632

TABLE XXIX (Continued)

Total moisture and:	493	.384510	2.972424		
Age at slaughter	493	3.101252	140.749082	.913084	-3.104566
Carcass length	493	.101386	.480710	-.012491	-.016289
Carcass backfat	493	.001630	.017701	.008281	-.002187
Loin eye area	493	.025611	.245686	-.013584	.103373
Lean cut weight	493	2.202991	11.764370	.035362	.004757
Liveweight lean yield	493	.338368	2.558323	-.027349	.009021
Carcass lean yield	493	.410172	3.634055	-.090954	.095954
Marbling score	493	.056920	1.356578	-.104913	-.965655
Color score	493	.009906	.721674	-.015056	.027172
Firmness score	493	.138799	1.610225	-.139286	-.599941
Dorsal penetrometer reading	493	.075731	1.344069	.144136	.657950
Medial penetrometer reading	493	.160373	1.302649	.174543	.695032
Lateral penetrometer reading	493	.094437	1.082594	.195820	.647117
Average penetrometer reading	493	.114231	1.053669	.170431	.666805
Ether extract	493	.415251	3.757751	-.388364	-2.661259

TABLE XXIX (Continued)

Shear value and:	358	.392987	4.722887		
Age at slaughter	358		146.202600		1.854312
Carcass length	358	.104962	.462803	.056229	.004386
Carcass backfat	358	.002541	.016818	-.005400	-.048604
Loin eye area	358	.031057	.245869	.045400	.167617
Lean cut weight	358	2.607731	12.105072	.362290	.544747
Liveweight lean yield	358	.352786	2.453264	.160333	.449098
Carcass lean yield	358	.483087	3.715576	.177086	.793075
Marbling score	358	.114490	1.442077	.077167	-.308896
Color score	358	.014119	.694180	.000018	.108957
Firmness score	358	.217585	1.766990	.038750	.003617
Dorsal penetrometer reading	358	.109351	1.409109	-.032495	-.312404
Medial penetrometer reading	358	.216793	1.346101	.036406	-.245635
Lateral penetrometer reading	358	.159763	1.108771	.048285	-.285274
Average penetrometer reading	358	.160640	1.077909	.017007	-.280614
Ether extract	358	.541442	4.033230	.075570	-.468119
Total moisture	358	.480869	3.088892	.077946	.196615

[a]Total variance and covariance are sum of the sire, dam and error variances and covariances, respectively, taken from the nested analyses of variance.

VITA

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