HERITABILITY OF CARCASS LENGTH,
CARCASS BACKFAT THICKNESS,
AND LOIN LEAN AREA
IN SWINE

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INTRODUCTION

During the past several years there has been an increasing demand by the consumer for more lean meat and less fat in the various pork cuts. During this same period lard has been largely replaced by the various vegetable fats in its use as a shortening. This change in demand has brought about a need for changes in the type of swine that will best satisfy this consumer preference.

Rate and economy of gain and sow productivity have been the major concerns of the producer in the past. Little emphasis has been placed on carcass merit by either the packer or the producer. It appears likely that consumer pressure will bring about increased emphasis on carcass value if pork is to maintain its place in the human diet.

In an attempt to meet the changing demand, the various swine breed associations have set up meat-type certification programs whereby certain sires and dams are given a "certified" classification if they meet the requirements as set up in the program. Backfat thickness, carcass length, and loin lean area were the carcass traits selected to be used in the certification program.

Since carcass merit cannot be measured in the live animal except in the case of backfat thickness where the probe technique has been developed, it becomes necessary to use closely related animals in predicting the breeding value of an individual. This relationship may be either collateral relatives or progeny of the individual being tested.

The extent to which closely related individuals resemble each other is dependent upon the relative genetic and environmental influences on the trait measured. A trait influenced to a large extent by environmental effects will be of little value in predicting the genetic composition of this same trait on related individuals. This is especially true if a small number of progeny or collateral relatives are used in making the determination. It becomes necessary, therefore, to choose traits of a highly hereditary nature if the progeny are to be indicative of the true breeding worth of the parent.

The objectives of this study were to (1) obtain estimates of heritability on carcass length, carcass backfat, and loin lean area, and (2) determine the phenotypic correlations between these traits.

REVIEW OF LITERATURE

Heritability may be defined as the fraction of the phenotypic variance which is caused by the differences between genes or genotypes of individuals. In a narrower sense it is a measure of the phenotypic variance between individuals which is due to differences in genes acting in an additive manner. This largely eliminates the genetic action due to dominance and epistasis. The narrow definition is more valid when thinking in terms of the portion of the variance in genic expression which will actually be transmitted to the offspring.

In determining estimates of heritability on carcass traits certain extraneous factors are often involved that may tend to bias the interpretation of the results. Such factors as sex, carcass weight, and season and station trends may contribute to variation. Sex and carcass weight can be controlled experimentally to a large extent. Season and station variations are more easily removed by statistical means.

a. Effect of Sex on Carcass Composition

Lacy (1932) in a study using 19 litters of Poland China pigs found highly significant differences between sexes. Gilts were found to have more loin while the barrows were considerably fatter when slaughtered on a constant weight basis.

Lush (1936) found gilts to be significantly longer than barrows. Gilts also had less backfat than barrows, but this difference was not as marked as the difference in length.

Crampton and Ashton (1945) in a study of 120 Yorkshire barrows and gilts found a statistically significant difference between sexes in loin lean area, backfat thickness, and carcass length. Gilts were longer with a larger loin eye but had less backfat. Results very similar to these were again reported by Crampton and Ashton (1946) in a study of 128 Yorkshires.

In their study of Yorkshire pigs from the Canadian Advanced Registry, Bennett and Coles (1946) found a mean difference of .15 inches in backfat thickness and .34 inches in carcass length between barrows and gilts. Two hundred eighty-one carcasses were used in the study.

Cobb (1952) at the Iowa Agricultural Experiment Station used data on 215 Poland China, 16 Landrace-Poland China, and 6 Landrace pigs in his study. Sex was found to have an important effect on both per cent lean cuts and backfat thickness.

Whiteman (1952) determined the mean difference on 81 full-sib pairs of barrows and gilts for several carcass traits. Gilts were found to average .61 inches longer and had .69 square inches greater loin area than barrows from the same litters. The barrows averaged .21 inches more backfat than gilts.

In a study involving carcass data from 12,084 Yorkshire barrows and gilts Fredeen (1953) found a difference of .23 inches in carcass length, .53 square inches in loin lean area, and .12 inches in backfat thickness between the two sexes. Anderson (1954) and DePape (1954) also found real sex differences in these traits.

Table I summarizes the effect of sex on the three traits being considered.

b. Effect of Season or Year on Carcass Variation

Lush (1936) in an analysis of Danish progeny testing records noted that there were definite yearly differences in feed economy and daily gain in addition to the various carcass traits. Body length and backfat thickness seemed most affected by yearly variation.

Yearly differences were significant on all performance traits considered by Johansson and Korkman (1950). Yearly differences were found to contribute 9 per cent of the total variation in body length and 14 per cent of the total variation in backfat thickness.

Stothart (1937) obtained data from 19 experiment stations covering a period of 6 years. He found that both station and season contributed a highly significant part to the total variation. Differing climatic conditions, health, and method of handling and feeding were considered partly responsible for this variation.

TABLE I

THE EFFECT OF SEX ON CARCASS TRAITS

Trait	Gilt to Barrow Equivalent	Carcasses in Study	Reference
Backfat Thickness	.12 inches	12,084	Fredeen (1953)
	.20	547	DePape (1954)
	.23	550	Anderson (1954)
	.15	281	Bennett & Coles (1946)
	.08	237	Cobb (1952)
	.21	162	Whiteman (1952)
	.13	128	Crampton, *et al.* (1946)
	.20	120	Crampton, *et al.* (1945)
Carcass Length	-.23 inches	12,084	Fredeen (1953)
	-.60	547	DePape (1954)
	-.19	550	Anderson (1954)
	-.34	281	Bennett & Coles (1946)
	-.61	162	Whiteman (1952)
	-.50	128	Crampton, *et al.* (1946)
	-.40	120	Crampton, *et al.* (1945)
Loin Lean Area	-.53 square inches	12,084	Fredeen (1953)
	-.55	547	DePape (1954)
	-.69	162	Whiteman (1952)
	-.70	120	Crampton, *et al.* (1945)

Fredeen (1953) reported that province and year differences accounted for 7 to 18 per cent of the total variance in nearly all carcass traits. A greater contribution was made by year differences in loin area, but this was attributed largely to differing measurement techniques.

c. Effect of Carcass Weight on Carcass Characteristics

McMeekan (1940) in an extensive study involving the effect of plane of nutrition on tissue development found a definite order of tissue development in the pig. Skeletal tissue was found to develop first followed by muscular tissue with fat deposition the last to occur.

Hammond and Murray (1937) found that an increase of ten pounds in carcass weight resulted in an increase of .48 inches in carcass length. Stothart (1938) obtained almost identical results in carcass length and an increase of .08 inches in backfat thickness for every ten pound increase in carcass weight.

Fredeen (1953) reported that carcass measurements showed an almost linear response to weight change with the heavier carcasses having more length, greater backfat thickness, and a larger loin lean area.

Anderson (1954) reported a greater effect of carcass weight on backfat thickness than the workers cited previously. In his investigation an increase of five pounds in carcass weight brought about an increase of .18 inches in backfat. Length also increased .18 inches for every five pound increase in carcass weight.

d. Estimates of Heritability

Several estimates of heritability for backfat thickness and carcass length are found in the literature; however, the estimates on loin lean area are few in number. A summary of the estimates for these traits as found in the literature is presented in Table II.

The variation in the estimates for a particular trait is probably due to a large extent to sampling error. It is possible, however, that actual breed differences do occur.

In general, it is thought that traits concerned with skeletal growth and development are the most highly heritable. This would include such traits as carcass length or leg length. Estimates of heritability of carcass length range from .40 (Fredeen, 1953) to .89 (DePape, 1954). The average of these estimates is about .60.

The estimates of heritability for loin lean area have not been consistent. DePape (1954) and Fredeen (1953) found this trait to be highly heritable. Their estimates of .71 and .66 respectively were over four times as large as the estimate of .16 obtained by Stothart (1947). With the wide range in heritability estimates for loin lean area and the limited amount of information available in the literature concerning the trait it appears that further investigations are needed to establish the extent to which this trait is affected by genetic influences.

TABLE II

SUMMARY OF HERITABILITY ESTIMATES FOUND IN LITERATURE

Trait	Statistical Method of Calculation[1]	Degrees of Freedom	Estimate	Reference
Carcass Length	P	647, sires	.40	Fredeen (1953)
	R_{fs}	58, sires	.42	Stothart (1947)
	P	67, sires	.48	Anderson (1954)
	P	445, sires	.52	Johansson & Korkman (1950)
	P	64, sires	.67	DePape (1954)
	P	127, sires	.89	DePape (1954)
	P	62, sires	.73	Dickerson (1947)
	P	122, sires	.78	Lush (1936)
	D	320, dams	.81	Lush (1936)
	Ave.	--	.54	Lush (1936)
Backfat Thickness	P	40, sires	.12	Blunn & Baker (1947)
	P	122, sires	.80	Lush (1936)
	D	320, dams	.55	Lush (1936)
	Ave.	--	.47	Lush (1936)
	P	62, sires	.54	Dickerson (1947)
	R_{fs}	58, sires	.37	Stothart (1947)
	P	445, sires	.52	Johansson & Korkman (1950)
	P	647, sires	.38	Fredeen (1953)
	P	67, sires	.40	Anderson (1954)
	P	19, sires	.67	Whiteman (1952)
	P	64, sires	.76	DePape (1954)
	P	127, sires	.22	DePape (1954)
Loin Lean Area	R_{fs}	58, sires	.16	Stothart (1947)
	P	647, sires	.66	Fredeen (1953)
	P	127, sires	.71	DePape (1954)

[1] Methods of calculation are as follows:

P - Paternal ½ sib correlation from the analysis of variance.

D - Maternal ½ sib correlation from analysis of variance.

R_{fs} - Regression of progeny on mean of parental full sibs.

Ave.- Average of 3 methods: paternal ½ sib correlation, maternal ½ sib correlation, and correlation between progeny average of sire and son.

Heritability estimates for backfat thickness range from .12 to .80 with the average about .45. Blunn and Baker's (1947) estimate of .12 is much lower than other workers have reported.

Method of statistical analysis may be responsible for some of the variation in heritability estimates obtained. Maternal half-sib correlation will give a higher estimate than a paternal half-sib correlation if a maternal influence exists. This maternal influence does not seem to be as important in carcass traits as it is with factors concerned with growth.

e. Phenotypic Correlations

Phenotypic correlations describe the linear relationship among different traits in the same individual in the particular population under study. These correlations are especially needed and useful in construction of selection indexes (Hazel, 1943). Phenotypic correlations will be determined by the environmental effects as well as the genetic contributions to the particular traits which are under consideration.

Numerous workers have reported on the relationship between backfat thickness, loin lean area, and carcass length. A summary of these reports is found in Table III.

The correlations between backfat thickness and carcass length are, in general, negative with the one exception to this being a positive correlation of .06 reported by Anderson

TABLE III

PHENOTYPIC CORRELATIONS BETWEEN TRAITS

Traits Correlated	Correlation	Reference
Backfat Thickness With Carcass Length	-.20	Lush (1936)
	-.38	Lush (1936)
	-.22	Aunan & Winters (1949)
	-.62	Brown, et al. (1951)
	-.36	Johansson & Korkman (1950)
	-.27	Fredeen (1953)
	.06	Anderson (1954)
	-.34	DePape (1954)
Backfat Thickness With Loin Lean Area	-.37	Brown, et al. (1951)
	-.44	Whiteman (1952)
	-.26	Whiteman (1952)
	-.12	Fredeen (1953)
	-.41	Hazel & Kline (1952)
	-.28	DePape (1954)
Carcass Length With Loin Lean Area	.38	Aunan & Winters (1949)
	-.07	Fredeen (1953)
	.06	Crampton (1940)
	-.18	Stothart (1938)
	.08	Bennett & Coles (1946)
	-.02	Bennett & Coles (1946)

(1954). The negative correlation between these two traits seems quite probable when slaughtering on a constant weight basis. Longer pigs would necessarily be smaller in some other dimension at a constant weight.

The correlations reported between carcass length and loin lean area have been varied and inconsistent. Estimates range from .38 (Aunan & Winters, 1949) to a -.18 (Stothart, 1938). These differences may well be representative of the differences in the populations which were studied. Increasing the length of carcass in certain lines or breeds may bring about a corresponding decrease in meatiness or muscling. Other lines may not be affected in this manner.

All correlations between backfat thickness and loin lean area as found in the literature have been negative. Estimates range from a -.12 to -.44. This indicates that the fatter carcasses produce less lean meat if these two traits are indicative of the total amount of fat and lean cuts in the carcass. This again would be expected assuming slaughter on a constant weight basis.

MATERIALS AND METHODS

1. Description of Data

a. Source of Materials

The data used in the study were obtained from 531 carcasses from pigs slaughtered in the Swine Breeding Project at the Oklahoma Experiment Station in conjunction with the Regional Swine Breeding Laboratory. From this number 304 carcasses were from the Stillwater station and 227 from Fort Reno. The Stillwater data covers a period of seven seasons from the fall of 1953 through the fall of 1956. The Fort Reno data includes the seasons from the spring of 1954 through the fall of 1956 with the exception of the fall of 1955 when no data were available. Pigs from the Fort Reno station were slaughtered by Wilson & Company, Oklahoma City. Backfat thickness and carcass length measurements were made in the coolers of the Wilson & Company plant. The loins from these carcasses were purchased and brought to the college meat laboratory for loin lean area measurements. Except for a small number of pigs, the Stillwater carcasses were processed at the college meat laboratory. Pigs which were not slaughtered at the meat laboratory were taken to Wilson & Company and handled in the same manner as the Fort Reno carcasses. All pigs were slaughtered at about 210 pounds.

A distribution of carcasses by season and station is given in Table IV. Information was available on only 336 carcasses for loin lean area while measurements were taken on all 531 carcasses for backfat thickness and carcass length. There were approximately two pigs per dam and eight pigs per sire represented in the analysis. Carcasses from 497 barrows and 34 gilts were used in the study. Carcass data on the gilts were adjusted to a barrow equivalent.

All pigs used in the study were crossbred pigs. This eliminated the possible error that might be introduced due to inbreeding of the litters. All pigs at the Stillwater station were a two-way cross as a result of mating the line 8 Durocs with the line 9 Beltsville No. 1. A three-way cross was used at Fort Reno breeding the line 14 Hampshires to the 8 x 9 crossbreds described above. Reciprocal crosses of the above mating systems were used at both stations.

The method of handling the pigs used in the study was somewhat different at the two stations. The pigs at Fort Reno were self-fed in groups on pasture while the pigs at Stillwater were self-fed by test litters of 4 pigs in dry-lot from weaning to market weight.

b. Carcass Measurements

All measurements were taken on the chilled carcasses with at least a 24 hour chilling period after slaughter. The following techniques and methods were used in measuring.

TABLE IV

DISTRIBUTION OF CARCASSES BY SEASON AND STATION

STILLWATER

Season	Carcasses Length	Carcasses Backfat Thickness	Carcasses Loin Lean Area	Sires
1953 Fall	32	32	31	8
1954 Spring	40	40	40	5
1954 Fall	56	56	54	6
1955 Spring	47	47	46	6
1955 Fall	42	42	--	5
1956 Spring	50	50	50	6
1956 Fall	37	37	37	6
Totals	304	304	258	42

FORT RENO

Season	Carcasses Length	Carcasses Backfat Thickness	Carcasses Loin Lean Area	Sires
1954 Spring	59	59	--	6
1954 Fall	56	56	--	7
1955 Spring	33	33	--	5
1956 Spring	30	30	30	3
1956 Fall	49	49	48	6
Totals	227	227	78	27

carcass length - the average of both sides of the carcass measured from the anterior edge of the first rib to the aitch bone.

backfat thickness - the average of four measurements taken opposite the first rib, seventh rib, last rib, and last lumbar vertebra on both sides of the carcass.

loin lean area - (a)* the product of the width times the depth of the loin eye muscle at the last rib using the loin from the right side of the carcass.

(b)** planimeter tracing of the loin eye muscle at the last rib.

(c)*** planimeter tracing of the loin eye muscle at the 10th rib.

* = Stillwater data, fall of 1953 and spring of 1954.

** = Stillwater data, fall of 1954 and spring of 1955.

*** = Stillwater and Fort Reno data, spring of 1956 and fall of 1956.

The loin lean area tracings were made on the right loin whenever possible unless an uneven split of the carcass during slaughter had scored the loin eye muscle. It was found that a more accurate tracing could be made on an untrimmed loin as the backfat prevented the muscle area of the loin from spreading while the tracing was being made.

2. Statistical Methods

In the statistical analysis for determining estimates of heritability the major considerations are the removal of the nonhereditary factors discussed in the previous section and the estimation of variance components associated with sires, dams, and error.

a. Correction for Sex and Carcass Weight

In as much as only 34 gilts were represented in the data used in the present study it was not considered feasible to attempt to determine sex differences in the population under study because of the large error that might be introduced by the small numbers. Recognizing from previous work that real sex differences do occur, it was thought necessary to make some adjustment to convert the records on these 34 gilts to a barrow equivalent. A weighted mean difference was used to make this adjustment by averaging all results which could be found in the literature. The weighted mean gave more emphasis to studies involving large numbers of pigs. This was accomplished by multiplying the differences found in a particular study times the number of pigs in that study, and finally, dividing these results by the total number of pigs in all the investigations which were reviewed. The previous work used in arriving at these sex differences are those summarized in Table I. From this analysis the following results were applied to the data as correction factors for converting the gilt measurements to a barrow equivalent:

carcass length - -.25 inches

backfat thickness - .13 inches

loin lean area -	
(length x width)	-.53 square inches
(planimeter)	-.35 square inches

The adjustments made on planimeter readings for loin lean area were adjusted downward in direct relationship to the means for the two methods of measurement.

Complete information was not available concerning the carcass weights on the pigs used in the analysis. As a result, the analysis was computed on the basis of slaughter at a constant weight. The mean and standard deviation were computed on the weights which were available on 236 carcasses. The average carcass weight was 148 pounds with a standard deviation of 6 pounds. It is thought that this small variation due to differences in carcass weight will have little effect on the final heritability estimates.

b. Analysis of Variance

The analysis of variance in a nested classification with unequal sub-class numbers used in determining the variance components has been described by Snedecor (1956) and Anderson and Bancroft (1952). An application of this method as it applies to animal breeding and determination of heritability is given in a study by King and Henderson (1954). The theoretical analysis of variance as it applies to the present study is given in Table V.

The statistical model for analysis of the data adjusted for sex is as follows:

$$Y_{ijklm} = u + a_i + t_{ij} + s_{ijk} + d_{ijkl} + e_{ijklm}$$

For backfat thickness and carcass length:

$i = 1, 2 .$
$j = 1, \ldots\ldots, 12.$
$k = 1, \ldots\ldots, 69.$
$l = 1, \ldots\ldots, 260.$
$m = 1, \ldots\ldots, 531.$

For loin lean area:

$i = 1, 2 .$
$j = 1, \ldots\ldots, 8.$
$k = 1, \ldots\ldots, 46.$
$l = 1, \ldots\ldots, 169.$
$m = 1, \ldots\ldots, 336.$

The symbols may be described as follows:

Y_{ijklm}	is the observed phenotypic value of the $m^{\underline{th}}$ pig, belonging to the $l^{\underline{th}}$ litter, sired by the $k^{\underline{th}}$ sire, farrowed in the $j^{\underline{th}}$ season at the $i^{\underline{th}}$ station.
u	is an effect common to all pigs.
a_i	is an effect common to all pigs farrowed at the $i^{\underline{th}}$ station.
t_{ij}	is an effect common to all pigs farrowed at the $i^{\underline{th}}$ station during the $j^{\underline{th}}$ season.
s_{ijk}	is an effect common to all pigs of the $i^{\underline{th}}$ station, $j^{\underline{th}}$ season, and sired by the $k^{\underline{th}}$ sire.
d_{ijkl}	is an effect common to all pigs of the $i^{\underline{th}}$ station, $j^{\underline{th}}$ season, $k^{\underline{th}}$ sire, and farrowed in the $l^{\underline{th}}$ litter.
e_{ijklm}	is an effect common to the $m^{\underline{th}}$ pig, of the $l^{\underline{th}}$ litter, by the $k^{\underline{th}}$ sire, in the $j^{\underline{th}}$ season, at the $i^{\underline{th}}$ station. This would include all environmental effects which would cause littermates to differ from one another.

TABLE V

THEORETICAL ANALYSIS OF VARIANCE IN DETERMINING HERITABILITY ESTIMATES

Source of variation	d.f.	Sums of Squares	Mean Squares	Variance Components
Total	$N - 1$	T		
Between stations	$y - 1$	Y		
Between seasons within stations	$r - y$	$R - Y$		
Between sires within seasons	$f - r$	$F - R$	V_3	$E + k_1D + k_2S$
Between dams within sires	$d - f$	$D - F$	V_2	$E + k_1D$
Between littermates	$N - m$	$T - M$	V_1	E

N = total number of carcasses

r = number of seasons

m = number of dams

Y = between station sum of squares

R = between season sum of squares

y = number of stations

f = number of sires

T = total sum of squares

TABLE V (Continued)

F = between sire sum of squares

M = between dam sum of squares

V = computed mean square of variance

k_1 = approximately the average number of carcasses per dam

k_2 = approximately the average number of carcasses per sire

E = variance between full-sibs

D = extra variance within groups of paternal half-sibs, this extra variance would be the amount contributed by different dams

S = variance which is contributed by the sire or the added variance between non-sibs as compared with paternal half-sibs

The assumptions under the above model are that all effects, except u, have a mean of zero and a variance of σ^2.

Variance components for sire, dam, and the error term as shown in Table V were determined by equating the expected mean squares to computed mean squares and substituting in the known elements of the equation. From these variance components estimates of heritability may be obtained by methods described by Lush (1948). Three methods of half-sib correlations may be used in obtaining estimates. These methods are:

$$\text{(I)} \qquad \frac{4\,(S)}{S + D + E}$$

$$\text{(II)} \qquad \frac{4\,(D)}{S + D + E}$$

$$\text{(III)} \qquad \frac{2\,(S + D)}{S + D + E}$$

The symbols are explained in Table V.

The paternal half-sib correlation is usually considered to give the most reliable estimate of heritability. It is less affected by maternal influences and common environmental effects than is the maternal half-sib correlation. The reliability of the paternal half-sib correlation is dependent upon the number of degrees of freedom for sires, the magnitude of the epistatic effect on the sire component, the amount of environmental correlations between paternal half-sibs, and the validity of the assumption concerning random mating.

Common pre-test environment could introduce some non-genetic likenesses which may tend to overestimate heritability.

Deviations from random mating may change the distribution of additive genetic variance and bias the results. The effects that the above two factors would have in the present study are not known, but their effects are presumed to be small.

c. Phenotypic Correlations

Phenotypic correlations were determined on an intra-season-station basis thus eliminating any effect due to differences in means which may be due to time trends or changes in management. This also eliminates any effect that differences in measurement techniques would have for loin lean area. The following formula as given by Snedecor (1956) was used in determining the correlations after removing the station and season effect.

$$r = \frac{\Sigma x_1 \ x_2}{\sqrt{(\Sigma x_1^2) \ (\Sigma x_2^2)}}$$

Where X_1 = variable 1 N = number of observations

X_2 = variable 2

$$x_1^2 = \Sigma X_1^2 - \frac{(\Sigma X_1)^2}{N}$$

$$x_2^2 = \Sigma X_2^2 - \frac{(\Sigma X_2)^2}{N}$$

$$x_1 x_2 = \Sigma X_1 X_2 - \frac{(\Sigma X_1) \ (\Sigma X_2)}{N}$$

RESULTS AND DISCUSSION

a. Season and Station Variability

The means and standard deviations by seasons are given for each trait under consideration in Table VI. The means, standard deviations, and coefficients of variation computed on an intra-station, intra-season basis are summarized in Table VII.

A slight increase in carcass length over the period of the study is apparent in the Stillwater data. This same trend is not so obvious in the Fort Reno data although there are marked seasonal differences. There is a steady increase in carcass length from the fall of 1953 to the spring of 1956 with a mean difference of .7 inches between these two seasons at the Stillwater station. At Fort Reno large increases were made in the mean carcass length up to the spring of 1955, but much of this increase was lost the next two seasons. The standard deviations for carcass length would indicate there is less variability in the Fort Reno herd.

Seasonal trends for backfat thickness are not apparent in the Stillwater data, however a definite reduction did occur in backfat thickness at the Fort Reno station. This reduction amounted to about .25 inches in the 3-year period covered in the study. There appears to be little difference

TABLE VI

SEASON MEANS AND STANDARD DEVIATIONS

STILLWATER

Season	Carcass Length mean	Carcass Length standard deviation	Backfat Thickness mean	Backfat Thickness standard deviation	Loin Lean Area mean	Loin Lean Area standard deviation
1953 Fall	28.9	.84	1.65	.17	5.63	.77
1954 Spring	29.2	.85	1.75	.14	5.50	.45
1954 Fall	29.1	.73	1.63	.16	3.87	.47
1955 Spring	29.3	.84	1.57	.18	3.76	.44
1955 Fall	29.4	.74	1.62	.19	--	--
1956 Spring	29.6	.91	1.77	.15	3.48	.53
1956 Fall	29.3	.91	1.56	.16	3.85	.47

FORT RENO

Season	Carcass Length mean	Carcass Length standard deviation	Backfat Thickness mean	Backfat Thickness standard deviation	Loin Lean Area mean	Loin Lean Area standard deviation
1954 Spring	28.7	.66	1.70	.14	--	--
1954 Fall	28.9	.73	1.73	.14	--	--
1955 Spring	29.5	.56	1.74	.24	--	--
1956 Spring	29.3	.70	1.62	.16	3.42	.45
1956 Fall	29.1	.81	1.47	.16	3.50	.44

TABLE VII

MEANS, STANDARD DEVIATIONS, AND COEFFICIENTS OF VARIATION

(Corrected for Sex and Computed on an Intra-station, Intra-season Basis)

Trait	Mean	Standard Deviation	Coefficient of Variation
Carcass length	29.2	.78	2.7%
Backfat thickness	1.66	.16	9.6%
Loin lean area	4.05	.50	12.3%

in the variation for backfat thickness at the two stations.

The differences in the season means for loin lean area can be largely attributed to the change in measurement technique. Data from the first two seasons were obtained by the multiplication method explained earlier. Calculation of the coefficient of variation by season indicates that both the multiplication method and planimeter readings may be used in an analysis if computation is on an intra-season basis.

The standard deviations and coefficients of variation shown in Table VII compare favorably with those reported by other workers. Fredeen (1954) reported a coefficient of variation of 2.9 per cent and a standard deviation of .84 for carcass length. A coefficient of variation of 13.9 per cent for backfat thickness and 14.4 per cent for loin lean area also compares quite closely with the results in the present study. DePape (1954) found a standard deviation of .24 and .57 for backfat thickness in his analysis of earlier data from the Fort Reno and Stillwater stations. Since the mean and standard deviation given in Table VII for loin lean area are a pooled result of two different methods of measurement, they are not indicative of either method specifically.

b. Estimates of Heritability

The mean squares obtained in the analysis of variance for each trait are given in Table VIII. Significant differences were found between seasons, between sires, and between dams for carcass length and backfat thickness. The highly

TABLE VIII

ANALYSIS OF VARIANCE FOR CARCASS TRAITS (MEAN SQUARES)

Source of Varation	Carcass Length		Backfat Thickness		Loin Lean Area	
	d.f.	mean squares	d.f.	mean squares	d.f.	mean squares
Between Stations	1	5.23	1	.0069	1	36.3446
Between Seasons within Stations	10	2.58*	10	.3787**	6	29.1692**
Between Sires within Seasons	57	1.23**	57	.0548*	38	.6022**
Between Dams within Sires	191	.63**	191	.0317**	123	.2187
Between Littermates	271	.46	271	.0194	167	.2059

* Significant at the 5% level
** Significant at the 1% level

significant seasonal variance for loin lean area is attributed to the change in measurement technique during the study. Differences between dams were not significant for loin lean area. Sire differences were highly significant at the one per cent level.

The components of variance were computed from the calculated mean squares by the formula as shown in Table V. Using these components the heritability estimates were calculated by the half-sib correlation as shown in Table IX.

TABLE IX

ESTIMATES OF HERITABILITY

	$\frac{4S}{S+D+E}$	$\frac{4D}{S+D+E}$	$\frac{2(S+D)}{S+D+E}$
Carcass length	.50	.54	.52
Backfat thickness	.42	.84	.63
Loin lean area	.79	.10	.44
(planimeter only)	.54	.26	.40

The estimates obtained by all three methods for carcass length are in close agreement with the estimates of Lush (1936), Johannson and Korkman (1950), Stothart (1947), and Anderson (1954). Almost identical estimates were obtained by the three methods in the present study indicating the maternal influences for this trait are small. DePape (1954) also found a small maternal effect on this trait.

The paternal half-sib correlation estimate of .79 for loin lean area in the present study is larger than other workers have reported but is in relatively close agreement with DePape (1954) and Fredeen (1953). The maternal half-sib correlation estimate of .10 is much lower than would be expected but the reason for this is not apparent. The average of the paternal and maternal half-sib correlations gave similar results for loin lean area when the length times width measurements were not included as compared with pooling both methods of measurement as previously described.

The estimate of .42 for the heritability of backfat thickness using the paternal half-sib correlation is in close agreement with Lush (1936), Stothart (1947), Fredeen (1953), and Anderson (1954). The much higher estimate of .84 using the maternal half-sib correlation may give an indication of the effect of common environment and maternal influences on this trait.

c. Phenotypic Correlations

All phenotypic correlations were based on the total variance and covariance within season and station. This method eliminated any time trends and also any effect of changing methods of measurement used with loin lean area. The results of these simple correlations are shown in Table X.

Phenotypic correlations between carcass length and backfat thickness, and loin lean area with backfat thickness were negative and highly significant. This is in close agreement with the correlations reported by other investigators as summarized in Table III. The negative correlation between those traits is to be expected when slaughtering at a constant weight. An increase in length, for example, will require some other dimension of the carcass to be reduced. This would mean that either measures of fatness or leanness, or both, will be reduced. Similarly, increasing the amount of fat in a carcass will decrease the amount of lean on a percentage basis of the total carcass if other factors are constant.

TABLE X

PHENOTYPIC CORRELATIONS BETWEEN TRAITS
(computed intra-season and station)

	Backfat Thickness	Loin Lean Area
Carcass length	-.36**	.10
Backfat thickness		-.27**

**Significant at the 1% level

The correlation between carcass length and loin lean area was .10 and only approached significance at the 5 per cent level. Comparing this correlation with the correlation between carcass length and backfat thickness it appears that as the length of carcass increases it will have a greater effect on backfat thickness than on loin area.

The phenotypic correlations between these traits are influenced by the amount of genetic correlations and the various environmental effects. These may be either antagonistic or acting in the same direction.

d. Application and Significance of Results

The estimates of heritability are of value as an indication of how much emphasis to put on a trait or how much permanent improvement can be made per generation. In carcass traits where measurements cannot be made on the breeding animal, heritability becomes important in determining the breeding worth of the individual by the use of closely related individuals. As the heritability increases, more emphasis can be placed on the phenotype of these closely related individuals. Phenotypic selection for a trait of low heritability may actually impair the total improvement that can be made if this trait is given much importance in a selection program. As the number of traits being considered in a selection program increases less emphasis can be put on each individual trait. Emphasis on a trait of low heritability will actually result in slow improvement in this trait and at the same time, limit the selection pressure that can be exerted on other traits which may be of importance in total merit. This is an important consideration in determining what carcass traits should be used in swine improvement.

Hazel (1943) discusses a method of constructing selection indexes which will give the greatest genetic improvement per generation when selecting for several traits simultaneously. This genetic improvement will depend on (1) the selection differential, (2) the multiple correlation between aggregate breeding value and the selection index, and (3) genetic variability. The greatest opportunity for improvement from selection comes in making the multiple correlation between breeding value and the selection index as large as possible. Phenotypic correlations, heritability, genetic correlations and relative economic importance among traits are factors which should be considered to give maximum accuracy in constructing selection indexes to increase the multiple correlation between the breeding value and the selection index. The relative importance of carcass length, backfat thickness, and loin lean area in a selection program should be based on these relationships.

Phenotypic correlations are of value in determining if there is a linear association between traits. A high correlation indicates a change in one trait is associated with a corresponding change in the second trait. When increased length is desired and at the same time increased backfat thickness is undesirable, a negative correlation would be most advantageous. A positive correlation between these two traits would mean that as one trait increased in desirability, the other would become less desirable. If this correlation was genetically controlled, it would mean very slow improvement in total carcass merit. Fredeen (1953) found that the genetic correlations and the phenotypic correlations between the traits being considered were in relatively close agreement. The phenotypic correlations found in the present study indicate that simultaneous selection for the three traits being considered would give favorable results.

The importance of heritability in a selection program for several traits simultaneously has been discussed previously. Results of the present study and those reported in the literature indicate that differences in heritability of carcass length, backfat thickness, and loin area are not large. In most studies estimates for carcass length have been slightly higher than estimates for the other two traits. A more exact knowledge of the heritability of these traits would increase the accuracy of a selection index.

The relative economic importance of backfat thickness and loin lean area are interrelated to a great extent. Under the present system of marketing, either on a live grade or carcass grade basis, backfat thickness receives more emphasis than measures of leanness such as loin area. This is due mainly to ease of measurement in the carcass and the ability of most hog buyers to detect differences in backfat between hogs more easily than muscling differences on the live animal. This would indicate that from the producer's standpoint backfat thickness should be given more economic importance in construction of selection indexes than loin area.

It is difficult to make a tangible comparison between the economic importance of carcass length with the other two traits. An increase in length of carcass will increase the per cent loin and the per cent belly in the carcass. The economic importance of this change will be dependent on the relative prices between these two cuts and also their relationship in price to the other primal cuts. Due to the physiological and anatomical relationship between backfat thickness and length, it is necessary for a carcass to be of a certain length to be in the range of desirability for backfat thickness at a constant weight.

From the economic standpoint it appears that more emphasis should be placed on carcass backfat and length until a certain range of desirability is met for these traits. The index might then be modified with more emphasis placed on loin lean area.

The total amount of improvement that could be made by the use of a selection index would be increased tremendously if the genotypes could be recognized precisely and were not confused by the effect of environment, dominance and epistasis.

SUMMARY

The main purpose of the study was to obtain estimates of heritability for carcass length, backfat thickness, and loin lean area and to determine the phenotypic correlations between these traits.

Five hundred thirty-one carcasses from the swine breeding project at the Oklahoma Experiment Station were used in the study. These carcasses were from 304 pigs at the Stillwater station and 227 from the Fort Reno station. Carcasses from 34 gilts were included in this number. All carcasses from gilts were converted to a barrow equivalent by the use of correction factors before the analysis of the data. The data were collected over a four year period with a total of twelve pig crops represented in the study from the two stations.

Heritability estimates obtained from the analysis of variance using the paternal half-sib correlation were as follows:

carcass length	.50
backfat thickness	.42
loin lean area	.79

A much higher estimate of .84 was obtained for backfat thickness using the maternal half-sib correlations. This may be due to sampling error or to a large maternal influence on this trait. A maternal effect was not indicated in the data on loin lean area and carcass length.

Phenotypic correlations were calculated on an intra-season-station basis thus removing the effects any time trends or changes in management would have on the results. A highly significant negative correlation of -.36 was found between backfat thickness and carcass length. Backfat thickness was also significantly correlated with loin lean area with a correlation of -.27. Carcass length and loin lean area were positively correlated, but the correlation of .10 between these two traits was not significant.

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