A FURTHER INVESTIGATION OF SPECIFIC GRAVITY AND OTHER MEASURES OF PORK CARCASS VALUE

By

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INTRODUCTION

The relatively low prices paid for slaughter hogs in recent years has caused many swine husbandmen to re-evaluate the future of the swine industry. From the turn of the century, the average prices paid for hogs and cattle, though subject to minor fluctuations, followed about the same general increases and declines until about 1948. Since then, pork producers have been at a decided disadvantage with respect to prices paid for slaughter animals.

The usual reason given for this discrimination is that most slaughter hogs yield carcasses that are too fat, causing a surplus of lard which, in turn, depresses the value of the live hog. Packers, too, agree that this is one of the primary reasons for the comparatively low value of slaughter hogs, although they, as a group, make little or no attempt to pay prices that are indicative of differential carcass values. It would, therefore, appear that it is squarely up to the swine producer to make whatever changes are necessary in his breeding and management system to improve his product to the extent that consumer demand will cause pork products to regain their competitive position.

Although many attempts have been made to produce more desirable carcasses by changes in feeding and management, the resultant carcasses have not been increased in value to a very great extent. Consequently, these systems of producing leaner carcasses, though still receiving some attention, do not show much promise.

Breed differences in carcass merit indicate that some portion of the variation is of an hereditary nature. The extent of the heritable variation varies with the genotype of the animals concerned and with the environment in which they are grown. Any permanent improvement in pork carcasses must necessarily be made by changing the genotype of the animals through selection of the individuals with the more desirable phenotypes.

Carcass evaluation necessitates slaughtering the animals and, therefore, makes progeny or sib testing of potential breeding stock the only method of evaluating an individual's genotype, other than judging the individual on his external conformation. Investigations have shown that differences in external form are largely due to differential rates of skeletal growth and fat deposition.

The problem, therefore, becomes one of obtaining methods of carcass evaluation that are easily obtained, precise in demonstrating real differences, and heritable enough that real progress can be made by selection for leaner, more desirable carcasses.

Many measures of carcass merit are in use today. This study is an attempt to evaluate some of the more common of these measures and to investigate in detail the use of carcass density (specific gravity) as a measure of carcass value.

Since barrow and gilt carcasses are both utilized in slaughter studies and it is frequently impossible to balance experiments with respect to the sex of the animals, it is necessary to know to what extent sex is a factor in carcass studies. If the differences in the various measurements that are due to sex are relatively constant and not subject to hereditary and environmental differences, then corrections can be used to adjust data in which the proper sex proportions do not exist.

REVIEW OF LITERATURE

Reports on carcass investigations are not extensive. Whiteman (1951) reviewed the field of swine carcass work generally and Gard (1952) gave a review which covered the effect of limited rations on swine carcasses. McMeekan (1940) and (1941) and Callow (1948), (1949) and (1950) have reported the results of some very detailed investigations of the relationships between fat, lean, bone, and tendons from a very wide variety of carcasses from cattle, sheep, and swine.

There are several measures or evaluations of swine carcasses that are in use. Very few attempts have been made to compare these measures. It seems only logical that some are better than others, and that perhaps some may give no additional information and thus should be discarded.

One of the first workers to use fat thickness as a measure of carcass value was Scott (1927), who was studying the effect of carcass and leg length upon carcass yield and quality. He observed that as fat thickness increased, there was a decrease in the percentage lean cuts. He did not indicate where the measures of fat thickness were made, nor did he attempt to correlate the fat thickness to any other characteristic.

The value of average back fat thickness for estimating the fatness of carcasses was investigated by Hankins and Ellis (1934). Their study included 60 carcasses from hogs of different breeds fed under different systems of management. The correlation between the average of five back fat measurements (opposite the first and seventh thoracic vertebras, the last lumbar vertebra, and at three and one-half and seven vertebras forward from the last lumbar vertebra) and the ether extract of the edible portion of the carcass was 0.84 ± 0.04. The thickness at the seventh thoracic vertebra was the best single back fat measurement.

The ease with which back fat thickness could be obtained in addition to its apparent high degree of association with carcass fatness caused it to become one of the most common measurements taken on pork carcasses. Many workers have estimated its correlation with many other characteristics.

Ellis and Hankins (1937) obtained correlations of about 0.6 to 0.7 between the individual back fat thickness measures and the final live weight of the hog. Live weight varied from less than 100 pounds to over 300 pounds in their study.

McMeekan (1941), using a highly variable sample of hog carcasses, estimated the correlation between the fat content of the carcass and average back fat thickness to be 0.95. The same degree of association was found between the fat content of the carcass and the average of three measurements of back fat thickness over the rump. His most predictive single measurement of back fat thickness was that taken over the loin. It was correlated to the fat content of the carcass with a coefficient of 0.93. These correlation coefficients would appear to be higher than could be expected in a more uniformly treated lot of swine carcasses.

Willman and Krider (1943) attempted to judge the fatness of live hogs and found a correlation of 0.42 between visual estimates and the average back fat thickness. They also found back fat thickness positively correlated to live weight, 0.47 and ham circumference, 0.44. Small nonsignificant correlations were found between back fat thickness and loin lean area, -0.11 and ham lean area 0.01.

Aunan and Winters (1949) found that the average of three back fat measurements (thickest, thinnest, and opposite the seventh rib) was negatively correlated with the lean content of the carcass, -0.625, and with percentage of five primal cuts, -0.585. Average back fat thickness was positively correlated with the fat content of the carcass, 0.792, and with the fat content of the ham 0.656.

Brown _et al._ (1951) studied the association of carcass measures on the carcasses from two groups of hogs. They found average backfat thickness negatively correlated to specific gravity, -0.68 and -0.49; loin lean area, -0.37 and -0.54; percentage primal cuts, -0.67 and -0.56; percentage lean cuts, -0.72 and -0.70; ham lean area, -0.38 and -0.50; percentage protein, -0.51; and percentage moisture, -0.45. Average back fat thickness was positively correlated to percentage fat cuts, 0.69 and 0.74, and percentage ether extract, 0.48.

Cummings and Winters (1951) found a correlation coefficient of -0.65 between percentage yield of five primal cuts and average back fat thickness. This correlation was reduced to -0.61 when put on a within breed basis, and was -0.57 when carcass weight was held constant.

Aunan (1951) made detailed studies of 70 carcasses from hogs, of several different breeding groups varying in weight from 170 to 256 pounds. He found back fat thickness (average of thickest, thinnest, and opposite the 7th rib) positively associated with carcass weight, 0.74; dressing percentage, 0.47; percentage fat tissue in carcass, 0.70; and percentage fat of ham, 0.66. Back fat thickness was negatively correlated with percentage of five primal cuts, -0.63; percentage lean cuts, -0.67; percentage lean in the carcass, -0.61; and percentage lean of ham, -0.47. He also found that the back fat measure opposite the seventh rib was the best single back fat measurement.

Using partial correlations to remove the effect of carcass weight, Aunan found that back fat thickness was more strongly associated with the fat content of the carcass, the percentage primal cuts, and the percentage lean cuts, than when carcass weight was allowed to vary.

It, therefore, appears that the usefulness of average back fat thickness of the carcass to measure its fatness has been well established. It is positively associated with degree of fatness and negatively associated with degree of leanness. The strength of this association varies with the experimental material used.

Another measure of carcass merit that is in widespread use is that referred to thus far as "loin lean area". It is a measure in square inches of the cross-section of the loin eye muscle (longissimus dorsi) in the region of the last rib. The measurement used is usually the product of the two dimensional measurements. However, some workers are making tracings of the muscle for later, more accurate measurement with some kind of a planimeter.

McMeekan (1941) found a correlation of 0.84 between the loin lean area and the total muscle in the carcass. Winkler and others (1941) indicated that the size of the loin eye muscle was an indication of grade and carcass leanness in their system of grading carcasses. Dickerson and co-workers (1943) stated that the area of lean in the loin indicated muscling more accurately than their ham lean area which was the area of lean in the ham center cut calculated from the ham circumference, and the thickness of the ham fat.

Crampton (1941) and Bennett and Coles (1946) indicated separately, as evidence of the fact that gilts were leaner than barrows, that gilts had a larger area of lean in the loin cross section. Aunan and Winters (1949) found a simple correlation of 0.35 between loin lean area and the total lean in the carcass. However, the partial correlation coefficient was 0.58 when carcass weight was held constant.

Brown et al. (1951) found loin lean area correlated to the following carcass measurements to the indicated extent in two groups of data: specific gravity, 0.46 and 0.68; average back fat thickness, -0.37 and -0.54; percentage primal cuts, 0.41 and 0.20; percentage lean cuts, 0.51 and 0.78; percentage fat cuts, -0.47 and -0.80; ham lean area, 0.66 and 0.64; percentage ether extract in half carcass, -0.60; percentage protein in half carcass, 0.60; and percentage moisture in half carcass, 0.54. The slaughter weight of these 66 hogs was 216 pounds, with a standard deviation of 5.75 pounds. They concluded from partial correlation studies of their data that the relatively small difference in carcass weights had little effect on the correlations between the various items measured.

Aunan (1951) found relatively weak associations between loin lean area and four measures of carcass composition when weight was allowed to vary. When partial correlations were used to remove the effects of carcass weight, the correlations of loin lean area with the measures changed as follows: back fat thickness, 0.15 to -0.41; percentage fat in the carcass, -0.27 to -0.50; percentage primal cuts, 0.23 to 0.47; and percentage lean tissue in the carcass, 0.37 to 0.55.

It is, therefore, fairly well established that loin lean area is positively associated with carcass leanness and negatively associated with carcass fatness. Its usefulness does not appear to be as great as that of back fat thickness, because of its lower degree of association with the lean and fat components of the carcass.

Since Hankins and Ellis (1934) found a correlation of 0.93 between the percentage fat in the trimmed right ham and the percentage fat in the entire carcass, other workers have attempted to establish some measure or combination of measurements of the ham that would give a high predictive value for the merit of the whole carcass. Warner and others (1934) reported a correlation of -0.77 between the percentage trimmed ham and loin and the percentage fat in the carcass.

Hiner and Hankins (1939) showed that the plumpness of hams was positively correlated, 0.77, to the average back fat thickness. McMeekan (1941) found very strong associations between the fat, lean, and bone of the hams and the respective components of the carcasses. His correlations between the ham and carcass components were 0.90 for percentage bone; 0.97 for percentage lean; and 0.88 for percentage fat. By using the components of the loin also, these correlations were increased slightly.

As already indicated, Dickerson <u>et al.</u> (1943) calculated the area of the lean in the center cut of the ham and found that it was not as good a measure of muscling as the area of lean in the loin eye. Willman and Krider (1943) used a planimeter to measure the area of lean in the butt of the ham and found no relationship between this lean area and the fatness of the carcass as indicated by the thickness of the back fat. There was a correlation, however, between the ham lean area and loin lean area (measured with a planimeter) of 0.53. Ham lean area was also correlated to ham circumference, 0.58.

Hetzer and others (1950) found that the percentage yield of lean meat in the hams was correlated to the percentage yield of five primal cuts, 0.72 for barrows and 0.73 for gilts. Brown _et al._ (1951) used the product of the length and width measures of the lean in the face of the ham and found that it was, as a whole, somewhat less closely associated with the other carcass characteristics than was the loin lean area measured in the same manner. As in the case of loin lean area, it was positively associated with carcass leanness.

Cummings and Winters (1951) measured the association of percentage loss in skinning hams to other carcass measurements. They found a simple correlation of 0.47 between this ham trim and average back fat thickness. This correlation was 0.18 on an intra-breed basis, and 0.33 when calculated independent of carcass weight. The simple correlation was negative and nonsignificant between percentage loss in skinning hams and percentage primal cuts, but was -0.26 and significant on an intra-breed basis.

Aunan (1951) used the area of lean in the center cut of the ham but found that it was not significantly correlated to either the lean or fat content of the carcass. He did find, however, that the percentages of lean and fat in the ham were highly correlated to the percentages of lean and fat in the carcass. The correlation between percentage fat in the ham and percentage fat in the carcass was 0.88, and for lean in the ham and in the carcass, 0.89. He also stated that the components of the ham were more closely associated with the components of the carcass than were the component parts of either the loin or the belly.

It would appear that the use of ham measures are not very beneficial in predicting carcass merit. The use of the lean area of either the face or the center cut is less predictive of carcass leanness than is the loin lean area. Ham circumference is apparently associated with fatness, but to a lesser extent than back fat thickness. On the other hand, the component parts, i.e. lean and fat tissue, are very indicative of their respective percentages in the carcass as a whole.

The use of primal cuts (ham, loin, belly, and shoulder or picnic and Boston butt) and lean cuts (all of the former except the belly) has been widespread. These measures have usually, however, been used as the criterion of carcass value, with few attempts to actually determine if they are giving the desired information. These measures can be evaluated only by a complete dissection of the carcass or by chemical analysis.

Such studies have been few. Most workers who publish results of dissection or chemical studies do not indicate whether or not analyses were made of the association of their results with primal cuts or lean cuts.

Aunan and Winters (1949) found a correlation of 0.60 between the percentage lean of the carcass and the percentage of primal cuts. Brown *et al*. (1951) used chemical determinations and found the correlations between both primal cuts and lean cuts and percentage ether extract to be 0.67. However, percentage lean cuts was more highly correlated to percentage protein (0.66) than was percentage primal cuts (0.59). Percentage lean cuts also showed a higher association with specific gravity. The correlation coefficient was 0.78 compared to a coefficient of 0.69 between percentage primal cuts and specific gravity.

Aunan (1951) also found that percentage lean cuts was more closely associated to the fat and lean portions of the carcass than was percentage primal cuts. Percentage lean cuts was correlated to the percentage lean in the carcass, 0.86 and to the percentage fat in the carcass -0.85. Percentage primal cuts was correlated to these two components 0.77 and -0.73, respectively.

Although the evidence is limited, it appears that the percentage lean cuts is more closely associated to carcass leanness than percentage primal cuts. This is as expected, since it is the observation of several workers that the percentage of belly (the difference between lean an primal cuts) varies almost independently of the other cuts. In addition, the size of the belly cut is subject to more cutting error than are the other cuts.

In 1951 Brown and others introduced the use of specific gravity as a measure of pork carcass merit. They found that specific gravity was more highly correlated with the percentages of primal cuts, lean cuts, fat cuts, ether extract, and protein, than was average back fat thickness. It appeared that specific gravity gave as good a measure of the relative amounts of fat and lean in the carcass as did either fat or lean cuts, and was much easier to obtain.

Kraybill and others (1951) used a wide variety of cattle in a study of specific gravity as a measure of carcass fatness. They found a correlation between specific gravity and fat content of the carcass of -0.96.

Their range of specific gravity was from 1.017 to 1.070 and that of fat content was from 13.6 to 39.5 per cent. Thus, the range with which they worked was considerably wider than it would be in a practical application of their findings. Their degree of association is, therefore, probably higher than would be found in a less variable group of carcasses.

The effect of sex upon the pork carcass has long been observed, but few attempts have been made to measure its extent or to determine if it is influenced by breeding or environment.

Lacy (1932) studied the effect of sex on the primal cuts in swine carcasses. Using litter mates, it was found that barrows gain faster and have a higher yield of fat cuts other than belly. Gilts were found to yield more loin and ham. McMeekan (1940) in his work on the shape of the growth curve, found that barrows were characterized by less bone and muscle and more fat than gilts. The extent of the differences was modified by the rate of growth (plane of nutrition) imposed. Both High-High and Low-Low levels of maintenance caused the difference between sexes to be reduced.

Crampton (1941) found that gilts yielded more ham, shoulder, and more lean in the bacon rasher than barrows. Gilts also had a 13 per cent larger loin lean area than barrows. Bennett and Coles (1946), from a study of Yorkshire barrows and gilts, reported essentially the same findings.

Hetzer and others (1950) stated that gilts yielded about 1.0 per cent more primal cuts and .72 per cent more lean meat in the hams than barrows. It thus remains to be determined whether these differences are fairly constant or subject to alteration under different conditions.

MATERIALS AND METHODS

There were 316 carcasses used in the study. With the exception of 20 hogs that were obtained from the Animal Husbandry Swine Barn, the hogs were all from the Swine Breeding Project of the Oklahoma Agricultural Experiment Station in cooperation with the Regional Swine Breeding Laboratory. Table 1 shows the breeding groups represented and the season of birth of the pigs used in the study. Eight groups were inbred Duroc lines; twelve groups were single- or multiple-line crosses of Durocs; seven crossbred groups were included; and there were Landrace Polands, and outbred Durocs, Chester Whites, Poland Chinas, Hampshires, and Berkshires.

Except for the 20 pigs from the Animal Husbandry Department Swine Barn, and 20 pigs each from the 1949 spring and 1951 fall farrowing seasons, the pigs slaughtered were from test pens. These test pens usually include four pigs from a litter, which are self fed a good ration from weaning until they reach market weight to measure the individual rates of gain and the litter efficiency of gain. The two slaughter animals from each of the 1949 spring and 1950 spring litters were barrows. In the other seasons, one barrow and one gilt from each litter were slaughtered.

During the first four seasons, the first pigs in each test lot to reach the weight range desired were used in the carcass study, while the last two seasons, slaughter animals were chosen at random.

Symbol	Meaning
CxS (8)	Line cross pigs from line C sire and Line S dam. Combined to form line 8 in 1950.
OD	Outbred Duroc.
M2	Minnesota #2.
LCD	Line Cross Duroc.
Pol	Poland China.
LP (9)	Landrace Poland, now called line 9.
M1	Minnesota #1.
Line 13	MIxM2-S.
CW	Chester White.
Hamp	Hampshire.
Berk	Berkshire.

Letters and numbers indicate inbred Duroc lines unless otherwise indicated.

Table 1. Number of Hogs Slaughtered, By Breeding and Season of Birth.

Season:	'49S	'49F	'50S	'50F	'51S	'51F	
Breeding:							
DUROCS							
Line T	4		5	8			
3	5		6		(4)	1	
5	4						
C	4						
S	4						
10						3	
11						2	
12						2	
Tx3, 3xT	6	8	5	8			
Sx3	6						
Cx3	6						
5x3	6						
N10x5		4	4				
CxS(8)			6			8	
10x3						2	
11x3						1	
Tx3-5		6					
Sx3-5		6					
Cx3-5		6					
T-3xC-S				8			
OD	6	6					
CROSSBREDS							
M2xLCD		6					
PolxLCD		6					
TxLP				8			
M1xLP				8			
ODxLP				4			
8x9,9x8					47,(16)	16	
Line 13						3	
OTHER BREEDS							
LP(9)		5	5	4		8	
CW			6*				
Pol			4*				
Hamp			6*				
Berk			4*				
TOTALS	51	53	51	48	47,(20)	46	316

* Obtained from the Animal Husbandry Department, Oklahoma A & M College.

() These pigs were killed by students in class, and the right hams used in a specific gravity study.

Except for the 1951 fall pigs, the pigs were taken off feed when they reached the weight range of 218 to 230 pounds. The 1951 fall pigs were weighed off when they weighed from 200 to 214 pounds.

When animals reached the desired weight range, they were taken off feed for about twenty-four hours and then slaughtered in the college meat laboratory. The carcasses were prepared packer style, with head off and leaf fat removed. After chilling for a period of time, (this was held constant within seasons) the carcasses were air and water weighed (Brown, et. al., 1951) and carcass measurements were made. Figure 1 (Page 19) shows a photograph of the equipment used in obtaining the water weight of the carcasses. The half carcass was completely immersed in water in the tank from the string on the arm of the Toledo balance scales. The weight recorded on the scales was read to the nearest .01 pound. This weight represented the amount that the half carcass weighed in excess of the amount that the displaced water weighed.

The carcasses were again chilled for two to three days, and then cut to obtain lean measurements and cut-out weights. All measurements (except loin lean area) were obtained from both halves of the carcass, and the average used for purposes of analysis. The entire carcass (both sides) was cut to obtain the percentages of primal cuts.

The following measurements and evaluations were studied:

Specific gravity (Sg) was obtained by dividing the air weight of the carcass by the air weight minus the water weight.

Average back fat thickness (BF) was the average of three measurements which were taken opposite the first and last ribs, and opposite the sixth lumbar vertebra. Arrows indicate these locations (Fig. 4, Page 22).

Loin lean area (La) was the product of the two dimensional measurements of the loin eye muscle (longissimus dorsi). Figure 2 shows the location of these measurements.

Loin lean area (Lap) was the planimeter reading of a tracing of the loin eye muscle.

Ham lean area (Ha) was the product of the two dimensional measurements of face of the ham exposed when the ham was removed from the half carcass. Figure 2 shows the location of these measurements.

Ham lean area (Hap) was the planimeter reading of a tracing of the lean in the face of the ham.

The percentages (based on chilled carcass weight) of three lean cuts (LC), the ham (H), the loin (L), and the ham and loin (H&L).

Figure 3 shows the extent to which the cuts were trimmed. The hams were skinned about two-thirds of the way to the shank, and the fat was trimmed to less than one-fourth inch in thickness. The loins had all external fat removed, except scraps at the blade and ham ends. The shoulders were trimmed New York style, with all external fat removed about one-half to two-thirds of the way to the shank. Bellies were squared and trimmed as large as possible. The lower edge was trimmed to about the teat line, and the loin edge straightened to form a rectangle. The forward end of the belly coincided with the cut to remove the shoulder at the third rib. The posterior end was cut as long as possible after removing the ham at a line perpendicular to the long axis of the ham and halfway between the aitch bone and the sixth lumbar vertebra. Figure 4 shows the general method of dividing the carcass.

The specific groups of hogs used in each phase of this study will be described in more detail later. The methods of statistical analysis will also be indicated where appropriate.

Figure 1. The equipment used in obtaining the specific gravity values of the swine carcasses.

Figure 2. Cross section of loin and face of ham showing where measurements were taken for area of lean approximations.

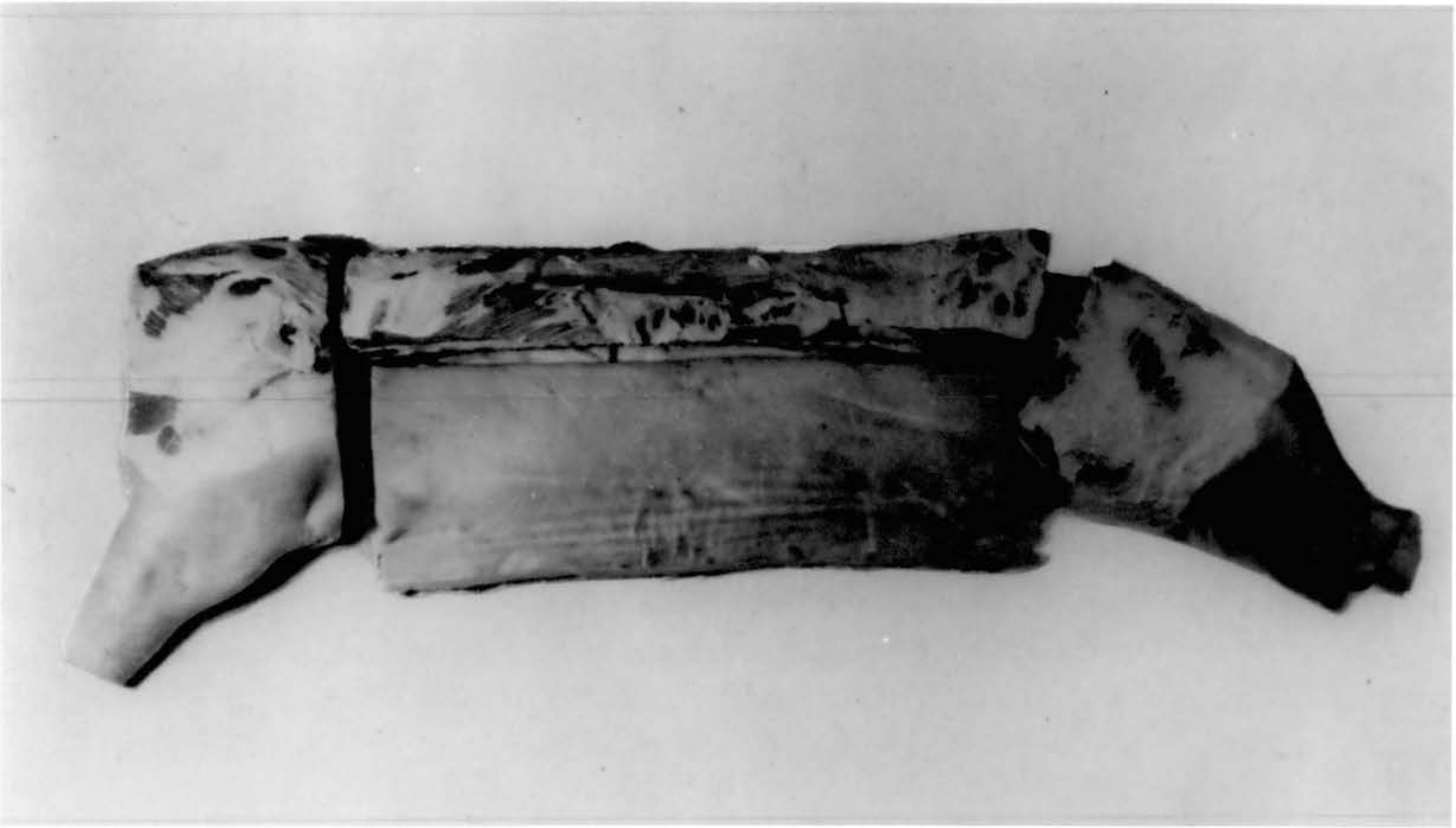

Figure 3. Four primal cuts from a half carcass showing the extent to which the cuts were trimmed.

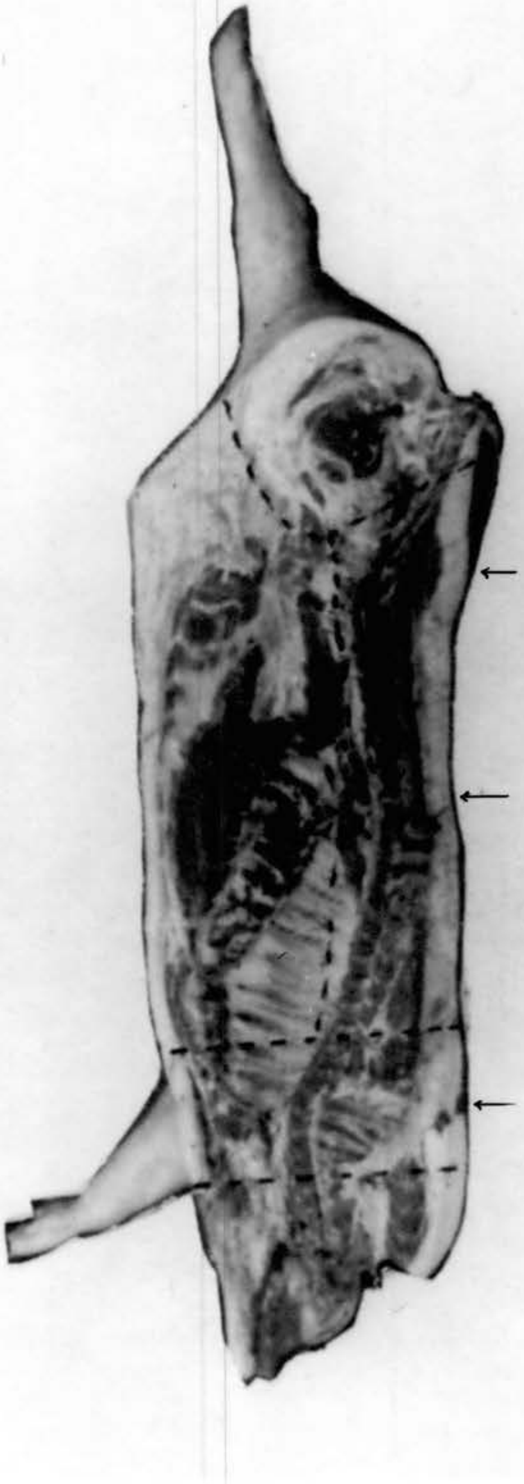

Figure 4. Half carcass showing the method of dividing the carcass (dashed line) and locations of back fat measurements (arrows).

SECTION I

Specific Gravity as a Measure of Carcass Leanness

The pork carcass is composed of three principal tissues, i.e. fat, muscle (lean), and bone. The skin is very difficult to separate from the subcutaneous fat and is usually included with it. In amount skin is proportional to body surface and should be relatively constant for hogs of a given weight. There are also ligaments and tendons, but these are usually included with the bone.

The amount of bone was found by McMeekan (1940) to be principally a function of the age of the animal. It was the most difficult tissue of the carcass to change by changing the level of growth of the animal. It is known of course that rachitic conditions will change bone growth and perhaps the density but this should not be a factor in normally grown, healthy animals.

McMeekan's (1940) findings that the number of muscle fibers in a muscle tissue is determined before the birth of the animal is in agreement with the general belief of most histologists. The size to which muscle fibers grow is determined by the amount of exercise that the animal gets, the level of maintenance to which he is subjected and probably genetic factors. The size of any muscle is determined by the number and size of the muscle fibers and the amount of intramuscular fat present. Callow (1948) indicates that as the animal fattens there is an increase in the ratio of muscle to bone tissue. Whether this change is due to muscle fiber growth, the deposition of intramuscular fat or both is not known.

It has long been known that the fat of the carcass was the most variable portion. It is easily altered by changes in the nutrition of the animal. The two principal locations of fat in the carcass are under the skin (subcutaneous) and throughout the lean tissues (intramuscular). There are also fat deposits in the bones. Callow (1948) indicates that there is a correlation between subcutaneous and intramuscular fat but that the proportions of the total that are in each location may vary greatly from animal to animal. It seems reasonable to assume that the fat in the bone may also vary with the total fat in the carcass.

With regard to their densities, these three tissues differ greatly. Fatty tissue is lighter than water, muscle (lean) tissue is heavier than water and bone is the heaviest of the three. If the percentage and density of skin and percentage and density of bone are constant for a given weight of carcass, then the lean and fat portions are the only two variables and their relative amounts should be measured by a measure of density. Probably, the original assumption is incorrect but it may be near enough to the truth to allow specific gravity to measure carcass composition with good precision. Also, the density of the lean tissues should vary with the amount of intramuscular fat present but this, too, may be of little overall importance.

The extent to which the foregoing assumptions are individually or collectively correct should determine the usefulness of specific gravity as a measure of carcass composition. This section of the study is devoted to determining the degree of usefulness of specific gravity and the degree to which these assumptions may be false.

One of the principal phases of the study was an attempt to determine how accurately specific gravity would measure the amounts of ether extract, water, and protein in the lean meat of hams. For this study three untrimmed hams from test carcasses were used as were the right untrimmed hams of 20 carcasses from hogs killed by the meats class. These 20 hogs were killed in one week, four daily, and the specific gravity determined on the right half of each carcass on the Saturday following their slaughter. The right ham was removed from each half-carcass by the students the following week and held in the cooler at about 36°F. until the following week.

At that time each ham was weighed to the nearest .05 pound and the water weight determined to the nearest .005 pound. The skin and all external fat was then removed in one piece and the same weights were taken on it. The bone and lean tissue remaining were also weighed in the same manner. The lean was then separated from the bone and kept in one piece and the weights were determined on it. These same weights were also taken on the bones. From these weights the percentages (based on untrimmed ham weight) and specific gravities were determined on each of the pieces. Table 2 shows the means and standard deviations of the percentages and specific gravities (Sg) of the parts of the hams. The average back fat thickness (BF) from the half-carcasses is also shown for the benefit of those who are familiar with this carcass measurement.

Table 2. Means and Standard Deviations of Specific Gravities* (Sg) and Percentages of Ham Parts and Analyses of the Lean Portion of the Ham.

	Mean	Standard Deviation	Coefficient of Variation %
Sg (half carcass)	37	9.0	24.3
Sg(ham)	54	8.3	15.4
% fat and skin	28.4	4.2	14.8
Sg (fat and skin)	-28	6.2	22.1
% lean and bone	71.3	4.2	5.9
Sg (lean and bone)	77	7.0	9.1
% lean	60.8	4.0	6.6
Sg (lean)	50	5.6	11.2
% bone	10.4	0.8	7.7
Sg (bone)	209	32.3	15.5
BF	1.50	0.27	18.0
Constituents of lean tissue:			
% Ether Extract	12.9	3.2	24.8
% Moisture	67.0	2.6	3.9
% Protein	19.1	0.9	4.7

* All specific gravities used (unless otherwise specified) are coded as follows:

(Specific Gravity - 1) X 1000 = Coded Value
(1.054 - 1) X 1000 = 54

The lean portions of the hams were run through a coarse grinder twice for mixing purposes then two samples were taken from each. Each sample was very finely ground and then re-sampled twice for determinations of percentages of ether extract, moisture and protein. These chemical determinations were made by Dr. V. G. Heller of the Department of Agricultural Chemistry. The means and standard deviations of these determinations are also shown in Table 2. The average values of the four samples that were analyzed on each ham were used to study the association of the percentages of ether extract, protein and moisture with specific gravity.

Results

Table 3 shows the simple correlation coefficients between the percentages of the three determinations on the lean and also their correlation with the specific gravity of the lean. If specific gravity accurately measures the proportions of ether extract, moisture and protein in tissue, then it must depend upon them for its value. It should be computable by the use of a multiple regression equation. Such an equation was developed and is given at the bottom of Table 3 (Snedecor, 1948).

Table 3. Simple Correlations Between the Ether Extract (EE), Moisture (M), Protein (P), and Specific Gravity (Sg) of the Lean Portion of the Ham.

	% M	% P	% EE
Sg (ham lean)	.832	.820	-.868
% M		.643	-.981
% P			-.741

Est. Sg = 1.54 (% M) + 3.61 (% P) + .23 (% EE) - 125

The correlation between the estimated specific gravities and those actually found measures the success of estimating specific gravity from chemical analysis. The method used to obtain this coefficient was the one described by Snedecor (1948). To develop the multiple regression equation given in Table 3 it was necessary to compute the standard partial regression coefficients of specific gravity on each of the independent variates, percentage moisture, percentage protein and percentage ether extract. These and the simple correlation coefficients between specific gravity and each of the independent variates were as follows:

	% M	% P	% EE
Correlations with Sg	.832	.820	-.868
Standard regressions of Sg on	.622	.508	.118

$R^2 = (.832)(.622) + (.820)(.508) + (-.868)(.118) = .831640$

$R = 0.912$

The quantity R (0.912) is known as the multiple correlation coefficient. It is the correlation between the estimates of specific gravity from the multiple regression equation and those actually calculated. As stated before, it measures the success of estimating the specific gravity of the lean of the ham from the percentages of moisture, protein and ether extract obtained by chemical analysis of the samples of lean of the ham.

The value of R^2 measures the portion of the variance of specific gravity that was dependent on the independent variates. $(1 - R^2)$ is the portion of the variance of specific gravity that was independent.

This means that only 17 per cent of the unrestricted variation in specific gravity would have occurred if the percentages of moisture, protein, and ether extract had remained constant.

The variance of the specific gravity of the lean of these 23 hams was 30.3 (sum of squares of the deviations from the mean, divided by n or 23.) Seventeen per cent of this quantity, 5.15 is what the variance of specific gravity would have been had the independent variates remained constant. If these data are considered to constitute a population, the square root of the above quantity, or 2.27, is the standard error of estimate.

However, if these data are considered to be a sample of a population, the standard error of estimate becomes the square root of $(1 - R^2)$ times the sum of the specific gravity deviations squared, divided by n - 4 or 19.

$$\sqrt{\frac{(1 - R^2)\sum sg^2}{n - 4}} = 2.50$$

Since four independent averages have been used in the regression (one for each variate), n-4 is the appropriate divisor for the partitioned sum of squares of deviations in calculating the standard error of estimate. This quantity, 2.50, measures the average failure of the specific gravity to be exactly determined by the percentages of moisture, protein and ether extract in the lean of the ham.

Since about 83 per cent of the variance of specific gravity was due to variation of the percentages of moisture, protein and ether extract, it seems reasonable to assume that specific gravity is measuring the proportions of these lean components fairly accurately. By comparing the regression coefficients of the multiple regression

$$\text{Est. Sg} = 1.54\ (\%\ M) + 3.61\ (\%\ P) + .23\ (\%\ EE) - 125$$

equation one can see that a unit change in percentage protein will have the greatest effect on specific gravity and the same change in percentage ether extract will have the least effect. Percentage protein and percentage moisture are positively correlated to each other and both are negatively correlated with percentage ether extract. Therefore, as percentage moisture and percentage protein increase, the percentage ether extract will decrease. But since the coefficients of the former are large relative to that of percentage ether extract, the value of specific gravity will increase also. This accounts for the positive correlations between specific gravity and percentage moisture 0.832 and percentage protein, 0.820 as shown in Table 3.

About 83 per cent of the variance of specific gravity has been accounted for. If specific gravity were a perfect criterion of the relative proportions of moisture, protein and ether extract, all or 100 per cent of its variance would be accounted for. It might, therefore, be interesting to figure out what factors could have accounted for the other 17 per cent of the variance.

It was assumed for purposes of the foregoing study that moisture, protein and ether extract constituted 100 per cent of the lean meat. Actually, about one per cent of these samples was not accounted for by the three constituents above. This includes, principally, the ash which though small in amount is nevertheless present and could account for part of the uncontrolled variance in specific gravity.

In any study involving the use of measurements, there are always mistakes. Some of these are made through carelessness and these one always tries to avoid, although one probably never is completely successful. Other mistakes are made through one's inability to measure with adequate accuracy. Both of these sources of variation are probably included in this study even though every effort was made to minimize or avoid them. There is no way to estimate their importance.

As will be discussed in more detail later, the temperature of the meat being water weighed, affects its specific gravity. The process of weighing and separating the hams was performed in a relatively warm room. It seems unlikely that the temperature of the lean meat at the time of water weighing was the same in every case.

Table 4. Mean Squares for Percentage Moisture, Protein and Ether Extract in the Ham Samples.

Portion of Lean	Source of Variation	Degrees of Freedom	Mean Square
Moisture	Between hams	22	26.25**
	Between samples	23	1.41**
	Within samples	41	.2790
Protein	Between hams	22	3.12**
	Between samples	23	.29**
	Within samples	46	.0277
Ether Extract	Between hams	22	40.93**
	Between samples	22	3.01**
	Within samples	40	.3903
Composition of Mean Squares	Between hams	$W + k_1 B + k_2 H$	
	Between samples	$W + k_1 B$	
	Within samples	W	

** Signifies probability of chance occurrence $< .01$

k_1 The average number of analyses per sample

k_2 The average number of analyses per ham

Another source of error involved the sampling of the hams preparatory to analysis of the samples. Brown and others (1951) were of the opinion that sampling error may have been of some importance in their work. An effort was made in this study to measure this error. Two samples were taken from the lean of each ham and two analyses were run on most of the samples. Table 4 gives the mean squares for percentages of moisture, protein, and ether extract in these ham samples. The composition of the mean squares is also included.

The variances were reduced to components of variance (Rigney and Blaser, 1948) in order to estimate the relative importance of each source. The basis for the reduction is given in the bottom of Table 4. The variance between analyses of the samples is W, that between samples of hams is W + B, and that between hams is W + B + H. It is very evident from the significance found among the mean squares in Table 4 that the components B and H were real sources of variation in these data. Table 5 shows the components of variance and gives the estimated importance of each.

Table 5. Components of Variance and Percentage of Total Variation Contributed by Each.

		Symbol	% Moisture	% Protein	% Ether Extract
Components of Variance	:Contribution of hams	H	6.571	7.082	10.249
	:Contribution of samples	B	.598	.130	1.358
	:Within Samples	W	.279	.028	.390
	:Total	T	7.448	7.240	11.997
Estimates of Relative Importance	:Ham differences	100 H/T	88.2	97.8	85.4
	:Sample differences	100 B/T	8.0	1.8	11.3
	:Analysis differences	100 W/T	3.8	.4	3.3

In the cases of percentage moisture and percentage ether extract, the sampling was certainly an important source of variation accounting for 8.0 and 11.3 per cent respectively of the total variation found in analyzing subsamples of the 23 hams. To go a step farther, the differences among hams accounted for 88.2, 97.8 and 85.4 per cent of the variation in the percentages of moisture, protein and fat in the subsamples analyzed.

If it can be assumed that the error variation between ham samples and between subsamples were from a normally distributed population, and there is no evidence that it was a radically non-normal one, the variability of the means can be estimated. The relationship, $\sigma^2_{\bar{x}} = \sigma^2/n$ indicates the extent that sample and subsample variances will affect the variance of the mean value. This is important because it was the mean values of the ham samples that were used in the calculations of correlation and partial regression coefficients. These means had a variance due to sampling and subsampling that was slightly less than half ($100B/K_1T$ plus $100W/K_2T$) of that portion which was not due to ham differences (H). In the cases of percentage moisture and percentage ether extract, 5.2 and 6.5 per cent of the variances of the means used in analysis were due to sampling and subsampling variations.

It seems, therefore, that the sampling of the ham lean for analysis was another cause of the failure of multiple regression technique to perfectly predict the specific gravity. The results here indicate that Brown and co-workers (1951) may have been correct in suspecting their sampling technique of being a source of error. They were sampling the lean cuts (lean and fat mixed), the fat cuts and the bones. In this case, we were sampling only the lean portion of the ham which was certainly a more homogenous mass than those which they were sampling.

It seems then in light of these known or suspected sources of variation, that some portion, perhaps most, of the seventeen per cent of the unaccountable variance in specific gravity is accounted for. It is conceivable that specific gravity was giving the exact relative proportions of the percentages of moisture, protein and ether extract in the samples. Certainly, it was giving sufficient accuracy to be a highly efficient method of comparing tissues for leanness.

Another method of checking the specific gravity technique for accuracy was also employed. Using the percentages and specific gravities of the pieces of these 23 hams, the specific gravity of each untrimmed ham was predicted. If there were no extraneous errors and if the specific gravity technique were perfect, the correlation between these predicted specific gravities and those actually obtained would be unity or 1.0. The method of estimation was as follows:

$$\text{Est. Sg (untrimmed ham)} = \% \text{ X Sg (fat and skin)} + \% \text{ X Sg (lean)} + \% \text{ X Sg (bone)}.$$

As would be expected, this correlation was not unity. It was 0.931. This should give a measure of the extent to which weighing errors and tissue temperature fluctuations prevented the expected unity correlation.

The Interrelations of Fat, Lean and Bone in the Ham and Half-Carcass.

In the ham as a whole or in the carcass, a higher proportion of the total is fatty and bone tissue as compared to the lean samples used in the previous study. As stated before, if the percentages and densities of skin and bone are relatively constant the carcass specific gravity should reflect proportions of fat to lean.

It was impossible to measure either amount or density of skin because of the inaccuracy of the method of skin separation. There were some data, however, on the amount and density of bone. The percentages and specific gravities of the parts of the previously described 23 hams were studied to get some idea of the relationships that existed between the parts. Table 6 gives the correlations that were obtained from this study. If specific gravity measures the relative densities of the tissues as suggested in the previous section, then it should vary with the amount of fat deposited in tissues such as lean or bone.

Table 6. Correlations Among the Percentages and Specific Gravities (Sg) of the Parts of the Ham.

	Sg (Half Carcass)	Sg (Ham)	Sg (Fat & Skin)	Sg Lean	Sg Bone	% Lean
Sg (Ham)	.949					
Sg (Fat & Skin)	.654	.611				
Sg (Lean)	.767	.779	.578			
Sg (Bone)	.554	.567	.220	.625		
% Lean	.761	.778		.521		
% Bone	.413	.468			-.181	.302
% Fat & Skin	-.828	-.849	-.630	-.558	-.253	-.948

$r = .413 = P_{.05}$ of chance occurrence.
$r = .526 = P_{.01}$ of chance occurrence.

The correlation of 0.949 between the specific gravities of the ham and of the half carcass suggests that the specific gravity measurement is not subject to large error. This relationship was studied a second time using the 46 carcasses from the 1951 fall farrowed pigs (Table 1). The correlation coefficient this time was 0.942. This high degree of association between the proportions of the tissues in the ham with the same tissues in the half carcass is in agreement with other workers (Aunan, 1951) (Hankins, _et_. _al_., 1934) (Hetzer, _et_. _al_., 1950) and (McMeekan, 1941).

Table 6 also indicates that as the percentage fat and skin of the ham increases, the specific gravities of all of the ham parts decreases. These results suggest that, as might be expected, the fat varies in both lean and bone with the level of fatness of the animal. The association between external fat and skin and intramuscular fat (as measured by its specific gravity) seems to be closer than between the former and the fat in the bone.

It is worth while to consider the original assumption that the percentage and density of bone be constant if specific gravity were to indicate the proportions of lean to fat. From Table 2 (Page 26) it will be noted that the specific gravity of bone was highly variable but that in percentage of the ham, bone was fairly constant. The estimated standard deviations were 32.3 and 0.8 respectively. The results in Table 6 suggest how the correlations were affected by these conditions.

Percentage bone, which was not highly variable, was less closely associated with the specific gravity of the ham than was bone density in these data. The correlation of -0.948 between percentage fat and skin and percentage lean suggests that one is almost exactly determined by the other. For this to be true, either percentage bone must be constant or it must be almost perfectly associated, on a percentage basis, with fat and lean. The correlation between the percentages of lean and bone suggests that the first alternative is more likely.

Another value from Table 6 was very interesting. The correlation estimate of -0.181 between percentage and density of bone may be of considerable significance. Bone has the greatest density of any tissue in the carcass. If the variation in amount or density of bone were sufficient to have a major effect on the carcass specific gravity, it could cause one who based selection on specific gravity to be exerting considerable selection pressure on the amount and density of bone. If these variables were strongly and positively correlated, this tendency would be increased.

In these data at least, both percentage lean and percentage fat were much more closely associated with specific gravity than was percentage bone. In fact, about 78 per cent $(1 - r^2)$ of the variance of specific gravity was independent of percentage bone. On the other hand, only about 28 and 39 per cent of the ham specific gravity variance was independent of percentage fat and skin and percentage lean respectively.

The density of the bone was associated with the density of the ham. However, since the density of the bone also contributes to the density of the ham, it is not known how much significance should be attached to this correlation value. The densities of lean and fat were more closely associated with ham density than was bone density.

These, also, contribute to ham density.

There were two other groups of carcasses (not reported in Table 1) from which some data could be obtained and studied. In the first of these groups of carcasses (32 Duroc carcasses from another project), percentage bone of the half carcass was correlated with the specific gravity (0.752), and to percentage lean cuts (0.763). Specific gravity was correlated to percentage lean cuts (0.783). When percentage lean cuts was held constant by a partial correlation technique (Snedecor, 1948) the correlation between percentage bone and specific gravity was reduced to 0.384. This suggests that the high association on the simple correlation basis was partially due to their joint correlations with percentage lean cuts.

The other group for study was composed of 31 half carcasses in which the following correlations existed:

	X_2 % Bone	X_3 % Lean Cuts	X_4 Sg (Bone)
X_1 Sg (half carcass)	.681	.904	.261
X_2 % Bone		.679	.111
X_3 % Lean Cuts			.132

$r_{12.3} = 0.214$

Although the correlation between specific gravity of the half carcass and percentage bone was high on a simple correlation basis, again it was materially reduced when percentage lean cuts were held constant by partial correlation.

Bone density was not, in this case, significantly correlated with any of the other variables.

These groups of data present some conflicting impressions. The last two groups indicate that percentage bone will cause specific gravity values to be in error with respect to the amounts of lean and fat in a carcass. Consequently, there seems to be little use in developing formulas of estimation based on specific gravity values.

On the other hand, selection for specific gravity would exert considerable selection pressure on percentage bone but this would be due to their joint covariation with lean cuts. The high correlation between specific gravity of the half carcass and percentage lean cuts is very desirable because an increase in lean cuts is what we really want in selecting for better carcasses. The amount of selection pressure, independent of percentage lean cuts, that would be exerted on percentage bone with a selection program based on carcass specific gravity would appear to be slight. This phase of the investigation needs further study.

External Factors Affecting Specific Gravity

External factors which affect the density of the water or the carcass would also affect a change and be a source of error in the specific gravity measurements taken. These factors might be classified as follows:

A. Factors affecting water density.
    1. Temperature
    2. Soluble Salts.

B. Factors affecting carcass density.
    1. Temperature.
    2. Surface tension.

These factors will be taken up individually.

Tap water in the college meat laboratory was found to vary in temperature from about 50°F. to about 75°F. during the year. According to a table of relative water densities (Hodgman, 1949) the difference in density at these two temperatures is about .00241. Specific gravity values are calculated to the nearest .001, and since tap water temperatures vary from season to season rather than from day to day it was not expected that water density would be a factor of any practical importance. Also, it had been observed that the temperature of the tank of water did not change even one degree with the weighing of as many as ten carcasses that were 20°F. colder than the water.

It was decided to measure the water temperature effect on specific gravity to see if this reasoning was correct. Since weighing a carcass in water has an effect upon subsequent water weights, the paired technique, using the two hams from a carcass, was used for this test. Water temperatures of 50°F. and 65°F. were used. A total of 16 pairs of hams were weighed.

From the table of water densities it was determined that the water density difference was .0011. The average difference in the specific gravities of the hams was .0007, even less than was expected. This might be partially explained by an observation that has been repeatedly made during the investigation of specific gravity. As will be explained later, as the carcass temperature goes up, the specific gravity goes down. From the moment that a carcass is immersed its water weight gets progressively less (for at least two hours). If this is due to the warming effect of the water, then the effect would have been more intense with the warmer water. This would tend to reduce the observed difference when weight records were slightly delayed while waiting for the pointer to come to rest. However, the deviation from expected needs no explanation because it was far from significant.

Any effects that varying concentrations of soluble salts might have on the specific gravity has not been investigated. The water supply at this institution is the product of a purification plant that draws the original supply from a large lake. This is thought to prevent any great deviation in the salt content of the water.

With respect to the effect of carcass temperature on specific gravity it has been observed in the course of the investigation that unchilled carcasses float. Several attempts were made to measure the effect of temperature on carcass density. On two different occasions sixteen half carcasses were water weighed, held in a warm room for a varying length of time and water weighed again. On one of these occasions a heater was blowing warm air on the carcasses between water weights.

A regression study indicated that the loss of water weight between weighings was definitely related to the time interval between weights. There was also a difference in regression coefficients between the occasion in which the warm air was blowing and when it was not. If it is assumed that the increased loss of carcass weight in water was due to the increased temperature of the carcass, then this study succeeded only in increasing confidence in the hypothesis that a warmer carcass weighs less in water. It gave no measure of the amount of weight loss per unit change in temperature. It was impossible to measure the average carcass temperatures.

Several attempts were made to get an estimate of this hypothesized dependency of specific gravity on temperature by separating the halves of the carcass at slaughter and putting a half carcass in each of two cooler rooms. This plan did not work because there were no clear cut differences in temperatures between the carcass halves. This procedure should work, however, if temperature differences could be obtained. It is suggested that under fairly standard conditions of measurement perhaps the effect of temperature on specific gravity is not of great practical importance. In all these data there have been no corrections made for temperature, yet specific gravity has apparently been quite accurate in measuring carcass differences.

It was not expected that surface tension would be a factor in obtaining specific gravity values. Nevertheless, in order to prevent overlooking a possibility, a small test was conducted. Seven chilled fatbacks were used. Each fatback was water weighed, quickly cut into four pieces so that surface area was increased about 50 per cent, and weighed again. The difference in these weights should measure the surface tension effect if it existed. The mean difference was less than what might have been expected due to the time element.

It seems then that of the suggested external factors that might cause the specific gravity technique to err, only carcass temperature appears to merit further investigation. It seems almost certain, both by reasoning and by observations, that as the carcass temperature increases, the specific gravity decreases. Neither the degree nor the practical importance of this relationship is known.

SECTION II

A Comparison of Some Measures of Carcass Leanness

The expense involved in the collection of research data and its analysis necessitates an occasional study to evaluate the measurements that are being taken. There have been many measurements developed to evaluate the pork carcass. Some of these have not stood the test of time and have been dropped. Others have never been investigated in sufficient detail to determine whether or not they warrant continued use.

There are certain requirements that should be met by good carcass evaluation methods or measures. These should include the following:

1. It is of utmost importance that any adequate carcass measure be highly associated with carcass leanness.
2. If improvement is to be made through breeding, the measure should be as highly heritable as possible.
3. In the interests of economy and accuracy, the carcass measure should be easy to obtain with a high degree of accuracy.
4. The carcass measure should be obtainable without appreciably reducing carcass value.

The purpose of this section of the study was an appraisal of the carcass measures in use at this institution.

The measurements that were studied included all of those listed under "Materials and Methods." The 203 carcasses used were from the 1949 spring, 1949 fall, 1950 spring, and 1950 fall pigs listed in Table 1. Simple intra breed correlations were calculated between all of the measurements for each of the seasons. It was apparent from these correlations that in the seasons (1949 fall and 1950 fall) in which there were sex differences, the coefficients of correlation were much higher than in those seasons in which sex was not a factor. Using the z transformation (Snedecor, 1948) it was determined that there were significant differences in the sizes of these correlation coefficients. Consequently, the coefficients for the seasons which included sex differences (1949 fall and 1950 fall) were combined to give the correlation coefficients hereafter referred to as the A group. The other two season's data were combined to give the B group. The z transformation was used in combining these coefficients of correlation.

Results

In order to make the results more readable, several tables have been prepared in which specific comparisons of interest were made. Specific gravity was compared to average back fat thickness (Table 7) because the latter has always been a good measure of carcass desirability.

Brown and others (1951) found that specific gravity was a better measure of carcass fatness than was average back fat thickness. These results in the present study (Table 7) are essentially the same.

In almost every case the association between specific gravity and the other measures of carcass leanness is closer than between fat thickness and the same measurements.

Table 7. A Comparison of Specific Gravity (Sg) and Average Back Fat Thickness (BF) Correlations and Other Carcass Measures.

Measure	Symbol	Group	Sg	BF
% Lean Cuts	(LC)	A	.868	-.785
		B	.647	-.590
% Ham & Loin	(H&L)	A	.888	-.701
		B	.586	-.457
% Ham	(H)	A	.806	-.634
		B	.572	-.527
% Loin	(L)	A	.789	-.623
		B	.450	-.311
Ham Lean Area (LXW)	(Ha)	A	.439	-.267
		B	.374	-.404
Ham Lean Area (Plan.)	(Hap)	A	.667	-.438
		B	.402	-.389
Loin Lean Area (LXW)	(La)	A	.602	-.436
		B	.336	-.264
Loin Lean Area (Plan.)	(Lap)	A	.689	-.433
		B	.465	-.289
Specific Gravity	(Sg)	A		-.746
		B		-.482

If there is a test that can be used to determine if these differences in correlation coefficients are significant, it is not known to the author. Some idea of the value of the size of the differences (assuming that they are real) can be had by determining the effect on the variance of one when the other is held constant. For instance, if percentage lean cuts were held constant, r^2 or about 75 per cent of the variance in specific gravity will be lost whereas only about 62 per cent of the variance in average back fat thickness would be lost (Data from first line, Table 7).

As mentioned before, the loin lean area measure can be obtained in two ways. The approximation method which is the product of the two dimensional measures is in much wider use at the present time than is the use of the planimeter to measure a tracing of the muscle. Table 8 gives a comparison of these two measures of the same thing.

Table 8. A Comparison of Two Measures of Loin Lean Area /Length x Width (La) vs Planimeter Reading (Lap)/.

Measure	Group	La	Lap
Sg	A	.602	.689*
	B	.336	.465
BF	A	-.436	-.433
	B	-.264	-.289
H	A	.604	.642
	B	.468	.471
L	A	.618	.668
	B	.440	.527
H&L	A	.681	.721
	B	.514	.590
LC	A	.667	.681
	B	.464	.562
Ha	A	.484	.497
	B	.607	.727*
Hap	A	.628	.668
	B	.607	.700
La	A		.878
	B		.796

* Probability of chance occurrence $<.05$, Hotelling's Test of Significance (1940).

It will be noted that although the planimeter reading gives a slightly higher set of correlation coefficients, the difference is significant in only two comparisons. According to Hotelling (1940) the test indicated in Appendix II is the appropriate one to use when testing the difference between the two correlation coefficients obtained when correlating two estimates of the same variable to another variable.

Table 9 is a comparison of the two methods of measuring the ham lean area. In this instance the planimeter method was better in the seasons where sex was a factor but the increased associations were not as great where sex differences were not included. The reason for this is not known.

Table 9. A Comparison of Two Measures of Ham Lean Area /Length x Width (Ha) vs Planimeter Reading (Hap)7.

Measure	Group	Ha	Hap
Sg	A	.439	.667**
	B	.374	.402
BF	A	-.267	-.438**
	B	-.404	-.389
H	A	.416	.611**
	B	.537	.554
L	A	.498	.624*
	B	.366	.491*
H&L	A	.513	.685**
	B	.490	.584
LC	A	.538	.706**
	B	.533	.602
La	A	.484	.628*
	B	.607	.609
Lap	A	.497	.668**
	B	.727	.700
Ha	A		.793
	B		.840

** Probability of chance occurrence $< .01$
* Probability of chance occurrence $< .05$
Hotelling's Test of Significance (1940).

Table 10 shows a comparison of the percentages of trimmed ham, loin and ham plus loin as measures of carcass leanness. It appears as if percentage ham plus loin was the best of the three followed by ham and loin in that order. The differences are not great but are substantially the same as reported by McMeekan (1941).

Table 10. A Comparison of the Percentages of Ham (H), Loin (L), and Ham Plus Loin (H&L) as Measures of Carcass Leanness.

Measure	Group	H	L	H&L
Sg	A	.806	.789	.888
	B	.572	.450	.586
BF	A	-.634	-.623	-.701
	B	-.527	-.311	-.457
Ha	A	.416	.498	.513
	B	.537	.366	.490
Hap	A	.611	.624	.685
	B	.554	.491	.584
La	A	.604	.618	.681
	B	.468	.440	.514
Lap	A	.642	.668	.721
	B	.471	.527	.590
LC lean cuts	A	.888	.817	.951
	B	.885	.738	.904
H	A		.614	.912
	B		.555	.852
L	A			.883
	B			.913

From the results of Section I and those in Table 7, (Page 46) it seems certain that the specific gravity of the pork carcass gives the best measure of leanness of any method used except the actual cutting percentages. It seems to be more closely associated with cut out measures of carcass leanness, it is easily obtained, not subject to great measurement error and does not affect the usefulness of the carcass in any way. If specific gravity is heritable to a reasonable extent, then it has all of the requirements of a good carcass evaluation measure.

To get an estimate of this necessary characteristic, all of the carcass records from the seasons included in Table 1 were studied in a search for half and full-sib slaughter animals. There were three seasons in which pigs from more than one dam by the same sire occurred. Hazel's (1947) method of half sib correlations was used (with simplifications) to estimate the heritabilities.

It was known that any estimate obtained would be subject to considerable error due to small numbers and varied breeding systems. To get some idea of this effect, the heritability was estimated for average back fat thickness because there are other estimates of its heritability for purposes of comparison. All heritability estimates were obtained from the same carcasses.

The sums of squares within sex were calculated separately for each season. The sire within line, dam within sire and pig within litter sums of squares were pooled. The mean squares for these three sources of variation and their composition are shown in Table 11.

It should be noted that the number of comparisons (degrees of freedom) on which these estimates are based is fairly small. Since heritability estimates are highly variable due to sampling, these estimates are only tentative. It can only be hoped that they are fairly precise.

Table 11. The Mean Squares for Sire Within Line, Dam Within Sire, and Pigs Within Litter and Their Theoretical Composition.

Source of Variation	Degrees of Freedom	Mean Squares		
		BF	Sg	H
Sire within line	19	.04744	56.3	.616
Dam within sire	26	.02822	35.4	.552
Pig within litter	61	.02433	23.0	.285

Composition of Mean Square:

Sire within line	$W + 2.05D + 3.62S$
Dam within sire	$W + 2.05D$
Pig within litter	W

The components of variance were calculated and estimates of the heritabilities of the three measures were computed. These estimates and components are included in Table 12.

Table 12. Components of Variance and Estimates of Heritability for Average Back Fat Thickness (BF), Specific Gravity (Sg), and Percentage Ham (H).

Component	Symbol	Measure		
		BF	Sg	H
Contribution from sires	S	.00531	5.77	.0177
Contribution from dams	D	.00190	6.05	.1302
Contribution of full-sibs	W	.02433	23.00	.2852
Total	T	.03154	34.82	.4331
Estimates of heritability	4S/T	.67	.66	.16

These data indicate that the heritabilities of specific gravity and average back fat thickness may be about the same. If this is true, it is very fortunate because the heritability of back fat has been estimated by other workers to be relatively high. Lush (1936), Dickerson (1947) and Johansson and Korkman (1950) found estimates of 0.47, 0.54 and 0.52, respectively, for the heritability of back fat thickness. In all cases large numbers of carcasses were used so that the effect of sampling would be less than in these data.

It was suspected in this tentative study that the heritability estimates would be too high because in many instances there were relatively high relationships between dams mated to the same sire and this would reduce the size of the component D in the analysis. If D were reduced, then T was also reduced by the same amount and the ratio 4S/T would be increased. The extent of this effect is not known and due to the tentative nature of the study no attempt was made to estimate it. Estimates of the relative importance of maternal effect could have been computed but these dam relationships would have been even more effective in making any estimates meaningless.

The heritability of percentage trimmed ham (0.16) was not as high as expected. Johansson and Korkman (1950) found an estimate of 0.61 for size and shape of the ham. It is not known just what constitutes their size and shape of the ham or how it was measured. It was hoped that percentage ham would be fairly highly heritable because of its high association with percentage lean cuts.

The comparable estimates of association that the two measures of loin lean area show with other measures of carcass leanness indicate that there is not much difference in their relative values. Since the length by width estimate is so much more easily obtained it is thought to be the more useful measure of the two. In either case the loin must be cut in two to determine the size of the eye muscle. This is a disadvantage to the commercial use of this measure of carcass merit, however, it should be remembered that the size of the loin eye muscle determines the real value of the pork loin to a large extent. Therefore, whatever its degree of association with carcass leanness it should be considered in any breeding system to improve pork carcasses from hogs that are deficient in this respect.

It might be reasoned that two measures are better than one. Since loin lean area is so important in determining the value of the loin its combination with a measure such as specific gravity might predict carcass leanness better than either taken alone. Using the multiple correlation technique described in Snedecor (1948) and percentage lean cuts as a criterion of carcass leanness such a study was made. It was found that the inclusion of loin lean area (La) to specific gravity raised the predictability of percentage lean cuts from 75 per cent (the square of the simple correlation between specific gravity and percentage lean cuts) to about 79 per cent (the square of the multiple correlation coefficient, 0.887) using data from the A group of carcasses.

The data indicates that the planimeter method of measuring the ham lean area is better than the estimate obtained from the product of the two dimensional measurements. However, even the better of these measurements is less closely associated with carcass leanness than is either specific gravity or average back fat thickness. Further, there is no carcass cut-out value that is dependent enough upon it to warrant its inclusion in a selection program. In short, there seems to be no justification for its use if such measures as specific gravity, average back fat thickness or loin lean area are used.

There seems to be little doubt that the ham value is a good index of the carcass value. Loin merit, too, is very indicative of carcass merit, but it does not appear to be quite as good an indication as the ham. A combination of the two is apparently better than either alone.

Throughout this portion of this study it has been assumed that percentage lean cuts was the best measure of carcass leanness. This may not be true in every case. As Callow (1948) observed there is a great variation in the amount of fat in the lean tissues of the body. In the 23 hams used in Section I the correlation between percentage fat and skin of the ham and percentage ether extract of the lean was 0.682. If certain hogs have a tendency to deposit more fat in their muscular tissue, this will increase the percentage lean cuts of their carcasses even though the actual leanness will not be changed.

SECTION III

The Effect of Sex on Carcass Measurements

The fact that gilt carcasses are leaner than barrow carcasses has been well established (Lacy, 1932; Warner _et_. _al_., 1934; Lush, 1936; McMeekan, 1940; Crampton, 1941; Bennett and Coles, 1946; and Hetzer _et_. _al_., 1950.) It is necessary that the extent of the carcass differences be known so that proper adjustment can be made in carcass data in which sex is a factor. It is also well to know if these differences are subject to great modification by either heredity or environment.

Among the slaughter animals listed in Table 1 there were four seasons (1949 fall, 1950 fall, 1951 spring, and 1951 fall) in which barrow-gilt full-sib pairs were slaughtered. These full-sibs had been subjected to the same general treatment throughout their lives so that the average differences which they showed in their carcass measurements should be a good measure of the overall sex effect. If the various measurements on the carcass are normally distributed in each sex, then the differences which they exhibited are also normally distributed. These differences were the units of measurement used in the statistical analysis.

Table 13 gives the number of full-sib pairs slaughtered each season, the mean difference for each carcass measurement each season, the overall average differences, and the standard error of the overall average differences.

Table 13. Average Differences Between Barrows and Gilts (Gilt Minus Barrow) for Some Carcass Measurements.

	'49F	'50F	'51S	'51F	Average	Standard Error
No. of Pairs	21	22	23	16		
Age at Slaughter, Days	1.86	5.68	18.00	10.01	8.99**	1.855
Specific Gravity	6.48	6.36	11.48	7.31	8.01**	.725
Average Back Fat, in.	-.17	-.16	-.32	-.18	-.21**	.023
Loin Lean Area (La) sq. in.	.62	.54	1.04	.50	.69**	.092
Carcass Length, in.	.65	.64	.64	.48	.61**	.098
Dressing Percentage[1]	-.37	-1.10	-1.03	-.79	-.83**	.165
Percentage Lean Cuts[2]	1.99	1.56	2.86	2.15	2.15**	.210
Percentage Ham[2]	.98	.70	1.22	.88	.95**	.087
Percentage Loin[2]	.59	.68	1.00	.70	.75**	.088
Percentage Belly[2]	-.84	-.84	-.41	-.88	-.60**	.111

[1] The ratio of chilled carcass weight to shrunk live weight.

[2] Based on shrunk live weight.

** Signifies probability of chance occurrence $<$ .01 if difference equals zero.

The ratio of the average difference to the standard error of the difference is distributed as Student's *t*. Assuming no seasonal effect there are 81 degrees of freedom for testing the deviation of the mean differences from zero. The mean differences were all highly significant indicating that gilts are leaner than barrows, have a lower dressing percentage, but in spite of the latter, yield a higher percentage of lean cuts. They are also lighter in percentage belly.

To check the mean deviations and assuming that all seasons were from the same population analyses of variance were run. There were significant differences for specific gravity and average back fat thickness. Apparently the differences between sexes were greater in the carcasses from the 1951 spring pigs. The same trend is shown for nearly all of the carcass measurements. The reason for this seasonal difference is not known. Breeding differences are so confounded with seasonal effects that the true source of these trends cannot be separated. No analysis was made on the interaction between breeding and sex differences because it was not thought that there were enough comparisons within the different breeding groups to get a good measure of sex differences by breed.

Age at slaughter was included in the study to get a measure of rate of gain (the pigs were killed at a fairly constant weight) and also because the stage of development of certain tissues may be related to age. Table 13 shows that on the average the gilts were almost nine days older when slaughtered than were their full brothers. This difference was highly significant. It may be noted that the seasonal means were highly variable. Analysis of variance indicated that season was a source of variation in the difference in age of barrows and gilts at time of slaughter.

It was thought that perhaps age differences had an effect on the measurement differences. This might help to explain the seasonal differences in carcass measurements. Accordingly, correlations were run between the differences in age at slaughter and the corresponding sex differences in specific gravity, average back fat and loin lean area. These estimated correlation coefficients were as follows:

	Specific Gravity	Average Back Fat Thickness	Loin Lean Area
Age at Slaughter	.137	-.088	.211

None of these correlation coefficients are significantly different from zero, which indicates that sex differences in carcass measurements are not due to differences in rate of gain.

There is reason to believe that the differences between the carcass measurements of barrows and gilts may be modified by other factors. The exact nature of the factors is not known. Lacy (1932) could find no sign of any interaction between sex differences and litter. Comstock and others (1943) found differences in growth rate between barrows and gilts and there were interactions between lines and these sex differences. However, if the differences in growth rate are not associated with differences in leanness or are associated to the extent found in these data, the former will have little or no effect on the latter.

SUMMARY AND CONCLUSIONS

The carcasses from 316 hogs were used in this study. There were inbred, outbred, single- and multiple-line cross Durocs and a varied assortment of crossbreds and other breeds. Section I was a study of parts of 23 hams to determine the extent to which specific gravity values reflected the differential proportions of the tissues of the carcass. Section II was a comparison of several measures of carcass merit based on the carcasses of 203 hogs. Section III involved a study of 82 full-sib pairs of carcasses to estimate the differences between barrows and gilts for the various carcass measurements.

1. A multiple correlation coefficient of .912 between the specific gravity of the lean of the ham and the percentages of moisture, protein, and ether extract indicates that specific gravity was measuring the relative amounts of those constituents fairly accurately.

2. A component of variance analysis indicated that sampling may be a source of considerable error when carcass merit is determined by chemical analysis.

3. A breeding program based on carcass specific gravity values may exert some selection pressure on the amount of bone in the body but this pressure should be less than that placed on percentage lean and percentage fat since the latter seem to be much more closely associated with specific gravity than is percentage bone.

4. There seems to be a low association, if any, between percentage and density of bone.

5. Using other measures of leanness as criteria, specific gravity is more highly associated with carcass leanness than is any other measure studied except actual carcass cut-out values.

6. A tentative heritability study indicates that specific gravity may be about as highly heritable as average back fat thickness. Some other workers have found the heritability of the latter to be high enough to be very useful in a selection program.

7. The method of approximating the size of the loin lean area by using the product of the length and width was found to be about as good as a planimeter measure of a tracing of the muscle and is much easier to obtain.

8. The planimeter measure of the lean in the face of the ham butt appears better than the length by width approximation but adds little or no valuable information about the carcass if the specific gravity, average back fat thickness, or loin lean area are known.

9. Gilt carcasses are longer and leaner than barrow carcasses. Although the former have a lower dressing percentage, they yield a higher percentage of lean cuts and a lower percentage of belly. These carcass differences may be affected by some unknown factors, but the extent of these effects may not be of enough importance to prevent the use of corrections on raw data.

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Symbol	Meaning
A	Signifies the groups of carcasses in which sex differences existed, d.f. = 84.
B	Signifies the groups of carcasses in which no sex difference existed, d.f. = 82.
Sg	Specific gravity.
BF	Average back fat thickness.
Ha	Approximation of the lean area in the face of the ham.
Hap	Planimeter reading of the area in the face of the ham.
La	Approximation of the lean area in the loin eye muscle.
Lap	Planimeter reading of the area in the loin eye muscle.
L	Trimmed loin as a percentage of chilled carcass weight.
H	Trimmed ham as a percentage of chilled carcass weight.
H&L	The sum of the two previous percentages.
LC	Trimmed ham, loin and New York shoulder as a percentage of chilled carcass weight.
r	Correlation coefficient.
s_r	Standard error of the correlation coefficient calculated as per Snedecor (1948) using the z transformation. The numbers in the A and B groups were so nearly the same that the standard errors were essentially the same.

APPENDIX I

Simple Correlations Among Ten Carcass Measurements on Two Groups of Carcasses

		BF	Ha	Hap	La	Lap	L	H	H&L	LC
Sg	A	-.746	.439	.667	.602	.689	.789	.806	.888	.868
	B	-.482	.374	.402	.336	.465	.450	.572	.586	.647
BF	A		-.267	-.438	-.436	-.433	-.623	-.634	-.701	-.785
	B		-.404	-.389	-.264	-.289	-.311	-.527	-.457	-.590
Ha	A			.793	.484	.497	.498	.416	.513	.538
	B			.840	.607	.727	.366	.537	.490	.533
Hap	A				.628	.668	.624	.611	.685	.706
	B				.609	.700	.491	.554	.584	.602
La	A					.878	.618	.604	.681	.667
	B					.796	.440	.468	.514	.464
Lap	A						.668	.642	.721	.681
	B						.527	.471	.590	.562
L	A							.614	.883	.817
	B							.555	.913	.738
H	A								.912	.888
	B								.852	.885
H&L	A									.951
	B									.904

If r equals:		.30	.40	.50	.60	.70	.80	.90
s_r equals:	+	.097	.088	.078	.066	.052	.036	.019
	-	.103	.096	.087	.075	.061	.043	.023

APPENDIX II

Hotelling's (1940) Test of the Significance of Correlation Coefficients.

$$\text{Student's } t = (r_1 - r_2)\sqrt{\frac{(n-3)\ (1 + r_o)}{2\ D}}$$

r_1 - The estimated correlation of one measure of a characteristic to another characteristic.

r_2 - The estimated correlation of another measure of the same characteristic to the same second characteristic.

r_o - The estimated correlation between the two measures of the first characteristic.

$$D - \begin{vmatrix} 1 & r_1 & r_2 \\ r_1 & 1 & r_o \\ r_2 & r_o & 1 \end{vmatrix}$$

$$= 1\begin{vmatrix} 1 & r_o \\ r_o & 1 \end{vmatrix} - r_1\begin{vmatrix} r_1 & r_o \\ r_2 & 1 \end{vmatrix} + r_2\begin{vmatrix} r_1 & 1 \\ r_2 & r_o \end{vmatrix}$$

$$= 1\ (1 - r_o^2) - r_1\ (r_1 - r_o\ r_2) + r_2\ (r_o\ r_1 - r_2)$$

$$= 1 - r_o^2 - r_1^2 + r_o\ r_1\ r_2 + r_o\ r_1\ r_2 - r_2^2$$

$$= 1 - r_o^2 - r_1^2 - r_2^2 + 2\ r_o\ r_1\ r_2$$

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