GENETIC ANALYSIS OF SOME GROWTH AND CARCASS CHARACTERS IN BEEF CATTLE

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1961

Submitted to the faculty of the Graduate School of the
Oklahoma State University of Agriculture and
Applied Science in partial fulfillment
of the requirements for the degree of
MASTER OF SCIENCE
May, 1964

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ACKNOWLEDGEMENT

The author wishes to express his appreciation to Dr. Doyle Chambers, Professor of Animal Husbandry and Associate Director of the Agricultural Experiment Station, for his guidance during the course of this study and in the preparation of this thesis.

He is also indebted to Dr. R. L. Willham of the Animal Husbandry Department for his assistance in the analyses of the data and his helpful suggestions and constructive criticisms during the preparation of the manuscript.

Further acknowledgement is due to Dr. Lowell Walters, Professor of Animal Husbandry, for his assistance in improving the manuscript.

Appreciation is also extended to the author's wife, Laura, for her assistance in the preparation of this thesis.

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INTRODUCTION

Numerous experiments have evaluated certain phases of production in beef cattle. Measures of growth, efficiency, and conformation have varied in importance as production indices. Carcass studies have been included in some production experiments; however, the majority of carcass studies have been conducted without preslaughter records. Similarly, information of growth has often been obtained without carcass appraisal. Thus, production studies have proceeded with very little information on the effect of selection for rapid gains on the composition and quality of beef carcasses. Such selection possibly is antagonistic to more desirable carcasses. Hence, knowledge of the genetic and environmental correlations among these traits is needed.

The purposes of this study were: 1) To estimate the heritabilities of indicators of growth rate, muscular development, fatness, and carcass quality and composition, and 2) To investigate the genetic and environmental correlations among these traits.

REVIEW OF LITERATURE

Heritabilities

Tables I and II summarize heritability estimates pertinent to this study. All estimates were obtained using the paternal half-sib correlation method of analysis.

The heritability of final weight following a feeding period was considered since it is similar to carcass weight per day of age and since no estimate of the latter was reported to date. Knapp and Nordskog (1946a) recognized that their estimate for final weight of .81 was unrealistically high. Later publications by Knapp and Clark (1950), Shelby et al. (1955), Shelby et al. (1960), and Shelby et al. (1963) from the same station also gave large estimates for the heritability of this trait. The cattle of all of these studies were fed for 252 days.

Blackwell et al. (1962) reported a heritability estimate of .70 for final weight of steers approximately 2 years old after a 169 day feeding period. Swiger (1961) found a heritability estimate of .47 for final weight after a 140 day feeding period. This estimate was lower than the majority of those reported when final weight was recorded at an older age.

Swiger et al. (1963) evaluated postweaning gains of calves and reported heritability estimates for weights taken at 200 days, 396 days and 550 days of age of -.06, .18, and .37, respectively. They concluded that the heritability for body weight increased as the postweaning period became a larger portion of the life of the calf. These estimates appear

TABLE I

HERITABILITIES OF FINAL WEIGHT FOLLOWING A FEEDING PERIOD

Reference	Sex[a]	Number of Individuals	Number of Sires	Heritability
Knapp and Nordskog (1946a)	S	177	23	.81
Knapp and Clark (1950)	S	880	110	.86
Shelby *et al.* (1955)	S	616	87	.84
Shelby *et al.* (1960)	B	542	116	.77
Swiger (1961)	B,H	748	23	.47
Blackwell *et al.* (1962)	S	499	36	.70
Christians (1962)	S,H	176	24	1.00
Wilson *et al.* (1962)	S	336	43	.33
Shelby *et al.* (1963)	S	616	87	.64
Swiger *et al.* (1963)	S	288	49	.37

[a]Steers (S), bulls (B) and heifers (H)

too low with respect to the others reviewed. These authors inferred that this could be due to differences in management regimes.

Only a few heritabilities of carcass weight appear in the literature. The estimate for carcass weight reported by Christians (1962) of .96, and that by Shelby *et al.* (1963) of .57, were approximately equal to their respective values for final weight. Blackwell *et al.* (1962) presented a heritability estimate of .92 for carcass weight which was higher than that of .70 for final weight. Further analysis of the two traits by Blackwell *et al.* showed that the two traits were highly correlated both genetically and phenotypically.

Workers at the Miles City station have presented heritability estimates for rib-eye area ranging from .26 to .72 (Knapp and Nordskog, 1946b; Knapp and Clark, 1950; Shelby *et al.*, 1955; Shelby *et al.*, 1963). The estimate reported by Shelby *et al.* (1963) was increased from .26 to .46 when

TABLE II

HERITABILITIES OF CERTAIN CARCASS CHARACTERISTICS

Character	Sex[a]	Number of individuals	Number of sires	Heritability
Carcass weight				
Blackwell *et al.* (1962)	S	421	36	.92
Christians (1962)	H,S	176	24	.96
Shelby *et al.* (1963)	S	616	87	.57
Rib-eye area				
Knapp and Nordskog (1946b)	S	177	43	.69
Knapp and Clark (1950)	S	880	110	.38
Shelby *et al.* (1955)	S	635	88	.72
Shelby *et al.* (1963)	S	616	87	.26
Shelby *et al.* (1963)	S	616	87	.46[b]
Christians (1962)	H,S	176	24	1.08
Christians (1962)	H,S	176	24	.76[c]
Backfat thickness				
Shelby *et al.* (1955)	S	635	88	.38
Shelby *et al.* (1963)	S	616	87	.24
Christians (1962)	H,S	176	24	.38
Carcass grade				
Knapp and Nordskog (1946b)	S	177	23	.84
Knapp and Clark (1950)	S	880	110	.33
Dawson *et al.* (1955)	S	58	9	.67
Shelby *et al.* (1955)	S	635	88	.16
Blackwell *et al.* (1962)	S	421	36	.59
Christians (1962)	H,S	176	24	.78
Shelby *et al.* (1963)	S	616	87	.17
Percent major wholesale cuts				
Christians (1962)	H,S	176	24	.56

[a]Steers (S) and heifers (H)
[b]Adjusted for slaughter weight
[c]Adjusted for carcass weight

adjustment was made for carcass weight. Christians (1962) obtained an estimate of heritability of rib-eye area of 1.08. However, when carcass weight was held constant a more realistic value of .76 was obtained.

The heritability estimates reported for backfat thickness indicated that it is moderately heritable. Estimates of the heritability of carcass grade differ widely. A range of .16 to .84 is shown in Table II. Christians (1962) obtained a heritability estimate of .56 for percent primal cuts expressed on a live weight basis. He also found percent lean, fat, and bone of the 9-10-11th rib section to be 30, 31, and 41 percent heritable, respectively.

Genetic and Phenotypic Correlations

The studies of Blackwell *et al.* (1962) and Shelby *et al.* (1963) are the only investigations including the genetic interrelationships among traits measuring growth and carcass merit. Certain genetic and phenotypic correlations obtained by these workers are summarized in Table III. Carcass weight is used as representative of growth in this table. In both reports the genetic and phenotypic correlations were quite high between average daily gain in the feed lot, final weight, and carcass weight.

The terminology of Shelby *et al.* (1963) will be used in discussing various correlations reviewed. It is as follows: 0 to .25, low; .26 to .50, fairly high; .51 to .75, high; and .76 to 1.00, very high.

Table III shows that backfat thickness had a fairly high genetic correlation with cold carcass weight and rib-eye area. Blackwell *et al.* (1962) reported a very high genetic correlation between cold carcass weight and carcass grade. The genetic correlations among the other carcass traits were low.

The phenotypic correlations showed a fairly high degree of association

TABLE III

GENETIC (G) AND PHENOTYPIC (P) CORRELATIONS AMONG TRAITS MEASURING CARCASS MERIT AND GROWTH IN STEERS

		Carcass grade		Rib-eye area	Backfat Thickness
	Ref.[a]	1	2	2	2
Cold carcass wt.	G	0.79	0.24	0.15	0.47
	P	0.43	0.41	0.46	0.36
Carcass grade	G			-.11	0.23
	P			0.22	0.44
Rib-eye area	G				0.30
	P				0.05

[a] 1. Blackwell et al. (1962)
2. Shelby et al. (1963)

between growth and carcass grade, rib-eye area, and backfat thickness. Phenotypically carcass grade was found to have a low positive association with rib-eye area and a fairly high positive relationship to backfat thickness. Rib-eye area was observed to be essentially independent of fat thickness phenotypically (Shelby et al., 1963).

Simple Correlations

The literature concerning estimates of simple correlations among traits of beef cattle is more abundant than that pertaining to genetic correlations. Table IV summarizes certain reports relevant to this study.

Measures of growth, such as final weight, carcass weight, and weight per day of age, have been found to be very highly correlated (Christians, 1962; Neville et al., 1962). Correlations of these measures of growth with carcass traits differ widely.

TABLE IV

RANGES OF SIMPLE CORRELATIONS REPORTED IN THE LITERATURE AMONG CERTAIN TRAITS MEASURING GROWTH AND CARCASS MERIT

Traits Correlated	Range of correlations	References[a]
Final weight to:		
Carcass weight	0.93 to 0.96	9,12
Weight/day of age	0.86	12
Carcass grade	0.00 to 0.52	1,5,12
Rib-eye area	0.45	5
Rib-eye area/cwt. carcass	-.40	12
Backfat thickness	0.05	1
Carcass weight to:		
Weight/day of age	0.77	12
Carcass grade	-.01 to 0.63	10,11
Rib-eye area	0.19 to 0.52	11,12
Rib-eye area/cwt. carcass	-.40	12
Backfat thickness	0.23 to 0.24	10,12
% Fat 9-10-11th rib	0.12	10
% Lean 9-10-11th rib	-.14 to 0.63	7,10,11
Weight/day of age to:		
Carcass grade	0.35 to 0.39	4,12
Rib-eye area	0.20 to 0.38	4,5
Rib-eye area/cwt. carcass	-.34 to -.46	4,12
Backfat thickness	0.50	4
% Fat 9-10-11th rib	0.52	4
% Lean 9-10-11th rib	-.45	4
Carcass grade to:		
Rib-eye area	-.09 to 0.21	3,6,9,10
Rib-eye area/cwt. carcass	-.13	12
Backfat thickness	0.25 to 0.95	1,3,6,10
% Fat 9-10-11th rib	0.30 to 0.68	6,10,13
% Lean 9-10-11th rib	-.27 to -.60	6,10,13
Carcass yield grade to:		
% Fat 9-10-11th rib	0.75	13
% Lean 9-10-11th rib	-.74	13
Rib-eye area to:		
Backfat thickness	-.20 to 0.01	3,6,10,11
% Fat 9-10-11th rib	-.24 to -.32	6,10
% Lean 9-10-11th rib	0.18 to 0.40	6,7,10,11
Backfat thickness to:		
% Fat 9-10-11th rib	0.58 to 0.65	6,7,13
% Lean 9-10-11th rib	-.20 to -.60	6,7,10,11,13
Boneless retail cuts	-.81	8
% Fat 9-10-11th rib		
% Lean 9-10-11th rib	-.88	10

[a]See Table V.

TABLE V

REFERENCES CITED IN TABLE IV

1.	Hankins and Burk (1938)	8.	Murphey et al. (1960)
2.	Yao et al. (1953)	9.	Goll et al. (1961)
3.	Woodward et al. (1954)	10.	Christians (1962)
4.	Cartwright et al. (1958)	11.	Cole et al. (1962)
5.	Magee et al. (1958)	12.	Neville et al. (1962)
6.	Woodward et al. (1959)	13.	Ramsey et al. (1962)
7.	Cole et al. (1960)		

The findings of Hankins and Burk (1938) and Christians (1962) indicated that there was no relationship between traits measuring growth and carcass grade. On the other hand, other workers have reported fairly high to high correlations between growth and carcass grade (Cartwright et al., 1958; Magee et al., 1958; Neville et al., 1962).

Most studies have showed a fairly high correlation between growth and rib-eye area (Cartwright et al., 1958; Magee et al., 1958; Cole et al., 1960; Goll et al., 1961; Christians, 1962). Negative correlations of about the same magnitude were observed when rib-eye area per 100 pounds carcass was considered.

Hankins and Burk (1938), Christians (1962), and Neville et al. (1962) found the relationship to be low between measures of growth and backfat thickness, while Cartwright et al. (1958) reported a fairly high correlation of 0.50 between weight per day of age and backfat thickness. Christians (1962) reported a low positive correlation between carcass weight per day of age and percent fat of the 9-10-11th rib section. Cartwright et al. (1958) found weight per day of age and percent fat of the rib section to be highly related.

Reports regarding the correlation of carcass weight and percent lean of the 9-10-11th rib section were conflicting. Christians (1962) found carcass weight to be negatively associated with percent lean. Cole et al. (1960) and Cole et al. (1962) reported highly significant correlations of 0.63 and 0.35, respectively between the two traits. A fairly large negative correlation was obtained by Cartwright et al. (1958) between weight per day of age and percent lean of the 9-10-11th rib section.

The studies of Woodward et al. (1954), Woodward et al. (1959), Goll et al. (1961), Christians (1962), and Neville et al. (1962) indicated that the correlation between carcass grade and rib-eye area or rib-eye area per 100 pounds carcass was low. Hankins and Burk (1938), Woodward et al. (1954), and Woodward et al. (1959) have shown backfat thickness to be fairly highly correlated to carcass grade. A very high correlation between carcass grade and backfat thickness was reported by Christians (1962). Pierce (1957) found backfat thickness and carcass grade to be highly correlated when carcass weight was held constant.

Fairly high to high positive correlations have been found between carcass grade and percent fat of the 9-10-11th rib section (Woodward et al., 1959; Christians, 1962; Ramsey et al., 1962). Essentially the same correlation was observed in a negative direction when percent lean of the rib section was associated with carcass grade. Ramsey et al. (1962) reported that when yield grade was measured to the nearest five-hundredth it was correlated to separable fat by 0.75 and to separable lean by -.74. These correlations were reduced when yield grade was measured to the nearest one-tenth only.

A low correlation between rib-eye area and backfat thickness has been shown by Woodward et al. (1954), Woodward et al. (1959), Christians (1962), and Cole et al. (1962). Woodward et al. (1959) and Christians (1962) reported that rib-eye area was negatively correlated to percent fat of the 9-10-11th rib by -.24 and -.32, respectively. Cole (1960) and Gottsch (1961) reported that rib-eye area accounted for 18 percent of the variation in total carcass lean.

High positive correlations have been reported between backfat thickness and percent fat by Woodward et al. (1959), Cole et al. (1960), and Ramsey et al. (1962). They also reported fairly high to high negative correlations between backfat thickness and percent lean. In addition, similar correlations were observed by Christians (1962) and Cole et al. (1962). Murphey et al. (1960) reported a high negative correlation between backfat thickness and yield of boneless retail trimmed cuts. Ramsey et al. (1962) stated that fat had a more definite influence on percent separable lean than did rib-eye area.

Christians (1962) reported a very large negative correlation between percent fat and percent lean of the 9-10-11th rib section.

MATERIALS AND METHODS

Source of Data

The data were collected from 47 sire progeny groups containing 265 steers fed during a 2-year period at the Fort Reno Station. The calves were dropped during the spring calving season in 1961 in two different herds and in 1962 in three herds. Two of the herds were owned by the Oklahoma Agricultural Experimental Station, one being located at Fort Reno (project 650) and the other (project 670) at the Lake Carl Blackwell range area near Stillwater. The other herd was owned by the Federal Reformatory near El Reno, Oklahoma. The grade Hereford cows in the project 650 herd and the Angus cows in the Federal Reformatory herd were considered mature. The grade Angus cows in the project 670 herd were three years old.

The calves were weaned in late September or early October at an average age of approximately 210 days. Variation in weaning age was minimized by selecting calves nearest the average age.

The steers were divided into five groups by herd and year of birth and studied on an intra-group basis because management practices and other factors differed considerably. Table VI gives the distribution of calves into the five groups analyzed in this study. Breed of the calves and preweaning and postweaning management regimes are also presented.

The calves of group I were fed the rations presented in Table VII. The rations were formulated to contain equivalent levels of protein, fiber,

TABLE VI

DISTRIBUTION OF FIVE GROUPS OF STEERS BY STATION AND YEAR OF BIRTH SHOWING BREED AND PREWEANING AND POSTWEANING MANAGEMENT REGIMES

Group	Herd	Year of Birth	Breed	Preweaning Management	Postweaning Management		No. of obser-vations	No. of Sires
					Rations	Days on Feed		
I	Project 650	1961	Hereford	Noncreeped	Test rations	196	63	10
II	Project 650	1962	Hereford	Noncreeped	Test rations	168	74	13
III	Federal Ref.	1961	Angus	Creeped	Standard ration	168	60	10
IV	Federal Ref.	1962	Angus	Creeped	Standard ration	168	32	8
V	Project 670	1962	Angus	Noncreeped	Standard ration	168	36	6

and total digestible nutrients. Totusek <u>et al</u>. (1963a) gave a detailed description of the treatments and their effects on certain performance and carcass characters. The treatment differences were fairly large for average daily gain and carcass weight. Thus, within sire variation was increased for these traits. Differences in the means of other carcass traits were quite small.

TABLE VII

COMPOSITION OF RATIONS (PERCENT) FED TO STEERS OF GROUP I

Feed	Test Rations			
	Control	Corn	Milo	Barley
Corn-and-cob meal	32.5	----	----	----
Corn, ground	----	39.0	----	----
Milo, ground	----	----	39.2	----
Barley, ground	----	----	----	44.2
Oats, whole	10.0	----	----	----
Wheat bran	10.0	----	----	----
Cottonseed meal	10.0	13.5	13.8	11.8
Molasses	7.5	7.5	7.5	7.5
Cottonseed hulls	20.0	30.0	29.5	26.5
Alfalfa hay, ground	10.0	10.0	10.0	10.0

The steers of group II were also divided into four nutritional treatments according to sire. Comparisons of coarsely ground milo to finely ground milo and vitamin A supplementation (1500 I.U. per pound ration) to no vitamin A supplementation were made. Totusek (1963) found that these treatments had little effect on rate of gain and carcass characteristics.

Groups III, IV, and V were fed the standard Fort Reno test ration, composed of 35 percent corn-and-cob meal, 10 percent wheat bran, 10 percent whole oats, 10 percent cottonseed meal, 5 percent molasses, 20 percent cottonseed hulls and 10 percent alfalfa hay.

Groups IV and V were divided according to sire into three subgroups for intra ruminal injections of vitamin A. The levels studied were no vitamin A, one million I.U., and two million I.U. Totusek et al. (1963b) found small and inconsistent differences between calves that received no vitamin A supplement and those that received one million I.U. However, calves that received two million I.U. of vitamin A gained considerably more than those receiving no supplemental vitamin A. Therefore, within sire variation was increased for gain in these groups also. Differences in quality grade, retail cut yield, rib-eye area, and backfat thickness were small.

The various rations were self-fed and a mineral mixture was available free-choice in all five groups. A final weight was obtained following a 20-hour shrink. Postweaning average daily gain was obtained from this final weight. The cattle were slaughtered and carcasses were weighed, graded, and measured 72 hours after slaughter.

Data

Table VIII gives the 11 traits used. Weaning weight refers to the actual weight taken at weaning time. Carcass weight per day of age was calculated from an estimated chilled carcass weight which was 98.5 percent of the hot carcass weight.

A government grader evaluated the carcasses for carcass grade and carcass yield grade. Carcass grade was recorded to the nearest one-third of a grade. The government grader recorded carcass yield grades to the nearest one-hundredth for cattle of group III but only to the nearest one-tenth for cattle of the other groups.

Area of the Longissimus Dorsi (rib-eye area) and backfat thickness were measured following the procedures outlined by Naumann (1952) and Bray

TABLE VIII

MEANS AND STANDARD DEVIATIONS OF CHARACTERISTICS STUDIED IN FIVE GROUPS OF STEERS

Groups		Weaning age	Weaning wt.	Pre-weaning ADG	Post-weaning ADG	Carcass wt./day of age	Carcass grade	Carcass yield grade	Rib-eye area	REA/cwt. carcass	Backfat thickness	% Retail cuts
I	$\bar{x}$	211	478	1.91	2.48	1.40	9.70	3.91	10.71	1.84	0.79	48.05
	s	13	46	.19	.23	.10	.95	.41	1.06	.17	.12	1.03
II	$\bar{x}$	211	501	2.08	2.38	1.46	11.20	4.08	10.27	1.82	0.86	47.00
	s	15	50	.20	.20	.11	.91	.49	1.00	.17	.18	1.37
III	$\bar{x}$	214	474	1.83	2.69	1.34	9.74	3.61	9.90	1.75	0.70	48.61
	s	12	45	.21	.25	.12	1.03	.41	.85	.14	.14	1.18
IV	$\bar{x}$	210	484	1.97	2.48	1.47	10.84	4.08	9.80	1.73	0.86	46.83
	s	9	46	.12	.25	.11	1.00	.57	1.11	.18	.13	1.26
V	$\bar{x}$	211	450	1.85	2.45	1.35	10.36	3.61	9.78	1.91	0.72	48.08
	s	13	46	.17	.26	.12	.92	.48	.81	.16	.14	1.11

(1963). The percent of boneless retail trimmed cuts from the round, loin, rib, and chuck were estimated for each carcass by the multiple regression equation presented by Murphey et al. (1960):

Percent boneless retail cuts from round, loin, rib, and chuck = 52.66 - 5.33 (av. backfat thickness, in.) - 1.24 (percent kidney fat) + .665 (rib-eye area, sq. in.) - .0065 (carcass wt., lbs.)

The estimate of percent kidney fat, as made by the government grader, and the chilled carcass weight were used in the above equation. This factor will be referred to henceforth as percent retail cuts.

The means and standard deviations of these 11 traits are presented in Table VIII for the five groups. The means for the 47 sire progeny groups are given in the appendix.

Characteristics Studied

The 11 variables were investigated by a preliminary simple correlation analysis. The purpose of this preliminary analysis was to reduce the number of traits to those that would measure growth rate, carcass quality, and composition most effectively. The correlations were computed within each of the five groups. The within group simple correlations were pooled by the z transformation technique outlined by Snedecor (1946). The pooled simple correlations among these 11 variables are shown in Table IX.

Weaning age was directly proportional to final age at slaughter in each of the groups because all steers within each group were fed the same length of time. Since weaning age was available it was used to determine whether or not it would be necessary to adjust rib-eye area and other carcass traits to a constant age basis. The low correlations found between weaning age and the other variables indicated that variation in age was

TABLE IX

POOLED SIMPLE CORRELATIONS AMONG CERTAIN LIVE ANIMAL AND CARCASS CHARACTERISTICS

		(Y_2)	(Y_3)	(Y_4)	(Y_5)	(Y_6)	(Y_7)	(Y_8)	(Y_9)	(Y_{10})	(Y_{11})
Weaning age	(Y_1)	.39	-.19	.03	-.12	.14	.07	.14	-.04	.08	-.07
Weaning wt.	(Y_2)		.74	.30	.66	.09	.16	.40	-.37	.20	-.18
Preweaning ADG	(Y_3)			.21	.67	-.03	.10	.31	-.26	.25	-.18
Postweaning ADG	(Y_4)				.74	.15	.13	.32	-.36	.20	-.18
Carcass wt./day of age	(Y_5)					.15	.20	.47	-.41	.35	-.28
Carcass grade	(Y_6)						.27	.31	-.18	.32	-.35
Carcass yield grade	(Y_7)							-.36	-.61	.64	-.74
Rib-eye area	(Y_8)								.56	-.04	.41
REA/cwt. carcass	(Y_9)									-.42	.70
Fat thickness	(Y_{10})										-.82
% Retail cuts	(Y_{11})										

$r > .12$; Significance at $P < .05$ (d.f. = 250)
$r > .16$; Significance at $P < .01$ (d.f. = 250)

small and had very little effect on any of the other variables. Hence, no corrections were made for age.

The simple correlations between the various measures of growth and carcass merit were similar. Carcass weight per day of age was chosen to represent growth because it measured growth for the entire life of the individual and because it is not affected by variations in fill.

Carcass grade was evaluated in this study because of its importance in merchandizing beef. It represents an attempt to assess the quality of the meat. In this study carcass grade was determined largely by marbling since the cattle were all of the same maturity and of low choice or better conformation. Carcass yield grade was studied since it attempts to classify beef carcasses on the basis of their yield of retail trimmed cuts. Although, it was administered on a trial basis at the time, an estimate of the heritability of this character would be warranted should its use become accepted in the beef industry. It was not used in the genetic and environmental correlation analysis, however, as percent retail cuts offered a more precise estimate of the composition of beef carcasses (Murphey et al., 1960).

Rib-eye area and rib-eye area per 100 pounds carcass weight were used as indicators of muscular development in this study. Heritabilities and genetic and environmental correlations were estimated for both of these traits. Backfat thickness was used as an indicator of fatness of the beef carcasses.

Statistical Analyses

Paternal half-sib analyses were used to obtain estimates of the heritabilities and genetic, environmental and phenotypic correlations. The following mathematical model was used for all traits in this study:

$$Y_{ijk} = u + g_i + s_{ij} + e_{ijk}$$

where

Y_{ijk} = an observed phenotypic value recorded for the k^{th} steer sired by the j^{th} sire in the i^{th} group,

u = the effect common to all steers,

g_i = the effect common to all steers of the i^{th} group,

s_{ij} = the effect common to all steers belonging to the i^{th} group and sired by the j^{th} sire,

e_{ijk} = the effect unique to each steer.

The analysis of variance for unequal sub-class numbers, as outlined by Steel and Torrie (1960), was used to obtain the mean squares. The method described by Kempthorne (1957) was used to compute mean products. Estimates of the components of variance for sire (σ_s^2) and within sire (σ_w^2) were then made by equating the mean square expectations, shown in Table IX, to the observed mean squares. In a population mated at random these two components contain $1/4\ \sigma_g^2$ and $\sigma_e^2 + 3/4\ \sigma_g^2$, respectively. Hence, the genetic (σ_g^2), environmental (σ_e^2), and phenotypic (σ_p^2) variances were estimated by $4\ \sigma_s^2$, $\sigma_w^2 - 3\ \sigma_s^2$, and $\sigma_g^2 + \sigma_e^2$. The corresponding genetic ($\sigma_{gi\ gj}$), environmental ($\sigma_{e_i\ e_j}$) and phenotypic ($\sigma_{p_i\ p_j}$) covariances were estimated in a similar manner from the expected and observed mean products.

Heritabilities were then estimated by the following ratio:

$$h^2 = \frac{\sigma_g^2}{\sigma_p^2}$$

The standard errors of the heritability estimates (S_h^2) were calculated by the method presented by Dickerson (1960). The accuracy of estimating heritability by this method depends on the number of degrees of freedom available for estimating differences between sires. Major limitations are

TABLE X

EXPECTED MEAN SQUARES AND MEAN PRODUCTS FOR THE INTRA-GROUP PATERNAL HALF-SIB ANALYSIS

Source of Variation	Degrees of Freedom	Expected Mean Squares	Expected Mean Products
Sires/groups	s-g	$\sigma_{w_i}^2 + k\,\sigma_{s_i}^2$	$\sigma(w_i, w_j) + k\,\sigma(s_i, s_j)$
Half-sibs/groups	n-s	$\sigma_{w_i}^2$	$\sigma(w_i, w_j)$

s = the number of sires

g = the number of groups

n = the total number of observations

$$k = \frac{n_{..} - \sum_i \left(\sum_j n^2_{ij}/n_{i.} \right)}{s-g}$$

where $n_{..}$ is the total number of individuals, $n_{i.}$ is the total number in the i^{th} group and n_{ij} is the number of individuals in the i^{th} group by the j^{th} sire.

i and j = any particular pair of traits.

that sampling errors and failure to remove all environmental effects from σ_s^2 can lead to serious bias since the latter is multiplied by four (Lush, 1949; Dickerson, 1960).

The genetic, environmental and phenotypic correlations were estimated as follows:

$$r_{g_i g_j} = \frac{\sigma_{g_i g_j}}{\sqrt{(\sigma_{g_i}^2)(\sigma_{g_j}^2)}}$$

$$r_{e_i e_j} = \frac{\sigma_{e_i e_j}}{\sqrt{(\sigma_{e_i}^2)(\sigma_{e_j}^2)}}$$

$$r_{p_i p_j} = \frac{\sigma_{p_i p_j}}{\sqrt{(\sigma_{p_i}^2)(\sigma_{p_j}^2)}}$$

This method of estimating these correlations was first demonstrated by Hazel _et al._ (1943).

Path coefficients were obtained to evaluate certain genetic relationships (Wright, 1934). The path coefficients were calculated by the method given by Steel and Torrie (1960) for computing standard partial regression coefficients.

RESULTS AND DISCUSSION

Heritabilities

The analyses of variance for the traits studied are presented in Table XI. Differences between groups were highly significant ($P < .01$) for all seven traits. Thus, the intra-group analyses were effective in removing extraneous variation that would have otherwise been confounded with sire effects. The components of variance obtained from the paternal half-sib analyses along with the heritability estimates and their standard errors are given in Table XII.

The heritability estimate of .39 obtained for carcass weight per day of age was less than the very high estimates for carcass weight reported by Blackwell et al. (1962), Christians (1962), and Shelby et al. (1963). It was also lower than the majority of the estimates for final weight shown in Table I; although, it agrees favorably with those reported by Swiger (1961), Wilson et al. (1962), and Swiger et al. (1963). The heritability of carcass weight per day of age may be less than the estimates with which it was compared because the sires of the progeny groups were selected for their superior gaining ability. This would reduce between sire variation for carcass weight per day of age and consequently reduce its heritability. The present heritability estimate may also be smaller because of differences in management of the cattle prior to slaughter. The steers in this study were fed for a shorter period of time than those in most instances where the heritabilities were quite high. The report of Swiger et al. (1963) indicates

TABLE XI

ANALYSES OF VARIANCE FOR CERTAIN CARCASS CHARACTERISTICS OF BEEF CATTLE

Item	Mean Squares Groups	Sires/groups	Half sibs/groups
Degrees of freedom	4	42	218
Carcass wt./day of age	.1771**	.0186	.0116
Rib-eye area	8.4824**	1.7918	.7882
Rib-eye area/cwt. carcass	.2055**	.0361	.0252
Backfat thickness	.2794**	.0306	.0183
Carcass grade	25.95 **	1.66	.82
Carcass yield grade	2.8597**	.3074	.1974
Percent retail cuts	30.8526**	2.1375	1.3190

** $P < .01$

TABLE XII

COMPONENTS OF VARIANCE AND HERITIBILITY ESTIMATES OF CERTAIN CARCASS CHARACTERISTICS OF BEEF CATTLE

Characteristic	σ_s^2	σ_w^2	σ_p^2	h^2	S_h^2
Carcass wt./day of age	.0013	.0116	.0129	.39	.24
Rib-eye area	.1795	.7882	.9677	.73	.29
Rib-eye area/cwt. carcass	.0020	.0252	.0271	.29	.22
Backfat thickness	.0022	.0183	.0205	.43	.33
Carcass grade	.1502	.82	.9702	.62	.27
Carcass yield grade	.0197	.1974	.2170	.36	.31
Percent retail cuts	.1464	1.3190	1.4654	.40	.24

$k = 5.5919$

that the shorter postweaning period could account for the lower heritability estimate. Also, three of the five groups of steers were subjected to nutritional treatments that increased within sire variation slightly relative to the between sire variation for this trait. This would bias the heritability estimate downward slightly.

A heritability of .73 was obtained for rib-eye area. This agrees favorably with all but two of the estimates shown in Table II for this character. Those of Knapp and Nordskog (1950) and Shelby et al. (1963) are much lower. The rather high estimate for the heritability of rib-eye area is probably attributable in part to the minimized variation in age. A much lower estimate of .29 was obtained for rib-eye area per 100 pounds carcass. This estimate is slightly lower than that reported by Shelby et al. (1963) for rib-eye area with carcass weight held constant and is substantially less than the estimate obtained by Christians (1962) when slaughter weight was held constant. Rib-eye area per 100 pounds carcass had a lower heritability than rib-eye area because it is a ratio of rib-eye area to carcass weight and these traits had a high positive genetic correlation (Table XVI). This statistical consequence would be illustrated more clearly if the data were linearized by converting it to a logarithmic scale. There the heritability of rib-eye area per 100 pounds carcass ($h^2_{R/W}$) in logarithmic terms would contain $\sigma^2_g(R-W)$ which is equivalent to $\sigma^2_g R - 2\ \sigma_g RW + \sigma^2_g W$. The covariance ($\sigma_g RW$) being positive lowers the genic variance of rib-eye area per 100 pounds carcass. Therefore, this ratio has a low heritability. However, this still indicates that selection for rib-eye area per 100 pounds carcass would be less effective than selection for rib-eye area.

The heritability estimate of .43 for backfat thickness is in close agreement with those cited in Table II. The heritability estimate of carcass grade was .62. This estimate agrees favorably with four of those for carcass grade presented in Table II, but is higher than three of them.

The heritability estimates of carcass yield grade and percent retail cuts were .36 and .40, respectively. These traits were expected to have similar heritabilities since the method of determining yield grade was developed from an equation very similar to that used for predicting percent retail cuts.

The relatively high heritabilities obtained indicate that progress could be expected from selection for the various carcass traits studied. Selection would, of course, have to be based on progeny or sib tests because information on carcass traits requires that individuals be slaughtered.

Correlations

Genetic and environmental correlations are measures of the genetic and environmental relations affecting the phenotypic correlation between two traits. A genetic correlation measures the degree of association between the average effects of all genes affecting two traits (Hazel *et al*., 1943). The various genetic correlations will be discussed individually in some detail as their interpretation is of value in developing selection programs. Certain genetic interrelationships were evaluated by the method of path coefficients. Path coefficients are standard partial regression coefficients. They indicate the influence of an independent variable on a dependent variable when the other independent variables are held constant.

The environmental correlations will not be discussed in detail since they can only be interpreted in terms of the correlation between non-genic effects and environmental effects influencing two traits. They will be mentioned only where their influence caused the phenotypic correlations to differ appreciably from the genetic correlations.

The between sire and within sire covariances obtained by the intra-group paternal half-sib analyses are given in Table XIII. The components of sire and within sire covariance computed from the paternal half-sib analyses are shown in Table XIV. Table XV gives the genetic, environmental, and phenotypic variances and covariances used in computing the genetic, environmental, and phenotypic correlations tabulated in Table XVI. The terminology of Shelby et al. (1963) will be used in discussing the correlations.

Genetic Correlations. A high genetic correlation was obtained between carcass weight per day of age and rib-eye area. This estimate is appreciably higher than that reported by Shelby et al. (1963) between carcass weight and rib-eye area. Rib-eye area per 100 pounds carcass was genetically independent of carcass weight per day of age. The lower genetic correlation obtained when rib-eye area was expressed as a ratio to carcass weight can be understood more clearly by expressing it in terms of logarithms. If logarithms were used to linearize the data the correlations between carcass weight per day of age (W) and rib-eye area per 100 pounds carcass (R/W) would be

$$r_{R/W \cdot W} = \frac{\sigma\,[(R - W)(W)]}{\sqrt{(\sigma^2(R-W) \cdot \sigma^2 W}} = \frac{\sigma RW - \sigma^2 W}{\sqrt{\sigma^2(R-W) \cdot \sigma^2 W}}$$

Thus, the genetic correlation ($r_g = -.02$) is nearly the difference between σRW and $\sigma^2 W$. This causes the genetic correlation to be low automatically. Nevertheless, the genetic correlations indicate that selection for rib-eye area would lead to improvement in growth rate while selection for rib-eye area per 100 pounds carcass would not.

The relative effects of rib-eye area and carcass weight per day of age on rib-eye area per 100 pounds carcass were analyzed by the method of path coefficients (Figure 1). The path coefficients show that carcass weight exerts a strong negative influence on rib-eye area per 100 pounds carcass.

TABLE XIII

ANALYSES OF COVARIANCE FOR CERTAIN CARCASS CHARACTERISTICS OF BEEF CATTLE[a]

		Rib-eye area	Rib-eye area/cwt. carcass	Backfat thickness	Carcass grade	% Retail cuts
Carcass wt./day of age	B[b]	0.0967	-.0074	0.0063	0.0472	-.0341
	W	0.0416	-.0073	0.0048	0.0112	-.0354
Rib-eye area	B		0.1564	-.0026	0.4084	0.6946
	W		0.0783	-.0116	-.0340	0.4411
Rib-eye area/cwt. carcass	B			-.0099	-.0170	0.1662
	W			-.0096	-.0278	0.1332
Backfat thickness	B				0.1304	-.2218
	W				0.0284	-.1265
Carcass grade	B					-.9519
	W					-.2905

[a]These values were carried to six decimal places in the actual computations.
[b]Covariance between sires within groups (B), and covariance within sires within groups (W).

TABLE XIV

COMPONENTS OF COVARIANCE COMPUTED FROM THE ANALYSES OF COVARIANCE FOR CERTAIN CARCASS CHARACTERISTICS OF BEEF CATTLE[a]

		Rib-eye area	Rib-eye area/cwt. carcass	Backfat thickness	Carcass grade	% Retail cuts
Carcass wt./day of age	S[b]	0.0098	-.0000	0.0003	0.0064	0.0002
	W	0.0416	-.0073	0.0048	0.0112	-.0354
Rib-eye area	S		0.0140	0.0016	0.0791	0.0453
	W		0.0783	-.0116	-.0340	0.4411
Rib-eye area/cwt. carcass	S			-.0000	0.0019	0.0059
	W			-.0096	-.0278	0.1332
Backfat thickness	S				0.0182	-.0170
	W				0.0284	-.1265
Carcass grade	S					-.1183
	W					-.2905

[a]The components were carried to six decimal places in the actual computations.
[b]Sire components of covariance (S) and within sire components of covariance (W).

TABLE XV

GENETIC, ENVIRONMENTAL, AND PHENOTYPIC VARIANCES AND COVARIANCES FOR CERTAIN CARCASS CHARACTERISTICS OF BEEF CATTLE[a]

		Carcass wt./day of age	Rib-eye area	Rib-eye area/cwt. carcass	Backfat thickness	Carcass grade	% Retail cuts
Carcass wt./day of age	G[b]	0.0050	0.0394	-.0001	0.0010	0.0258	0.0009
	E	0.0079	0.0121	-.0072	0.0041	-.0081	-.0361
	P	0.0129	0.0515	-.0073	0.0051	0.0176	-.0351
Rib-eye area	G		0.7179	0.0559	0.0064	0.3165	0.1813
	E		0.2498	0.0364	-.0163	-.2713	0.4411
	P		0.9677	0.0921	-.0100	0.0451	0.6224
Rib-eye area/cwt. carcass	G			0.0078	-.0002	0.0077	0.0236
	E			0.0193	-.0095	-.0336	0.1156
	P			0.0271	-.0097	-.0259	0.1391
Backfat thickness	G				0.0088	0.0730	-.0682
	E				0.0117	-.0263	-.0754
	P				0.0205	0.0466	-.1436
Carcass grade	G					0.6008	-.4731
	E					0.3694	0.0643
	P					0.9702	-.4088
% Retail cuts	G						0.5855
	E						0.8799
	P						1.4654

[a]These values were carried to six decimal places in the actual computations.
[b]Genetic (G), Environmental (E), and Phenotypic (P) variances appear on the diagonal and the respective covariances to the right of the diagonal.

TABLE XVI

GENETIC, ENVIRONMENTAL, AND PHENOTYPIC CORRELATIONS
AMONG CERTAIN CARCASS CHARACTERISTICS
OF BEEF CATTLE

		Rib-eye area	Rib-eye area/cwt. carcass	Backfat thickness	Carcass grade	% Retail cuts
Carcass wt./day of age	G[a]	0.66	-.02	0.15	0.47	0.02
	E	0.35	-.58	0.43	-.15	-.43
	P	0.46	-.39	0.31	0.16	-.26
Rib-eye area	G		0.75	0.08	0.56	0.28
	E		0.52	-.03	-.89	0.94
	P		0.57	-.07	0.05	0.52
Rib-eye area/cwt. carcass	G			-.02	0.13	0.35
	E			-.63	-.40	0.89
	P			-.41	-.18	0.70
Backfat thickness	G				1.00	-.95
	E				-.40	-.16
	P				0.33	-.83
Carcass grade	G					-.80
	E					0.11
	P					-.03

[a]Genetic (G), environmental (E), and phenotypic (P)

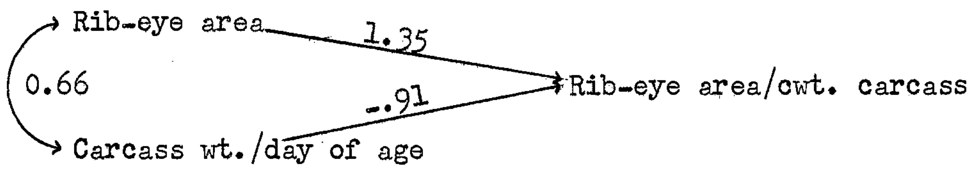

Figure 1. Path coefficient diagram for genetic relationships among rib-eye area, carcass weight per day of age, and rib-eye area per 100 pounds carcass.

This supports the above argument and also indicates that eye muscle development is not proportional to carcass weight. These results indicate that selection for rib-eye area per 100 pounds carcass alone would lead to slight improvement in rib-eye area, but growth rate would be reduced.

A low positive genetic correlation was obtained between carcass weight per day of age and backfat thickness, indicating that selection for rapid growth would lead to only a slight increase in backfat thickness. Shelby et al. (1963) reported a fairly high genetic correlation between carcass weight and backfat thickness. This discrepancy could be due to sampling error or it could be accredited to differences in the length of the post-weaning feeding periods, for as cattle get older the percent composition of fat increases. The cattle in the present study were fed for a substantially shorter period than those studied by Shelby et al. (1963).

The results of this study indicate that selection for growth rate would lead to improvement in carcass grade ($r_g = 0.47$). This agrees favorably with the correlation between carcass weight and carcass grade reported by Shelby et al. (1963).

The genetic correlation obtained between carcass weight per day of age and percent retail cuts was low. Percent retail cuts was estimated from a multiple regression equation that included rib-eye area, backfat thickness, carcass weight, and an estimate of the percent kidney knob as independent variables. Thus, it is a complex of several traits, rather than a single trait. However, it was used in this study, in spite of this limitation, with the idea that it would contribute some knowledge of the genetic correlation between growth rate and carcass composition. The low correlation obtained indicated that the traits are genetically independent and that simultaneous selection for the two traits is necessary in order to realize improvement in both traits.

A low genetic correlation was estimated between rib-eye area and backfat thickness. Shelby et al. (1963) reported a fairly high genetic correlation between these two traits. The difference in these estimates could be due to sampling error or it could also be attributed to differences in the length of the feeding period as discussed above. This correlation indicates that selection for rib-eye area would not lead to an increase in backfat thickness.

The high genetic correlation obtained between rib-eye area and carcass grade implies that cattle with superior genotypes for development of the rib-eye muscle also deposit more marbling in the lean. This conflicts with the negative correlation reported by Shelby et al. (1963).

The genetic correlation between backfat thickness and carcass grade was very high ($r_g = 1.0$). This would imply that the genes responsible for variation in backfat thickness are identical to those responsible for variation in marbling. However, this correlation is inconsistent with the genetic correlations of backfat thickness and carcass grade with other characters studied, since in some instances they differed appreciably. This evidences that the standard errors of the genetic correlations estimated in this study are rather large. Shelby et al. (1963) reported a low genetic correlation between backfat thickness and carcass grade. However, it appears that selection for carcass grade would lead to an undesirable increase in backfat thickness.

The most serious genetic antagonism evidenced in this study was that indicated by the very high negative genetic correlation obtained between carcass grade and percent retail cuts. This indicates that simultaneous and equally intense selection for the two traits would be ineffective in improving either trait. It also shows that selection effective in improving one trait would result in a decline in the other trait.

Phenotypic Correlations. The phenotypic correlations among the various carcass traits evaluated in this study agree reasonably well in most instances with the phenotypic correlations cited in Table III and the simple correlations cited in Table IV. The phenotypic correlation of 0.16 obtained between carcass weight per day of age and carcass grade was the only estimate that differed appreciably from those cited in the review of literature. This correlation is lower than the two fairly high phenotypic correlations reported by Blackwell *et al.* (1962) and Shelby *et al.* (1963) between cold carcass weight and carcass grade.

Several of the phenotypic correlations differed substantially from their respective genetic correlations. The phenotypic correlations between carcass weight per day of age and carcass grade, rib-eye area and carcass grade, and backfat thickness and carcass grade were effected by fairly high to high positive genetic correlations. However, the respective environmental correlations influencing these phenotypic correlations were negative and low to very high in magnitude. This indicates that selection for either trait of each pair correlated would lead to improvement in the other trait, even though the respective characters were independent or had much lower correlations phenotypically.

The reverse situation was found for the correlations affecting the low phenotypic correlation estimated between carcass grade and percent retail cuts. The genetic correlation was negative and very high, while the environmental correlation was low and positive. Thus, the phenotypic correlation of -.03 indicates that the traits are independent phenotypically and fails to show that they are genetically antagonistic.

Conclusions

Carcass weight per day of age, rib-eye area and rib-eye area per 100 pounds carcass, and backfat thickness and carcass grade are classified in Figure 2 as measures of growth, muscular development, and fatness, respectively. Percent retail cuts, determined primarily by backfat thickness and rib-eye area, is an overall measure of composition of the beef carcass.

Rib-eye area is a more satisfactory estimate of muscular development than rib-eye area per 100 pounds carcass since the method of calculating the latter leads to statistical complications that automatically reduce its heritability and its genetic correlation with growth rate. Backfat thickness measures separable fat of the beef carcass while carcass grade measures intra-muscular fat or marbling. The very high genetic correlation ($r_g = 1.00$) between the two traits indicates that the deposition of both kinds of fat is controlled by the same genes. This is unfortunate since marbling contributes to the economic value of the beef carcass while excessive external and inter-muscular fat reduces carcass value.

Growth rate is more highly correlated genetically to muscular development than fat deposition, when cattle are slaughtered at a relatively young age (one year). The path coefficients given in Figure 3 show that growth rate is influenced more by muscular development than fat deposition. Thus,

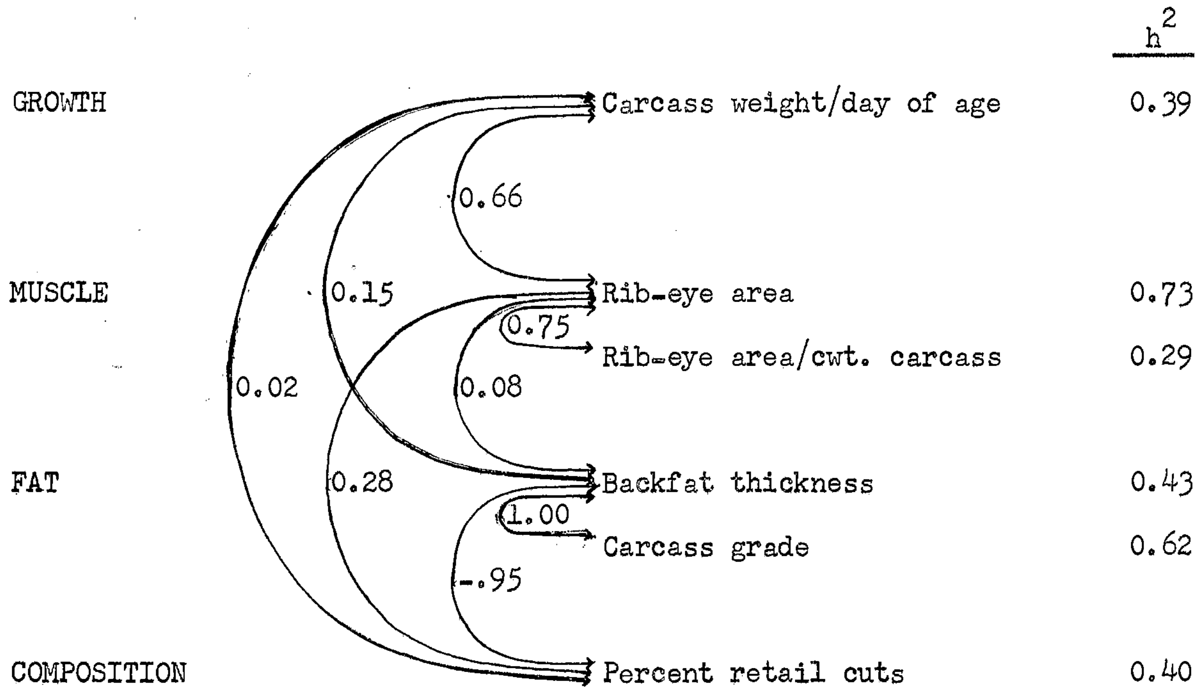

Figure 2. Genetic relationships among characters measuring growth, muscular development, fatness, and composition.

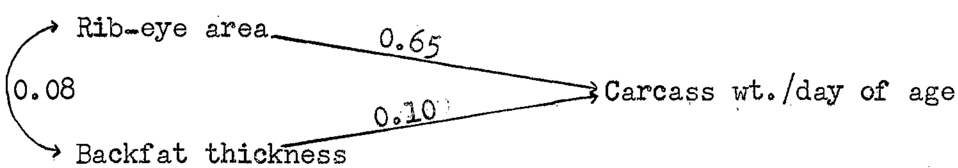

Figure 3. Path coefficient diagram for genetic relationships among rib-eye area, backfat thickness, and carcass weight per day of age.

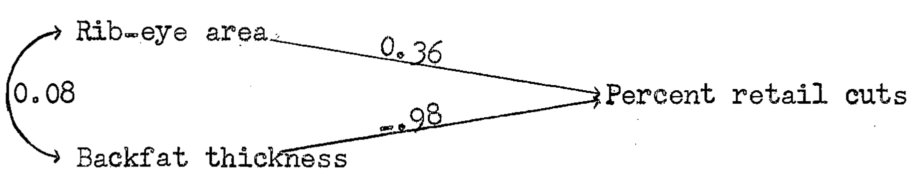

Figure 4. Path coefficient diagram for genetic relationships among rib-eye area, backfat thickness, and percent retail cuts.

it might appear that cattle with superior genotypes for growth rate would have carcasses above average in percent retail cuts. However, the genetic correlation between carcass weight per day of age and percent retail cuts indicates that the two are independent. Perhaps, this is because the slight increase in backfat thickness resulting from selection for growth rate has a greater influence on percent retail cuts than does the increase in muscling (Figure 4).

The heritability estimate obtained for carcass weight per day of age indicates that selection for growth rate would be effective. There are several other measures of growth rate that do not require progeny testing. The results of this study indicate that direct selection for growth rate would lead to increased muscular development (rib-eye area), to improved carcass quality, and to a slight but undesirable increase in backfat thickness. The overall composition of the carcass (percent retail cuts) is uneffected by selection for growth rate. Thus, it appears that progeny or sib testing is necessary if improvement in percent retail cuts is desired. Since growth rate and percent retail cuts are both highly heritable and are not genetically antagonistic, simultaneous selection for the two characters would be effective. The strong preferences of consumers for leaner meats indicates that percent retail cuts is growing in economic importance. Therefore, progeny or sib testing may be warranted in spite of the added expense and time required.

Selection for percent retail cuts is, however, genetically antagonistic to carcass grade. Improvement from selection for one would result in a simultaneous reduction in the other. This makes it necessary for the breeder to decide which of these economically important traits he should emphasize in a breeding program.

SUMMARY

The data were taken from the records of 265 steers fed at the Fort Reno station and slaughtered at about one year of age in 1962 and 1963. The steers were divided into five groups by herd and year of birth among which 47 sire groups were represented. The heritabilities of and the genetic, environmental, and phenotypic correlations among carcass traits measuring growth, muscular development, fatness, and carcass composition were estimated from intra-group paternal half-sib analyses of variance and covariance.

The heritability estimates obtained for carcass weight per day of age, rib-eye area, rib-eye area per 100 pounds carcass, backfat thickness, carcass grade, carcass yield grade, and percent retail cuts were .39, .73, .29, .43, .62, .36, and .40, respectively. These estimates indicate that selection for any one of these traits would be effective.

Genetic, environmental, and phenotypic correlations were computed among 6 of the above traits (Table XVI). Carcass yield grade was not included in these analyses since percent retail cuts offered a similar, but more precise measure of carcass composition.

The genetic correlations indicated that selection for growth rate was not antagonistic to the production of desirable carcasses. On the contrary, the genetic correlations revealed that effective selection for growth rate would lead to improvement in rib-eye area and carcass grade while backfat thickness would be increased only slightly and rib-eye area per 100 pounds carcass and percent retail cuts would be unaffected.

The major genetic antagonism evidenced in this study was that between carcass grade and percent retail cuts. The very high negative genetic correlation estimated between the two traits indicates that selection for one would lead to a reduction in the other. The genetic correlation of 1.00 obtained between backfat thickness and carcass grade indicates that the deposition of external fat and marbling is probably controlled by the same genes. This correlation is largely responsible for the antagonism between carcass grade and percent retail cuts since backfat thickness was found to have a strong negative influence on percent retail cuts.

In many instances the environmental and genetic correlations influencing the phenotypic correlations between a particular pair of characters differed appreciably. Thus, the phenotypic correlations frequently were not indicative of the underlying genetic correlations. This was especially apparent in the correlations involving carcass grade.

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APPENDIX

Detailed Notation on Data in Tables

Weaning age: Weaning age refers to age in days at weaning.

Weaning weight: Weaning weight was the actual weight measured in pounds at weaning.

Preweaning ADG: Preweaning average daily gain was recorded to the nearest one-hundredth of a pound and calculated by

$$\frac{\text{Weaning weight - Birth weight}}{\text{Weaning age}} .$$

Postweaning ADG: Postweaning average daily gain was recorded to the nearest one-hundredth of a pound and calculated by

$$\frac{\text{Final weight - Initial weight}}{\text{Days on feed}} .$$

Carcass wt./day of age: Carcass weight per day of age was recorded to the nearest one-hundredth of a pound and calculated by

$$\frac{\text{(Hot carcass weight)(.985)}}{\text{Age in days at slaughter}} .$$

Carcass grade: Carcass grade was evaluated to the nearest one-third of a grade by a government grader and coded low good = 7, average good = 8, high good = 9, low choice = 10, average choice = 11, high choice = 12, and low prime = 13.

Carcass yield grade: Cutability differences were reflected by six yield grades, 1 to 6, where carcasses with a yield grade of 1 excell in cutability and those with a yield grade of 6 yield a low percent of trimmed retail cuts. Yield grades were recorded to the nearest one-hundredth of a grade for cattle of group III but only to the nearest one-tenth for cattle of the other four groups.

Rib-eye area: Rib-eye area refers to the cross section area of the *longissimus dorsi* cut between the 12th and 13th ribs. It was recorded to the nearest one-hundredth of a square inch.

REA/cwt. carcass: Rib-eye area per 100 pounds carcass was recorded to the nearest one-hundredth of a square inch and calculated by

$$\frac{\text{(Rib-eye area)(100)}}{\text{(Hot carcass weight)(.985)}} .$$

Backfat thickness: Backfat thickness refers to an average of three fat thickness measurements taken at 1/4, 1/2, and 3/4 the longest axis of the rib-eye muscle between the 12th and 13th rib. It was recorded to the nearest one-hundredth of an inch.

% Retail cuts: Percent boneless retail cuts from round, loin, rib, and chuck = 52.66 - 5.33 (av. backfat thickness, in.) - 1.24 (percent kidney fat) - .665 (rib-eye area, sq. in.) - .0065 (carcass wt., lbs.). It was calculated to the nearest one-hundredth of a percent.

TABLE XVII

SIRE PROGENY MEANS IN GROUP I (HEREFORD, 1961)

Sire	No.	Pre-Weaning age	Post-Weaning age	Pre-weaning ADG	Post-weaning ADG	Carcass wt./day of age	Carcass grade	Carcass yield grade	Rib-eye area	REA/cwt. carcass	Backfat thickness	% Retail cuts
715	8	214	477	1.86	2.54	1.36	9.38	3.81	10.34	1.83	0.71	48.61
E906	8	208	449	1.79	2.48	1.31	8.88	3.86	9.63	1.80	0.72	48.17
533	6	216	525	2.05	2.48	1.46	9.83	4.10	10.66	1.72	0.82	47.35
865	4	221	481	1.82	2.72	1.43	10.75	3.78	11.72	1.90	0.72	48.53
816	6	214	492	1.95	2.47	1.40	9.83	3.95	10.94	1.84	0.80	47.89
C785	3	199	425	1.80	2.59	1.36	10.33	4.30	9.31	1.63	0.79	47.03
875	4	214	486	1.92	2.27	1.35	9.50	4.00	10.35	1.82	0.80	47.92
609	12	208	485	1.97	2.46	1.45	9.58	3.90	11.32	1.88	0.82	47.98
ZH450	6	213	460	1.82	2.50	1.40	10.33	3.73	12.09	2.06	0.79	48.74
D324	6	200	481	2.01	2.31	1.40	9.67	3.88	10.12	1.76	0.79	47.70

TABLE XVIII

SIRE PROGENY MEANS IN GROUP II (HEREFORD, 1962)

Sire	No.	Weaning age	Weaning wt.	Pre-weaning ADG	Post-weaning ADG	Carcass wt./day of age	Carcass grade	Carcass yield grade	Rib-eye area	REA/cwt. carcass	Backfat thickness	% Retail cuts
944	10	219	485	1.86	2.90	1.39	10.20	3.67	9.98	1.70	0.70	48.43
948	7	219	483	1.82	2.72	1.33	9.29	3.50	9.82	1.74	0.67	49.15
951	5	215	472	1.82	2.74	1.36	10.40	3.64	10.17	1.76	0.69	48.55
660	6	214	487	1.90	2.62	1.34	9.50	3.55	10.08	1.79	0.73	48.46
662	6	223	478	1.79	2.48	1.28	9.67	3.20	10.56	1.92	0.65	49.25
E8	6	209	453	1.78	2.50	1.26	9.67	3.78	9.44	1.80	0.65	49.04
E9	6	215	458	1.78	2.66	1.32	10.17	3.92	9.63	1.73	0.85	47.75
E11	5	219	416	1.70	2.78	1.30	9.40	3.54	9.70	1.75	0.67	48.60
S96	7	207	476	1.88	2.74	1.37	10.00	3.76	9.79	1.72	0.72	48.41
533	4	196	462	1.70	2.60	1.34	9.00	3.35	9.77	1.79	0.67	48.94
605	4	212	530	2.08	2.65	1.48	10.75	3.82	10.10	1.61	0.82	47.24
647	4	203	440	1.78	2.65	1.32	9.00	3.52	9.50	1.74	0.63	49.07
865	4	219	479	1.82	2.75	1.35	9.00	3.52	10.08	1.75	0.68	48.97

TABLE XIX

SIRE PROGENY MEANS IN GROUP III (FED. REF. ANGUS, 1961)

Sire	No.	Weaning age	Weaning age	Pre-weaning ADG	Post-weaning ADG	Carcass wt./day of age	Carcass grade	Carcass yield grade	Rib-eye area	REA/cwt. carcass	Backfat thickness	% Retail cuts
038	6	205	475	2.01	2.42	1.42	10.33	3.71	10.23	1.89	0.61	48.50
048	6	203	487	2.25	2.43	1.49	11.50	4.32	10.16	1.80	0.97	46.24
158	6	212	554	2.27	2.65	1.61	11.00	3.70	11.65	1.86	0.84	47.79
258	6	213	515	2.10	2.27	1.46	10.83	3.76	10.54	1.86	0.82	47.41
328	6	219	518	2.09	2.44	1.47	11.33	4.02	10.35	1.78	0.82	47.11
468	6	209	508	2.10	2.42	1.46	11.83	4.29	9.77	1.73	0.92	46.15
21	6	218	465	1.84	2.20	1.33	11.50	4.53	9.79	1.86	0.90	46.57
22	6	205	453	1.91	2.14	1.36	11.17	3.98	10.15	1.96	0.86	47.22
23	6	213	528	2.15	2.43	1.50	11.67	4.39	10.09	1.72	0.98	46.18
24	6	213	511	2.07	2.43	1.50	10.83	4.12	9.91	1.71	0.84	46.80

TABLE XX

SIRE PROGENY MEANS IN GROUP IV (FED. REF. ANGUS, 1962)

Sire	No.	Weaning age	Weaning age	Pre-weaning ADG	Post-weaning ADG	Carcass wt./day of age	Carcass grade	Carcass yield grade	Rib-eye area	REA/cwt. carcass	Backfat thickness	% Retail cuts
039	4	212	449	1.92	2.36	1.39	9.75	4.30	9.48	1.75	0.89	46.31
209	4	207	509	2.05	2.75	1.60	10.25	4.15	10.20	1.67	0.80	47.01
269	4	209	474	1.92	2.53	1.51	11.25	3.50	10.69	1.84	0.80	47.96
339	4	206	475	1.96	2.52	1.47	11.25	4.22	9.50	1.70	0.90	46.04
22	4	212	469	1.91	2.51	1.46	11.00	4.00	10.32	1.82	0.88	47.08
23	4	217	496	1.98	2.48	1.45	11.75	3.95	9.98	1.76	0.90	46.76
25	4	204	501	2.10	2.22	1.44	10.25	4.48	9.04	1.66	0.88	46.63
26	4	211	472	1.90	2.42	1.43	11.25	4.05	9.19	1.67	0.80	46.84

TABLE XXI

SIRE PROGENY MEANS IN GROUP V (ANGUS, 1962)

Sire	No.	Weaning age	Weaning age	Pre-weaning ADG	Post-weaning ADG	Carcass wt./day of age	Carcass grade	Carcass yield grade	Rib-eye area	REA/cwt. carcass	Backfat thickness	% Retail cuts
KB30	8	209	447	1.87	2.51	1.38	10.88	3.61	9.69	1.85	0.79	47.50
EL39	6	210	440	1.80	2.54	1.36	10.50	3.83	9.67	1.87	0.80	47.42
KM196	7	205	432	1.82	2.41	1.36	10.71	3.94	9.93	1.99	0.74	47.81
038	8	217	455	1.81	2.50	1.36	10.00	3.41	10.29	1.97	0.64	48.65
OS920	5	208	466	1.94	2.33	1.31	9.20	3.24	9.18	1.87	0.58	49.18
EL125	2	224	502	1.94	2.18	1.30	11.00	3.55	9.50	1.85	0.72	48.35

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