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To the Graduate Council:

I am submitting herewith a dissertation written by Sam K. Winfree entitled "Influence of Exotic Beef Cattle Crossbreeding on Performance, Carcass Characteristics and Meat Palatability." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

J B McLaren
Major Professor

We have read this dissertation
and recommend its acceptance:

Wm R. Backus

Curtis C. Melton

Karl M. Barth

W W Overcast

M R Johnston

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

INFLUENCE OF EXOTIC BEEF CATTLE CROSSBREEDING ON PERFORMANCE, CARCASS CHARACTERISTICS AND MEAT PALATABILITY

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

Sam K. Winfree

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ABSTRACT

Performance of 65 steers and heifers from Hereford (H) dams and sired by either a H, Maine-Anjou (MA), Simmental (S), Limousin (L) or a Charolais (C) bull or from Charolais X Hereford (CH) dams and sired by either a H or C bull was evaluated at various intervals from birth to weaning. Calves were born in February and March and nursed the cows without creep feed during the summer grazing season.

Forty-five of these animals were selected at weaning and were fed a daily ration of 6 lb. shelled corn, 3 lb. legume hay and late dent corn silage ad libitum per head (roughage feeding phase). Following the roughage phase, animals were fed a daily concentrate ration consisting of 2 lb. of shelled corn per 100 lb. of weight and 6 lb. of legume hay until the predetermined fat thickness level (0.40 in.) over the longissimus dorsi muscle was attained. Animals then were slaughtered and carcasses evaluated with respect to U.S.D.A. quality and retail yield traits. A representative retail cut from each carcass was subjected to organoleptic and chemical evaluations.

Least squares procedures as described by Harvey (1960) were used to evaluate differences among breed groups with respect to growth rate, carcass traits and meat palatability. Orthogonal contrasts were used for mean separation when significant differences were observed. Three breed comparisons were of primary interest. These contrasts compared H calves to all F_1 calves, MA X H calves to other F_1 calves, and H X CH to C X CH calves.

Hereford calves were fatter ($P < .01$) than F_1 calves at the end of the roughage phase. Mean subcutaneous fat thickness for H calves was 0.36 in. MA X H, S X H and L X H measured about 0.18 in. fat thickness. C X H, H X CH and C X CH were intermediate with respect to fatness and averaged about 0.25 in. after 140-days roughage feeding.

All animals with less than 0.40 in. subcutaneous fat were fed a concentrate ration until an estimated fat thickness of 0.40 in. was attained. H calves attained this predetermined level of fatness at a lighter ($P < .05$) weight, a younger ($P < .05$) age and required fewer ($P < .01$) days on feed than F_1 calves. MA X H calves were heavier ($P < .01$) and had maintained a higher ($P < .01$) lifetime growth rate than the other F_1 calves. No differences were found between F_1 calves with respect to final age. Heifers fattened faster ($P < .01$) than steers and had lower ($P < .01$) total gains on feed.

Differences in carcass dollar value were directly related to carcass weight. No breed or sex differences were found with respect to carcass value per cwt. All breeds were similar with respect to U.S.D.A. carcass quality grade and other quality attributes. Carcasses from MA X H, S X H and C X CH groups graded an average of low choice. All other breeds graded high good.

Differences in estimates of carcass retail yield were associated with differences in carcass fatness and were significant ($P < .01$) between H X CH and C X CH carcasses and between steer and heifer carcasses; however, steers also had larger ($P < .01$) 1. dorsi muscle areas and less ($P < .01$) actual kidney, heart and pelvic fat than heifers.

No significant trends were found with respect to palatability or Warner-Bratzler shear of cooked meat from these animals. F_1 crosses were similar to H with respect to organoleptic scores; however, roasts from H carcasses had lower ($P < .05$) Warner-Bratzler shear values than roasts from F_1 calves. Sex of calf significantly ($P < .05$) affected percent lipid in a sample of the l. dorsi muscle. Other sources of variation in muscle lipid content were not significant. A significant ($P < .001$) rank correlation of ($r = 0.83$) existed between rank of panel tenderness scores and rank of Warner-Bratzler shear values.

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CHAPTER I

INTRODUCTION

The beef cattle industry in the United States has recently experienced the introduction of new germ plasm from many large European breeds. These European breeds, which have not previously been used extensively in beef production systems in this country, are often referred to as "exotic" breeds. Modern breeding techniques allow a producer to use genetic material from a number of performance-tested bulls of both exotic and British breeds. Beef producers in the southern part of the United States became aware of the value of crossbreeding when Brahman (Zebu) cattle were introduced and the resulting crosses were shown to exhibit increased heat tolerance and resistance to parasites (Kincaid, 1962; Mason, 1966).

Much of the current animal breeding research is directed toward re-evaluating crossbreeding systems in an attempt to obtain maximum heterosis from the diverse germ plasm available through artificial insemination. The Charolais breed was first used in the United States in 1936 and has received considerable review since that time. This breed is proposed to offer (1) diverse genetic material for cross-breeding and (2) delayed maturity which results in a higher potential for growth (Damon et al., 1959; Klosterman, Cahill and Parker, 1968; Pahnish et al., 1969). The increasing use of exotic breeds in commercial herds suggests that beef producers are intensifying their search for genetic material to increase size and growth potential in their cattle.

This interest in crossbreeding by the beef cattle industry has stimulated increased investigation of the value of various new breeds in modern crossbreeding production systems.

Results from current breeding research should aid producers in taking full advantage of the genetic material available without sacrificing the advantages of existing production systems. Previous research results indicate that crosses of the British breeds produce beef cattle which gain more rapidly than straightbreds of these breeds and are more nearly the optimum with respect to external finish at slaughter, carcass yield and eating quality. Exotic breeds which exhibit extremely high growth potential as straightbreds offer an opportunity to increase productivity of many beef herds through crossbreeding. However, the effect of these breeds in a crossbreeding program on carcass yield, quality and organoleptic properties has not been established.

In view of the limited knowledge in this area, this study was undertaken (1) to evaluate the magnitude of the variation which existed in retail yield and consumer acceptability of carcasses from a diverse group of crossbred animals slaughtered at a constant external finish, (2) to study organoleptic and chemical differences between meat from various breeds and breed crosses and (3) to compare performance from birth to slaughter and feed efficiency between seven breed subclasses.

CHAPTER II

REVIEW OF LITERATURE

I. CROSSBREEDING RESEARCH

Early in the twentieth century the trend among beef cattlemen was, according to Ackerson (1967), toward a purebred herd which became a matter of pride, a status symbol and, better still, profitable. Purebred animals contribute a more homogenous genetic base than animals heterozygous with respect to breed. Concentration of like genotypes has been practiced as "line-breeding" and more intensely as "in-breeding," thus today we have many breeds of livestock. Beef producers began planned crossbreeding (crossing two pure lines within a species) in an effort to benefit from heterosis or hybrid vigor which may contribute an increased capacity for growth. Recent research reports by Gregory et al. (1965; 1966a; 1966b; 1966c) substantiate the beneficial heterotic effect on various production and carcass traits of British breeds and Charolais crosses. Heterotic effects on performance and carcass traits in four mating systems were evaluated and summarized in a report by Turner and Mailhes (1969).

Limited research results with respect to the performance and/or carcass characteristics of various crosses involving exotic breeds are available. However, these reports are generally preliminary and deal with only one phase of the total beef production cycle. In addition, they only partially evaluate the usefulness of these newly imported

breeds in various crossbreeding systems. A summary of some of these findings was presented by Warwick (1971).

Factors Related to Calving Difficulty

Data now available indicate that exotic cross calves are heavier at birth than British-bred calves. The problem of calving difficulty has been associated with calf weight and shape at birth (Warwick, 1971). Research in Europe (French et al., 1966) showed that the mean birth weight of purebred Charolais, Limousin, Maine-Anjou and Simmental calves was 99, 79, 99 and 101 lb., respectively, for males and 92, 77, 88 and 92 lb., respectively, for females. Reports by the United States Department of Agriculture (U.S.D.A.)(1972) further indicated that Simmental and Charolais crossbreds were heavier at birth than crosses involving other European breeds. Simmental X Hereford (S X H) and Charolais X Hereford (C X H) calves averaged 93 and 92 lb., respectively, at birth and Limousin X Hereford (L X H) averaged 87 lb. Purebred Herefords in this study averaged 80 lb. at birth. Rank of mean birth weight of calves sired by the aforementioned sires and out of Angus dams was similar but the magnitude of their birth weights were lower. These variations indicated a breed of dam influence on calf birth weights. The similarity of birth weights in Simmental and Charolais crosses was substantiated by Newman and Martin (1971).

Calving difficulty is a major concern in crossbreeding programs involving bulls of large breeds since some increased calving difficulties have been reported. A system of characterizing calving difficulty with respect to degree of dystocia was used to objectively

evaluate this problem in several crosses by the U.S.D.A. (1972). Preliminary reports (U.S.D.A., 1972) verified the hypothesis that problems with respect to dystocia resulted more frequently with two-year-old cows than with older cows (3-4-5-year-olds) and that some breeds tend to have more difficulty calving than others. In this report, Jersey bulls crossed on Angus and Hereford cows resulted in less calving difficulty than any cross studied. Hereford sires followed by Limousin, Simmental and Charolais sires ranked in increasing order of calving severity scores. These data indicated similarity in calving severity between Charolais and Simmental sires when mated to either Angus or Hereford cows. A slight advantage in calving ease in Simmental crosses over Charolais crosses (7.2 versus 10.6 percent difficult calving) was reported by Neuman and Martin (1971). An extensive study by Bellows (1963) indicated that factors other than calf losses at birth affected total breeding efficiency.

Pre-Weaning Performance

Pre-weaning gain has traditionally been considered as an estimate of merit of beef production programs. Average daily gain (ADG), weaning weight per day of age (WDA) and subjective type and condition scores are commonly used criteria for evaluating production. Several conditions can affect individual pre-weaning performance. Steer calves were reported by McLaren (1970) and High (1970) to grow more rapidly than heifer calves. Calves from young cows (2-4 years old) were generally lower in most pre-weaning performance traits than calves from older dams. Several systems for adjusting pre-weaning performance for sex of calf

and age of dam have been developed and are applicable to British-type dams. McLaren (1970) found that similar adjustments were in order for crossbred dams, primarily Charolais X Angus and Charolais X Hereford cross females. Weaning ages often vary as much as 90 days or more, therefore High (1970) and McLaren (1970) suggested that weaning weights should be adjusted to an age-constant basis for direct comparison among calves. Since rate of gain generally decreased with increased age, McLaren (1970) suggested that an additional error was introduced by calculating age-constant weights by conventional methods when weaning age of individual calves varied extremely.

Klosterman, Cahill and Parker (1968) found that Charolais calves were significantly heavier than purebred Hereford steers at weaning and that the heterotic effect on pre-weaning performance traits in the crossbred C X H was significant in most cases. A comprehensive report by the U.S.D.A. (1972) included data on L X H, C X H and S X H calves and showed that S X H and C X H calves were similar in pre-weaning performance but were superior to L X H calves in most traits. All crossbred calves involving exotic breeds were more desirable with respect to pre-weaning performance traits than straightbred Angus and Hereford calves. Mean 200-day weights were 445, 476, 491 and 498 lb. for H, L X H, S X H and C X H calves, respectively. Pre-weaning rate of gain and 200-day weight ratios followed similar trends. Although the Maine-Anjou breed has been included in only a few crossbreeding studies, Warwick (1971) suggested that the Maine-Anjou breed may be equal to or superior to the other exotic breeds with respect to performance in crosses with British breeds.

Post-Weaning Performance

According to Chapman, Utley and McCormick (1971) H steers were significantly lighter at slaughter than S X H, C X H or Santa Gertrudis X H (SG X H) calves. However, the three crosses were similar in weight. No significant breed differences were observed with respect to rate of gain or feed efficiency during the first 112 days of the finishing period, rate of gain during the entire 204-day period, final weight per day of age or total gain to about 457 days of age. The heavier crossbred steers produced heavier carcasses and had higher weight per day of age than the H steers but no difference was reported among the various crosses. Average final weights of 1,008, 1,093, 1,105 and 1,145 lb. were reported for the H, C X H, SG X H and S X H groups, respectively. Average daily gain from birth to 204 days of age was 2.73, 2.88, 2.82 and 2.75 for the respective breed groups above. These results generally agree with reports by Neuman and Martin (1971) who found no major differences in performance or carcass traits among breed crosses.

Some criterion other than feed efficiency, growth rate and carcass yield or quality may be needed to evaluate animals resulting from crossbreeding programs. Crossbred animals tend to be scored lower with respect to U.S.D.A. quality traits when fed to popular market weights but they tend to yield heavier carcasses and a higher percent of retail cuts. Total carcass value and average marginal profit may be better criteria for comparing various crossbred groups (Adams et al., 1971). They suggested that error due to the inversely related factors

such as carcass yield and quality might be minimized by reporting differences in net returns.

Recent experiments conducted by Adams et al. (1971) involved 70 calves from Hereford dams and sired by bulls of the Simmental (S), Limousin (L), Maine-Anjou (MA), Lincoln Red (LR), Brown Swiss (BS), Charolais (C), and Angus (A) breeds. They presented conventional evaluations of each breed cross with respect to growth, efficiency and carcass merit. Comparisons were also reported on the basis of average net return per head for each breed group. The MA X H calves gained 634 lb. from the beginning of the feeding period until slaughtered, compared to 508, 444 and 305 lb. for S X H, L X H and C X H crosses, respectively. MA X H calves gained 3.24 lb. per head per day. They were followed by S X H, L X H and C X H calves which gained 3.20, 2.80 and 2.68 lb. per head per day, respectively. The MA X H cross required 6.9 lb. of feed per lb. of gain and was the most efficient of all the crosses. The C X H required 8.1 lb. of feed per lb. of gain and were the least efficient. The S X H and L X H crosses were similar and intermediate with respect to feed conversion.

Post-weaning ADG of 2.71, 2.70, 2.45 and 2.40 lb. per head per day for H, C X H, S X H and L X H calves, respectively, was reported by the U.S.D.A. (1971). The C X H group required 5.89 lb. feed (90 percent DM basis) per lb. of gain and were the most efficient of the crosses studied. S X H calves required 5.89 lb. of feed per lb. of gain compared to 6.21 lb. required by the L X H calves. Straightbred H calves were the least efficient and required 6.33 lb. of feed per lb. of gain.

Research reports now available indicate that the growth rate of crosses involving the C and S breeds is generally higher than that of L crosses but the L crossbred calves are generally superior to purebred British cattle. Warwick (1971) suggested that MA crosses may excel other exotic crosses in growth and performance. However, there is a lack of information with respect to performance of MA calves and carcass acceptability of all of these crosses.

II. ESTIMATING BEEF CARCASS COMPOSITION

The physical composition of beef carcasses has traditionally been evaluated either by measuring carcass muscle, fat and bone or by weights and percentages of retail or primal cuts. Many equations which predict total body composition have been developed based on the composition of various dissected retail cuts, muscles, wholesale cuts and various linear anatomical measurements. Generally, body composition has been expressed as the weight of carcass components or the ratio of these components to carcass weight.

Hankins and Howe (1946) applied linear regression techniques to carcass data to measure the significance of relationships of separable muscle, fat and bone in the 9-10-11th rib roast with total separable carcass muscle, fat and bone. Brackelsburg et al. (1968), using a more homogenous sample, obtained similar results using the 9-10-11th rib cut and found that smaller samples were representative of total body composition. This procedure reduced the time involved in physical separation of larger cuts. Busch et al. (1968) extended work initiated by Hankins and Howe (1946) to include carcass weight, percent of fat

in the 9-10-11th rib roast and the area of the longissimus dorsi (l. dorsi) muscle at the 12-13th rib interface (REA) in linear equations for predicting total edible portion of the carcass rather than total carcass muscle.

Several equations were developed by Cole et al. (1960, 1962) and Ramsey et al. (1962) using carcass weight, carcass grade, fat thickness, wholesale cut separation data and REA to predict total separable carcass muscle. Ramsey et al. (1962) proposed the use of a single fat thickness measurement to predict ratios of muscle to fat. Cole et al. (1962) added carcass weight to the previous equation and obtained estimates comparable to detailed dissection data.

A series of equations using either carcass data or live animal measurements to predict percent carcass muscle, percent fat trim and percent bone were developed by Bracklesburg and Willham (1968). They found that measures of fatness in the live animal were equal to conventional carcass fat measurements previously used in prediction equations and suggested the possibility of using these data to predict body composition of live animals. The use of prediction equations using carcass data gave more valid estimates of carcass composition but the authors suggested that the increased precision obtained was not justified.

In another study, cutability estimates calculated by the U.S.D.A. equation (Murphey et al., 1960) were compared to actual retail yield data from 835 steers. These comparisons indicated that variation due to breed existed and that this variation was not accounted for in the U.S.D.A. equation. Abraham et al. (1968) proposed equations to predict the

percent of boneless steak from carcasses of four breed groups. They found that the U.S.D.A. equation for predicting percent boneless retail yield resulted in higher coefficients of determination (R^2) for Angus carcasses (.6148) followed by Herefords (.5688), Brahmans (.4045) and Charolais (.3922). They further reported that when the same factors (carcass weight, REA, fat thickness and kidney fat percent) were used to predict weight of boneless retail cuts the R^2 values were increased to .8613, .9044, .8109 and .9463, respectively. Carcass weight contributed significantly to estimates of retail cuts weight but was of little value in a multiple regression equation for predicting percent retail cuts. Fat thickness and kidney fat were of greater value in multiple regression equations than either carcass weight or REA when predicting percent cuts.

Low positive relationships between REA and percent total retail cuts were reported by Epley et al. (1969) and Abraham et al. (1968). Cole et al. (1962) reported that hot carcass weight and REA accounted for only 3 percent more variation in weight of retail cuts than hot carcass weight alone. Tuma et al. (1967) reported that the deletion of REA from predictive equations for weight of retail cuts resulted in no loss of predictive accuracy.

In an evaluation of several quantitative estimates of beef carcass composition, Powell and Huffman (1968) found that the equation proposed by Hankins and Howe (1946) for predicting total carcass fat and percent protein was more closely related to actual carcass composition than estimates derived using other methods. However, the Hankins and Howe equation was the least practical of the procedures used.

The U.S.D.A. yield grade equation (Murphey et al., 1960) and the Tennessee method (Cole et al., 1962) were the most practical since the carcass need not be separated into cuts when using these procedures. All prediction equations evaluated by Powell and Huffman (1968) yielded highly significant estimates of carcass composition.

Retail yields reported by the U.S.D.A. (1972) were lower for H carcasses than for crossbred carcasses. Carcasses of exotic crosses had considerably less external fat, yielded about 3 or 4 percent more retail cuts, and were 50 to 90 lb. heavier than straightbred H carcasses. Hereford calves were about 1 to 1.5 percent lower with respect to dressing percent than L X H and C X H crosses but were similar to S X H. This fact is somewhat inconsistent with previous findings in that fatter cattle usually have a higher dressing percentage.

In summary, carcass weight and estimates of carcass fatness were significantly related to estimates of carcass cutability. Criteria for evaluating carcass merit are the responsibility of the individual researcher and dependent on the situation.

III. METHODS OF EVALUATING CARCASS QUALITY

Another aspect of beef carcass evaluation is the estimation of "quality" or "eatability." Currently, quality grades are composites of several factors which may influence tenderness, juiciness and flavor. These factors are marbling, maturity, conformation and muscle color score. These will be discussed individually in subsequent sections.

U.S.D.A. Quality Grades

Carcass grade standards have evolved from attempts to categorize carcasses into groups of similar eating quality. Carcass grades are commonly used to establish carcass value in wholesale and retail trade. Carcass quality grades are based on age, sex, marbling (intramuscular fat) and carcass conformation and are considered an index of eating quality. Khalil (1972) reported relationships of low magnitude between various U.S.D.A. quality grade factors and eating satisfaction measured by a taste panel. Cole et al. (1962) and others, have suggested that other characteristics may be of significance in arriving at a more accurate estimate of quality. Other factors which have been considered include scores for muscle color, muscle firmness, muscle texture, marbling texture and exterior fat color and distribution.

Maturity

Carcass maturity is determined by evaluation of bone ossification, structure, color and size. Muscle color and texture also aid in determining carcass maturity. Muscles in mature carcasses are darker and have coarser texture than in young carcasses. Sliger (1966) studied the effect of age on physical and chemical composition of the carcass, Warner-Bratzler shear values, and taste panel preference scores. Carcass quality grade increased with age from 3 to about 42 months, then decreased sharply until 48 months and remained about constant through 102 months of age. There was a general decrease in tenderness scores and shear values with age but the magnitude of change was not consistently significant. Taste panel juiciness and flavor scores increased with age.

Intramuscular Fat (Marbling)

Degree of marbling is the major factor used to determine final carcass grade. Recent research results (Khalil, 1972) indicated that the effect of marbling on eating quality may be over-emphasized in current grading systems. This study supported the suggestions by Hankins, Gaddis and Sulzbacher (American Society of Animal Science) (A.S.A.S.), (1963) that the use of final carcass grade as an estimate of eating quality (or palatability) had some weakness since grade was a composite of several factors. Breed differences with respect to palatability traits have been reported. Ramsey et al. (1963) found that round and loin steaks from Jersey steers were more tender than the same cuts from six other breeds. They reported significant breed differences in tenderness as measured objectively by trained taste panels. They further suggested that factors other than marbling play an important role in determining eating quality. These data agree with results reported by Alsmeyer et al. (1959) and Cartwright et al. (1957) that significant breed differences existed with respect to tenderness. Available research as reviewed by Warwick (1971) is inconclusive regarding the ability of crosses involving exotic breeds to attain marbling sufficient to grade U.S.D.A. Choice. Chapman, Utley and McCormick (1971) reported that some crosses involving exotic breeds were lacking in U.S.D.A. carcass quality attributes when slaughtered at popular market weights.

Marbling has been shown by Khalil (1972) to influence juiciness and flavor more than it affects tenderness. Blumer (1962) suggested that fat stimulated saliva flow and added to the overall juiciness.

He reflected low positive coefficients of correlation between marbling and juiciness from three separate studies.

Beef flavor is more difficult to evaluate than tenderness and juiciness according to Cover, Butler and Cartwright (1956). However, beef flavor was shown, by Cole and Badenhop (1958), to significantly influence the final preference rating of beef steaks by a family panel.

CHAPTER III

EXPERIMENTAL PROCEDURE

Source of Data

Data used in this study were collected from 65 steers and heifers in the Middle Tennessee Experiment Station herd at Spring Hill, Tennessee, during 1971. The animals were offspring of Hereford (H) cows bred to either Hereford (H), Charolais (C), Limousin (L), Maine-Anjou (MA) or Simmental (S) bull and from CH cows mated to a H or C bull.

The seven breeds and breed crosses represented in the study are shown in Table 1. Data collected included various measures of performance from birth to weaning, post-weaning growth rate and feed efficiency, carcass quality and value, chemical and organoleptic measures of carcass quality, and carcass retail yield. Experimental procedure, animal management and results of this study will be discussed in four sections: (1) pre-weaning, (2) post-weaning, (3) carcass traits and, (4) evaluation of quality by chemical and organoleptic procedures.

Pre-Weaning Phase

Hereford cows were randomly assigned to be bred to H, S, L, C or MA bulls and CH cows were randomly assigned to C or H bulls during the 1970 breeding season. All calves were born in the spring (January through March) of 1971. The calves nursed their dams, without creep

Table 1. Distribution Among Breed Groups[a]

Breed of Sire Breed of Dam	H H	MA H	S H	L H	C H	H CH	C CH	Total Number
Pre-Weaning Sample	18	7	8	7	5	12	8	65
Post-Weaning Sample	5	7	8	7	5	7	6	45

[a]H = Hereford, MA = Maine-Anjou, S = Simmental, L = Limousin, C = Charolais.

feed, during the spring and summer grazing season. All cows and calves were pastured together and grazed fescue-clover-lespedeza and/or orchardgrass-clover pasture. Male calves were castrated at about 120 days of age.

Calves were weighed at birth, and weights, type scores and subjective estimates of condition were recorded at about 135 days of age. The calves were weaned in October at about 256 days of age. At weaning, they were weighed and scored with respect to type (conformation) and condition. In addition, fat thickness at the 12th rib was measured with a Branson Model 12 Sonoray. Various linear body measurements, intended to define size and shape, were recorded at weaning according to procedures described by Compton (1972).

Dams of the calves used in this study ranged in age from 3 to 12 years. Measures of pre-weaning performance were adjusted for variation in age of dam, sex of calf and weaning age using procedures described by High (1970) and McLaren (1970).

Post-Weaning Phase

A total of 45 calves were selected at weaning on the basis of age and sex and were allotted to feeding groups by breed with a minimum of five calves in each group. The calves were fed in a pole-type barn open to the south with the north side completely closed. About one-half of each pen was outside with concrete floors which were scraped periodically with a tractor and blade.

Breed group estimates of feed efficiency (F.E.) were based on data from seven pens of five animals each. After a 21-day post-weaning

adjustment period, the animals were weighed on two consecutive days and the mean weights were used as initial weights. Subsequent weights were taken at 28-day intervals during the first 140 days and at 14-day intervals thereafter.

During the first 140 days of the post-weaning period the calves were fed a ration of 6 to 7 lb. of shelled corn, 3 lb. of hay and corn silage ad libitum. This will subsequently be referred to as the roughage phase.

Grain intake was gradually increased and silage intake decreased following the roughage phase. From the end of the roughage phase until slaughter the ration consisted of concentrates ad libitum, 3 lb. of hay and about 10 to 12 lb. of silage per head per day. Feed consumption was recorded by pens. Individual weights, ultrasonic estimates of fat thickness and linear body measurements were recorded at the end of the roughage phase.

Criterion for Terminating Feeding

Previous research (Backus, 1968, and Compton, 1972), indicated that animals were similar in body composition when the subcutaneous fat thickness at the 12-13th rib was ten millimeters. In this study, fat thickness at the 12-13th rib was used as the terminating criterion.

Use of this criterion (constant subcutaneous fat thickness) allowed evaluation of the effect of breed and other factors on variation in live weight, carcass weight, feed efficiency, cumulative rates of gain, carcass quality, chronological age and days on test of animals similar in body composition and carcass yield traits.

Carcass Data

Animals selected for slaughter were transported approximately 200 miles to the University of Tennessee Meat Laboratory on the day prior to slaughter. The animals were held off feed but had free access to water for approximately 12 hours prior to slaughter. Slaughter weights were recorded just prior to exsanguation.

Individual hide weights, gastro-intestinal tract weights, combined weights of the heart, lungs, liver, esophagus and trachea (pluck) and hot carcass weights were recorded after skinning and dressing. Carcasses were chilled 48 hours at approximately 36° F. Carcasses were ribbed and allowed to chill two additional hours before U.S.D.A. quality attributes were recorded. Special effort was made to rib each carcass so that the exposed plane of the l. dorsi muscle interface was flat and perpendicular to the muscle fibers.

Carcass quality attributes were evaluated by University of Tennessee meat research personnel. Carcass scores with respect to conformation; maturity and marbling; estimated percent kidney, heart and pelvic fat; carcass grade; muscle color; firmness and texture scores; and marbling texture scores were recorded. The exposed l. dorsi surface and surrounding tissues were traced on acetate paper and permanently identified. The muscle area of each tracing was measured to the nearest 0.01 square inch using a compensating polar planimeter.

Subcutaneous fat thickness over the l. dorsi muscle between the 12th and 13th ribs was measured to the nearest millimeter at a point three-fourths distal to the chine end as described by Ramsey et al. (1962). After aging for seven days, both sides of each carcass were

separated into wholesale cuts using the procedure described by Wellington (1953).

Wholesale round, loin, rib and chuck from the left side of each carcass were further separated into partially boneless retail cuts. Fat covering was trimmed to not exceed three-eighths inch and seam fat was removed when possible without separating muscles in the retail cuts. Total retail yield of each carcass was calculated using data from both sides. The 9-10-11th rib section and wholesale round were physically separated into muscle, fat and bone.

Two one-inch club steaks from the anterior end of the loin and the 6-7-8th rib roast from the left side of each carcass were retained for organoleptic evaluation by a ten-member trained panel. A sample from the l. dorsi muscle at the 12th rib was retained for detailed lipid content and percent moisture analysis.

Taste Panel and Objective Tenderness Evaluation

Roasts and steaks were assigned to cooking groups (four samples per group) so as to provide the maximum number of breed and sex comparisons.

Roasts were allowed to thaw at room temperature approximately 12 hours prior to preparation for cooking. The roasts were removed from the freezer wrap, wiped dry and weighed along with a previously weighed roaster pan. A dial-type thermometer was inserted to the center of the l. dorsi muscle and the roasts were placed in a pre-heated Despatch oven at 375° F. Roasts were cooked at an oven temperature of 300° F. until the internal temperature reached 163° F. After cooling,

data necessary for calculating drip and evaporation losses were collected.

The 1. dorsi muscle was removed from each roast and surfaces directly exposed to the drying heat of the oven were trimmed. Two one-inch slices were cut from the 7-8 rib section. Both slices were trimmed of extraneous fat and connective tissue and sectioned to yield ten samples for the ten-member panel. Each panel member sampled the same anatomical portion of each roast during the complete sampling schedule. The panel individually scored each sample for tenderness using a ten-point hedonic scale, ten being most desirable. Sample juiciness and flavor were scored using a nine-point hedonic scale, nine being most desirable. Three one-inch cores were removed from the 6th rib section and duplicate shear values obtained using the Warner-Bratzler shear device. Steaks were broiled to 163° F. internal temperature and were subjected to the objective tenderness evaluation described above.

All roast samples were ranked from 1 to 4 within cooking groups with respect to mean panel tenderness, juiciness and flavor scores and mean Warner-Bratzler shear values. Steaks also were ranked from 1 to 4 within cooking groups with respect to mean Warner-Bratzler shear values. A least square analysis of variance was applied to all numerical data and rank correlations of organoleptic were calculated.

Statistical Analyses

Least-square constants for the effect of age of dam and sex of calf were calculated as described by Harvey (1960). These least-square

constants then were applied to the unadjusted pre-weaning data to remove the effects of age of dam and sex of calf. The preliminary analysis of variance included tests for the effects of age of dam, sex of calf and calf age in days on adjusted pre-weaning performance data and is shown below:

$$Y = \mu + \text{breed} + \text{age of dam} + \text{sex of calf} + b_1 \text{ (calf age in days)}$$

The least-square constants for age of dam and sex of calf from the preliminary analysis were similar to those described by the Beef Improvement Federation (BIF, 1972); and McLaren (1970); therefore the adjustment factors for age of dam and sex of calf were those prescribed by the BIF. Weights at two stages of pre-weaning (135 and 256 days) were calculated to remove the effect of individual differences in calf age.

When significant differences between breeds were indicated by a least-square analysis of variance, orthogonal comparisons shown in Table 2 were used to identify the source and magnitude of variation between breed means. The statistical model used to test for significant variation in data subsequent to weaning was:

$$Y = \mu + \text{breed} + \text{sex of calf}$$

Three of the orthogonal comparisons shown in Table 2 were of primary biological interest.

Contrast one allowed a comparison of mean data from purebred Herefords with mean data from F_1 offspring by four exotic breeds of sires and from purebred Hereford cows. Contrast two tested the variation between MA X H crosses and the mean performance of the

Table 2. Orthogonal Comparisons

	Breed						
	HXH	MAXH	SXH	LXH	CXH	HXCH	CXCH
Comparison 1	4	-1	-1	-1	-1	0	0
Comparison 2	0	3	-1	-1	-1	0	0
Comparison 3	0	0	0	0	0	1	-1
Comparison 4	0	0	2	-1	-1	0	0
Comparison 5	0	0	0	1	-1	0	0
Comparison 6	2	2	2	2	2	-5	-5

three other exotic crosses on Hereford dams. Contrast three compared the mean data from Hereford sires with mean data from (C) sires when each breed of sire was mated to CH cows.

Three other comparisons (Table 2) were made but are not of primary biological interest in this study. Variation between independent means in all comparisons were evaluated by relations between mean squares in the analysis of variance. The mean square for sex differences in all data was also evaluated.

CHAPTER IV

RESULTS AND DISCUSSION

Data from this experiment indicate that these results are similar to those reported by Warwick (1971) and the U.S.D.A. (1972) during relative time periods in the growth and development of calves. In this study, orthogonal comparisons were used to assess differences between groups of crossbred calves sired by bulls of different breeds. Three orthogonal comparisons were of major interest and major emphasis will be given them in subsequent discussions. They were:

1. Straightbred Hereford calves (H) compared to crossbred calves (F_1) which resulted from mating either a Maine-Anjou, Simmental, Limousin or Charolais bull to straightbred Hereford cows.

2. Maine-Anjou X Hereford (MA X H) calves compared to all other F_1 calves (Simmental X Hereford, Limousin X Hereford and Charolais X Hereford).

3. F_2 calves sired by Charolais bulls compared to F_2 calves sired by Hereford bulls when each breed of sire was mated to Charolais X Hereford (C X H) cows.

Three other orthogonal comparisons were made and significant differences will be briefly discussed. These were:

4. Simmental X Hereford (S X H) calves compared to the mean of Limousin X Hereford (L X H) and Charolais X Hereford (C X H) calves.

5. L X H calves compared to C X H calves.

6. Calves from straightbred Hereford cows compared to calves from C X H cows.

I. PRE-WEANING PERFORMANCE

The number of calves weaned per 100 cows bred is the most important factor influencing the success of a cow-calf production system. This may be influenced by conception rate or by calf losses. Increased birth weight has been associated with increased calving difficulty and calf losses at birth by Warwick (1971) and others. In this study, no attempt was made to objectively evaluate calving difficulty or the relationship between birth weight and calf loss at birth. However, differences in birth weight among the various breed groups are shown in Table 3.

Birth Weight

Mean birth weight of the various groups ranged from 67.3 lb. for MA X H calves to 81.4 lb. for S X H calves. Birth weight was significantly influenced by variation in age of dam ($P < .002$) and the trend was similar to that reported by McLaren (1970) and High (1970). Bull calves were 5.8 lb. heavier ($P < .001$) at birth than heifer calves. Analysis of variance of birth weight including the orthogonal comparisons which evaluate breed differences are shown in Table 4.

Hereford calves were 6.3 lb. lighter ($P < .05$) at birth than the F_1 calves from H dams. MA X H calves were 9.6 lb. lighter ($P < .01$) at birth than the mean birth weight of other F_1 calves. S X H calves averaged 81.4 lb. at birth and were 6.8 lb. heavier ($P < .10$) than the mean of the L X H and C X H calves. These results support findings by Neuman and Martin (1971) who compared S X H and C X H calves; however, they disagree with birth weights reported by French et al.

Table 3. Least Square Means for Pre-Weaning Performance Traits

Breed[a]	Number in Sample	Birth Weight (lb.)	135-Day[b] Weight (lb.)	256-Day[b] Weight (lb.)	256-Day[b] ADG (lb.)	Weaning[c] Condition Score
Overall	65	73.9	296.5	496.1	1.65	9.1
H X H	18	68.1	277.4	465.0	1.55	9.6
MA X H	7	67.3	300.5	509.6	1.73	8.9
S X H	8	81.4	295.1	486.7	1.58	8.2
L X H	7	71.7	250.7	411.3	1.33	9.1
C X H	5	77.5	267.6	438.1	1.41	8.8
H X CH	12	72.5	340.1	540.1	1.98	9.3
C X CH	8	78.8	344.1	541.9	1.97	9.6
Steers	35	76.8	298.1	496.6	1.64	8.7
Heifers	30	71.0	294.9	495.6	1.66	9.4

[a]H = Hereford, MA = Maine-Anjou, S = Simmental, L = Limousin, C = Charolais.

[b]Adjusted to a steer sex basis, 4-5-6-year-old dam basis.

[c]10 = Average Good, 8 = High Standard.

Table 4. Analysis of Variance of Pre-Weaning Performance Traits

Source[a]	Mean Squares				
	Birth Weight	135-Day Weight	256-Day Weight	256-Day ADG	Weaning Condition Score
Breed	228.3***	4692.4***	16673.0***	0.357***	1.02*
Comparison 1	212.0**	6.6	66.9	0.008	3.63*
Comparison 2	367.6**	3434.4*	16464.6**	0.332**	0.12
Comparison 3	174.4*	67.9	14.3	0.001	0.29
Comparison 4	178.2*	4956.3**	14771.3**	0.179*	1.87
Comparison 5	79.7	676.9	1708.7	0.016	0.30
Comparison 6	36.4	24185.4***	83811.2***	1.226***	1.62
Sex of Calf	401.7***	129.9	13.3	0.004	5.72***
Age of Dam	239.8***	2170.5	6101.9	0.071	1.52
Residual	52.4	957.4	3225.0	0.047	0.99
R^2	0.62***	0.60***	0.59***	0.58***	0.37*

[a]Orthogonal comparisons are described in Table 2, page 24.

*P < 0.10.

**P < 0.05.

***P < 0.01.

(1966). Birth weight of calves from H and C X H dams were similar. C X CH calves averaged 78.8 lb. at birth and were about 6 lb. heavier ($P < .10$) than H X CH calves.

135-Day Weight

Mid-season weights taken June 15, 1971 were adjusted to an age-constant basis of 135 days using adjustment factors published by BIF (1972). Orthogonal contrasts used previously (Table 2, page 24) were applied to the 135-day weights to test for breed differences.

The straightbred H and the F_1 calves were similar ($P < .93$) with respect to 135-day weights. The four-pound difference between H X CH and C X CH calves was not significant. Maine-Anjou X H calves were 29.4 lb. heavier ($P < .10$) than the other F_1 calves. Simmental X H calves were 35.9 lb. heavier ($P < .05$) than the mean of the L X H and C X H calves at 135 days of age; however, differences in average 135-day weights between L X H and C X H calves were not significant. Calves from C X H dams were 63.8 lb. heavier ($P < .01$) than calves from H dams. Steer calves were 3.2 lb. heavier at 135 days of age than heifer calves. This difference was not significant due to adjustment for sex differences. H X CH and C X CH calves were similar ($P < .01$) in weight at 135 days of age but they about 65 lb. heavier than the F_1 calves.

Performance from Birth to Weaning

Weaning weights were taken on October 15, 1971. The calves ranged in age from about 220 to 280 days. Individual weaning weights were adjusted for age of dam and sex of calf. In addition, weaning

weights were adjusted to a 256-day age-constant basis to allow comparison among breed groups. The 256-day weight of H and F_1 calves was similar. However, MA X H calves were 64.3 lb. heavier ($P < .05$) than the other F_1 calves at this age. S X H calves were about 60 lb. heavier than the average of L X H and C X H calves. These results are similar to those reported by Warwick (1971) who suggested that, generally, Simmental and Charolais crossbred calves gained faster than straightbred calves of British breeds. It is in conflict with his report that Limousin crossbred calves are generally superior in growth to straightbred calves.

Average daily gain from birth to weaning ranged from 1.33 lb. per head per day for L X H calves to 1.98 lb. per head per day for C X CH calves. Pre-weaning ADG's of the H and F_1 calves were similar. MA X H calves gained 1.73 lb. per head per day from birth to weaning which was higher ($P < .05$) than the ADG of the other F_1 calves. However, the C X H calves gained 1.73 lb. per head per day from birth to weaning which was higher ($P < .05$) than the ADG of the other F_1 calves. These results are similar in most respects to those reported by Warwick (1971), Klosterman, Cahill and Parker (1968) and U.S.D.A. (1972).

Hereford calves were fatter ($P < .10$) than F_1 calves at weaning as measured by weaning condition score. This trend was supported by subcutaneous fat thickness measurements at the 12th rib of a sample of calves from each breed group. Hereford calves had about 0.10 in. of subcutaneous fat cover and the F_1 calves had about 0.05 in. Heifer calves were fatter ($P < .01$) than steer calves. Mean condition scores at weaning were 8.7 for steers and 9.8 for heifers. Calves from C X H

dams were fatter than the F_1 calves and similar to H calves with respect to weaning condition scores.

II. POST-WEANING PERFORMANCE

Roughage Phase (140-Day)

Due to limited feeding facilities, a total of 45 calves were selected at weaning on the basis of age and sex and were allotted to feeding groups by breed. In order to evaluate post-weaning performance and feed efficiency, weight change and feed consumption data were collected during the 140-day roughage phase. The calves were fed a ration of 6 lb. concentrates, 3 lb. hay and silage ad lib. during this phase.

The overall mean initial weight of the calves in the post-weaning study was 518.1 lb. Initial weights of the various breed groups ranged from 458.5 lb. for the L X H to 575.6 lb. for the C X H group (Table 5). Differences in initial weight among the breed groups were similar to those discussed for all calves at weaning. The MA X H group was significantly ($P < .01$) heavier than the other F_1 groups and calves out of C X H dams were significantly ($P < .05$) heavier than calves from H dams.

Relationships similar to those which existed at weaning were found after 140 days on feed. Initial weight had a significant effect ($P < .01$) on subsequent weights but had no effect ($P < .04$) on average daily gain or total gain during the 140-day roughage phase. Differences in ADG and total gain of the various breed groups during the 140-day roughage phase were identical since ADG is a function of total gain.

Table 5. Least Square Means of Performance During the 140-Day Post-Weaning Roughage Phase[a]

Breed[b]	Initial Weight (lb.)	Final Weight (lb.)	ADG (lb./day)	Feed[c] Efficiency	Final Fat[d] Thickness (in.)
Overall	518.1	788.8	1.88	6.00	0.23
H X H	535.7	776.9	1.74	6.56	0.36
MA X H	573.3	880.3	2.12	5.55	0.18
S X H	477.8	742.5	1.87	5.92	0.18
L X H	458.5	740.2	1.79	6.41	0.17
C X H	473.6	743.2	1.88	5.84	0.23
H X CH	532.2	797.3	1.87	5.85	0.29
C X CH	575.6	841.2	1.90	5.85	0.26
Steers	530.0	791.6	1.90	5.86	0.20
Heifers	506.2	786.0	1.86	6.13	0.26

[a]Full feed of corn silage, 3 lb. hay, 6 lb. concentrates.

[b]H = Hereford, MA = Maine-Anjou, S = Simmental, L = Limousin, C = Charolais.

[c]Dry matter basis.

[d]Sonoray estimates, 12th rib.

Hereford calves were similar in weight to F_1 calves at the end of the roughage phase. Hereford calves gained only 1.74 lb. per head per day; however, this was not statistically different from the ADG (1.92 lb. per head per day) of the F_1 calves. The MA X H calves gained an average of 295.6 lb. (2.12 lb. per head per day) during the roughage phase. This was higher ($P < .05$) than the rate of gain of the other F_1 calves. These results were in agreement with those reported by Adams et al. (1971) who indicated that MA X H calves excelled all other crosses with respect to post-weaning performance. Other orthogonal comparisons presented in Table 6 indicated that no significant differences existed among the remaining breed groups with respect to rate of gain during the roughage phase.

Estimates of feed efficiency (FE) were calculated on an as-fed and dry matter basis. Differences in FE among breed groups were not statistically significant; however, the stimates ranged from 5.55 lb. of dry matter per lb. of gain for MA X H calves to 6.56 lb. per lb. of gain for H calves. These trends paralleled those reported by Adams et al. (1971) who reported that MA X H calves were the most efficient with respect to feed conversion (6.9 lb. of feed per lb. of gain) and that C X H were least efficient (8.1 lb. of feed per lb. of gain). Trends toward increased feed efficiency relative to increased rate of gain observed in this study was similar to that reported by U.S.D.A. (1972).

Subcutaneous fat thickness at the 12th rib was measured ultrasonically at the end of the 140-day roughage phase. Hereford steers and heifers were fatter ($P < .001$) than F_1 calves. MA X H, S X H

Table 6. Analysis of Variance of Performance During the 140-Day Post-Weaning Roughage Phase[a]

Source[b]	Mean Squares				
	Initial Weight	Final Weight	ADG	Feed Efficiency	Final Fat Thickness
Breed	13554.8***	17827.0***	0.078	2.78	14.17***
Comparison 1	4125.6	0.3	0.079	4.63	52.17***
Comparison 2	47376.1***	84974.9***	0.039**	5.31	0.13
Comparison 3	5994.1	6127.3	0.003	0.00	0.62
Comparison 4	555.7	2.5	0.005	0.77	3.89
Comparison 5	483.2	18.1	0.017	3.11	3.39
Comparison 6	21074.7**	15257.0*	0.001	1.57	9.08*
Sex of Calf	4411.7	244.4	0.012	2.64	19.92**
Residual	2865.7	5235.4	0.068	4.98	3.07
R^2	0.47***	0.40**	0.19	0.11	0.53***

[a]Full feed of corn silage, 3 lb. hay, 6 lb. concentrates.

[b]Orthogonal comparisons are described in Table 2, page 24.

*P < .10.

**P < .05.

***P < .01.

and L X H calves were similar with respect to subcutaneous fat thickness and tended to have slightly less fat cover than the other crossbred groups. The three crosses involving the Charolais breed were similar in fatness and intermediate to the straightbred Hereford and the other crossbred calves from Hereford dams. Calves from C X H dams were fatter than calves from Hereford dams after 140 days on feed. These trends were similar to those observed with respect to average condition scores at weaning (Table 3, page 28).

Performance During the Entire Finishing Period

Performance data reported in Table 7 combines the 140-day roughage phase and subsequent performance during the period when the animals were fed a concentrate ration. The animals were individually removed from the feedlot when they reached a predetermined subcutaneous fat thickness (0.40 in.). This constant end point was so designed to result in similar body composition among individual animals at slaughter regardless of weight.

Herefords were lighter than the F_1 crosses when they attained the predetermined level of fatness. MA X H calves were about 175 lb. heavier than the other F_1 calves at slaughter. Other orthogonal contrast shown in Table 8 indicated that S X H, L X H and C X H calves were similar in weight when this level of fatness was attained. Neuman and Martin (1971) also found no difference between C X H and S X H calves. Calves sired by H and C bulls and out of C X H cows were similar in weight at slaughter.

Table 7. Least Square Means for Total Performance From Weaning to Slaughter and Lifetime Average Daily Gain

Breed[a]	Final Weight (lb.)	Total Gain (lb.)	Feeding ADG (lb./day)	Lifetime ADG (lb./day)	Final Fat Thickness (in.)	Final Age (days)	Days on Feed
Overall	919.9	401.7	1.94	1.72	0.33	494.1	209.4
H X H	827.5	291.8	1.99	1.76	0.39	430.5	147.2
MA X H	1065.3	492.0	2.21	1.91	0.31	523.8	223.5
S X H	905.9	428.2	1.79	1.60	0.30	513.5	239.2
L X H	898.3	439.8	1.90	1.58	0.29	528.7	233.7
C X H	886.1	412.7	1.92	1.67	0.39	486.2	213.5
H X CH	905.7	373.6	1.86	1.79	0.38	467.2	200.7
C X CH	950.5	373.8	1.91	1.73	0.30	479.4	208.0
Steers	941.3	435.2	1.94	1.74	0.28	501.4	226.6
Heifers	898.5	378.2	1.94	1.70	0.38	486.8	192.2

[a]H = Hereford, MA = Maine-Anjou, S = Simmental, L = Limousin, C = Charolais.

Table 8. Analysis of Variance of Total Performance From Weaning to Slaughter and Lifetime Average Daily Gain

Source[a]	Mean Squares						
	Final Weight	Total Gain	Feeding ADG	Lifetime ADG	Estimated Final Fat Thickness	Final Age	Total Days on Feed
Breed	29333.6***	18714.6	0.113	0.085	5.92	5442.9***	3701.8**
Comparison 1	32231.4***	59495.6***	0.003	0.011	16.19**	17680.9**	16710.0**
Comparison 2	126156.2***	18824.4**	0.514**	0.380***	0.85	916.2	127.5
Comparison 3	6346.9	0.1	0.005	0.013	7.60	5436.1**	170.2
Comparison 4	751.2	15.0	0.058	0.002	5.15	147.4	987.0
Comparison 5	312.8	1544.1	0.001	0.020	3.06	3808.1*	866.9
Comparison 6	1098.8	12856.8**	0.051	0.027	0.15	624.8	422.4
Sex of Calf	14305.8*	35007.5***	0.000	0.010	46.48***	1645.6	9254.6***
Residual	3771.4	2876.6	0.085	0.028	3.96	1198.5	1109.3
R^2	0.65***	0.65***	0.21	0.38**	0.43***	0.50***	0.48***

[a]Orthogonal comparisons are described in Table 2, page 24.

*P < 0.10.

**P < 0.05.

***P < 0.01.

Final weight was not closely associated with final age. However, the final weight of animals fed to similar fat thickness was significantly affected by variation in initial on-feed weight.

The fact that Hereford calves reached the predetermined degree of finish faster than the F_1 calves was emphasized by the total days of post-weaning feeding required to reach that finish. Hereford calves were fed for an average of 147 days compared to an average of 228 days for the F_1 calves. Hereford calves required 80 days less total feed, were 82 days younger, weighed 112 lb. less and had about 0.1 in. more subcutaneous fat than the F_1 calves at slaughter.

Little difference was observed between the mean performance of H X CH and C X CH calves. The C X CH calves was slightly heavier but 8 days older at slaughter than the H X CH calves. Rate of gain on feed favored the C X CH calves but the H X CH calves had a slight advantage in lifetime ADG. The only statistically significant difference observed between these groups with respect to cumulative performance during the finishing was in final age. The C X CH calves were about 40 days older than the H X CH calves and had 0.08 in. less subcutaneous fat but these differences were not significant. Carcass fat thickness measurements indicated that the C X CH calves were slaughtered at a significantly lower level of fatness than the H X CH calves. This resulted from erroneous estimates of fatness on live animals in the C X CH group. Differences in final fat thickness shown in Tables 7 and 8 between H X CH and C X CH calves may not reflect valid estimates of feeding performance since they were slaughtered at different stages of body fatness.

The MA X H calves were significantly ($P < .01$) heavier at slaughter and had gained faster ($P < .05$) on feed than the other F_1 calves. The MA X H calves averaged 1,065.3 lb. after 223 days on feed. They gained 2.21 lb. per day during the entire finishing period which was 0.34 lb. per day higher than the mean ADG for the other F_1 calves. Lifetime ADG of the MA X H calves was 0.29 lb. higher ($P < .01$) than that of the other F_1 calves. This supports the results reported by Adam et al. (1971) that MA X H calves gained faster and were heavier at slaughter than other crossbred calves.

Calves from H dams gained about 40 lb. more ($P < .05$) during the finishing period than calves from CH dams. Some of this difference may be attributed to errors in estimating final fatness in the C X CH calves although the analysis of variance indicated the estimated fat thickness of the two groups were similar.

The effects of sex on feeding performance are traditional. Steers gained 67.4 lb. more ($P < .01$) than heifers and reflected the fact that heifers reached the terminal fat thickness faster ($P < .01$) than steers. Heifers were estimated to be about 0.1 in. fatter ($P < .01$) than steers when slaughtered after 34.4 fewer ($P < .01$) days on feed. Total gain or ADG of steers and heifers during the finishing period were not significantly different.

III. SLAUGHTER DATA

Factors Related to Dressing Percent

Slaughter weights were taken just prior to stunning and sticking. Breed means for this trait and other slaughter data related to wholesale

yield (dressing percent) are reported in Table 9. The overall mean slaughter weight was 878.0 lb. Breed group means ranged from 782.0 lb. for the H to 1,18.8 lb. for the MA X H group. Variations in slaughter weights due to breed difference were similar to variation in final off-test weights. Sex had a greater effect on slaughter weight than on final weight. Steers were 42.8 lb. heavier than heifers when taken off test but were 48.0 lb. heavier just prior to slaughter, indicating a higher shrink for heifers than steers. However, this difference was not significant. The orthogonal comparisons shown in Table 10 indicated that no significant differences existed between breed groups with respect to percent shrink.

During the dressing procedure, various carcass components were weighed to provide some estimate of total slaughter and dressing loss. Individual gastro-intestinal (G.I.) tract; heart, lungs, liver, esophagus and trachea (pluck); and hide weights were recorded. Offal percentages were expressed as the ratio of offal component weight to slaughter weight. The sum of percent hide, pluck and G.I. tract is reported as total percent offal in Table 9. The H and F_1 crosses had similar total offal percentages. The MA X H cross was similar to the other F_1 crosses with respect to this trait. There was a significant ($P < .01$) difference in average total offal percent between H X CH and C X CH calves. The C X CH lost 24.3 percent of their live slaughter weight as offal compared to 27.7 percent for the H X CH calves ($P < .01$).

Dressing percent was calculated as the ratio of chilled carcass weight to slaughter weight. The overall mean dressing percent was 59.9. The L X H group had the highest dressing percent (61.0) and the S X H

Table 9. Least Square Means of Slaughter Data

Breed[a]	Off Test Weight (lbs.)	Slaughter Weight (lbs.)	Percent Live Shrink	Offal Percentages				Dressing Percent
				Hide	Pluck	G.I. Tract	Total Offal	
Overall	919.9	869.7	5.5	8.2	2.7	15.6	26.6	59.9
H X H	827.5	782.3	6.5	8.7	2.8	15.4	26.9	59.7
MA X H	1065.3	1016.9	5.3	7.7	2.8	17.2	27.8	59.0
S X H	905.9	862.8	5.7	9.0	2.8	15.7	27.5	60.9
L X H	898.3	859.2	5.4	8.2	2.7	14.6	25.5	61.0
C X H	886.1	859.3	4.1	7.9	2.7	15.8	26.4	60.3
H X CH	905.7	860.1	6.2	8.6	2.7	16.4	27.7	60.8
C X CH	950.5	908.2	5.3	7.4	2.6	14.4	24.3	59.8
Steers	941.3	902.0	5.1	8.2	2.8	15.7	26.6	59.8
Heifers	898.5	854.0	5.9	8.2	2.7	15.6	26.5	60.0

[a]H = Hereford, MA = Maine-Anjou, S = Simmental, L = Limousin, C = Charolais.

Table 10. Analysis of Variance of Slaughter Data

Source[a]	Mean Squares							
	Off Test Weight	Slaughter Weight	Percent Live Shrink	Offal Percentages				Dressing Percent
				Hide	Pluck	G.I. Tract	Total	
Breed	29333.6***	27505.8***	2.47	2.06	67.50	6.12**	10.36	4.14*
Comparison 1	32231.4***	35355.4***	4.86	0.58	5.04	0.50	0.02	0.01
Comparison 2	126156.2***	109637.2***	0.31	1.76***	16.29***	15.37	7.41	4.70
Comparison 3	6346.9	7753.0	2.45	5.16***	53.25	11.93**	35.49***	2.59
Comparison 4	751.2	82.3	3.54	3.76***	93.44	0.82	9.91*	11.67**
Comparison 5	312.8	0.1	3.92	0.16	3.69	3.15	2.04	1.07
Comparison 6	1098.8	545.5	1.00	0.75*	221.19*	1.02	5.50	2.38
Sex of Calf	14305.8*	17940.6**	5.17	0.04	32.40	0.15	0.14	0.19
Residual	3771.4	3762.3	2.05	0.21	49.38	2.08	2.95	1.94
R^2	0.65***	0.64***	0.22	0.66***	0.22	0.36**	0.40**	0.29

[a]Orthogonal comparisons are described in Table 2, page 24.

*P < .10.

**P < .05.

***P < .01.

group had the lowest percent carcass yield (58.9). The only source of significant differences with respect to dressing percent was between the S X H and the average of the L X H + C X H groups. This difference was 1.70 percent. Sex of calf did not affect any of the factors related to wholesale carcass yield.

Chilled Carcass Weight and Value

Carcasses were allowed to age in the cooler for seven days post-mortem. Individual chilled carcasses were weighed to the nearest 0.1 lb. prior to being processed into retail form and means by breed group are presented in Table 11. The same significant differences found in comparisons of live weights were observed with similar magnitude when chilled carcass weights were compared. Carcass weight per day of age (CWD) was calculated as the ratio of carcass weight and age in days. These values are reported in Table 11. The overall mean CWD was 1.06 lb. Hereford calves averaged 1.08 lb. CWD and were found to be similar or slightly superior to the F_1 crosses with respect to this trait, although, the H group was slaughtered at a younger age than the other breeds. The S X H and L X H groups averaged 0.96 and 0.99 lb. of carcass per day of age, respectively. The MA X H group produced 1.15 lb. of chilled carcass per day of age and were significantly ($P < .05$) superior to the other F_1 crosses with respect to this trait.

The total dollar value of each carcass was calculated using chilled carcass weight and current carcass value per cwt. These data are reported in Table 12 as chilled carcass wholesale values. Carcass weight had the greatest influence on total carcass value. Carcass values of

Table 14. The U.S.D.A. quality grade is a composite of the degree of marbling, carcass conformation, carcass maturity, and muscle color and texture scores. Marbling scores contributed significantly to the final estimate of carcass quality.

In this study there were no significant breed differences with respect to U.S.D.A. quality grade. The overall mean quality grade was 11.50 or low choice. Breed group means ranged from 11.00 (high good) to 12.13 (low choice) for the H X CH and MA X H groups, respectively. There were no differences in average U.S.D.A. marbling scores or subjective carcass conformation scores between breed groups.

Muscle color scores were significantly ($P < .10$) higher for carcasses of calves out of H dams than for those of calves out of CH dams. Muscle firmness and muscle texture scores were similar for all breed groups. The S X H group had a significantly ($P < .01$) more desirable marbling texture than the L X H group. This undesirable coarse marbling resulted in some discrimination against the L X H group when evaluating overall carcass quality grade.

Sex of calf significantly affected ($P < .10$) U.S.D.A. carcass grade. Steer carcasses graded 0.64 units lower than heifer carcasses. Steers higher ($P < .05$) carcass conformation scores and lower ($P < .01$) muscle firmness scores than heifers.

Carcass Retail Yield

Estimates of the yield of partially boneless retail cuts were calculated using the U.S.D.A. yield grade equation (Murphy et al., 1960). Mean yield grade and estimated percent retail yield are reported in Table 14. Yield grades ranged from 1.90 to 3.07 for the C X CH and

Table 14. Analysis of Variance of Carcass Quality Traits

Source[a]	Mean Squares						
				Physical Attributes of l. dorsi Muscle			
	U.S.D.A. Quality Grade	U.S.D.A. Marbling Score	Carcass Conformation Score	Color Score	Firmness Score	Texture Score	Marbling Texture Score
Breed	8.13	5.80	2.01	3.35	3.44	5.02	8.00
Comparison 1	0.68	0.54	2.98	1.28	6.22	0.00	6.39
Comparison 2	22.61	1.43	1.00	1.95	2.97	3.97	0.06
Comparison 3	13.92	11.97	0.97	0.01	1.74	9.54	2.18
Comparison 4	2.05	12.43	0.48	0.52	5.72	3.86	1.05
Comparison 5	0.48	1.45	2.94	3.42	1.49	9.55	33.09***
Comparison 6	4.66	2.77	4.05	10.30*	2.33	6.90	0.07
Sex of Calf	32.72*	9.90	7.46**	0.04	32.72***	1.05	0.00
Residual	8.94	7.79	1.55	3.62	4.30	5.13	3.05
R^2	0.20	0.16	0.30*	0.16	0.28	0.17	0.35

[a]Orthogonal comparisons are shown in Table 2, page 24.

*P < .10.

**P < .05.

***P < .01.

H groups, respectively. The corresponding predicted retail cuts ranged from 52.56 to 49.76 percent of hot carcass weight. Actual percent partially boneless retail cuts determined from carcass cutout values ranged from 50.91 to 55.65 for the MA X H and C X CH groups, respectively.

Hereford carcasses had significantly ($P < .10$) lower estimates of predicted cutability than the F_1 crosses; however, differences in actual retail yields were not significant.

Retail yield from C X CH carcasses was higher ($P < .01$) than that of H X CH carcasses. Some of this variation can be attributed to the error in estimating fat thickness on the C X CH animals prior to slaughter. The MA X H group yielded a lower ($P < .05$) actual percent retail cuts than the other F_1 groups. Variation in carcass weights may have influenced the relationship between predicted percent retail cuts and actual percent retail cuts when H and F_1 crosses were compared.

A comparison of mean yield grades and predicted percent retail cuts from carcasses produced by H and CH dams favored the carcasses from CH dams ($P < .10$). Differences in actual retail yield of partially boneless cuts from these two breed groups were significant ($P < .05$). Sex had a significant ($P < .01$) effect on carcass yield. Steers had a more desirable yield grade and predicted yield and higher actual retail yield than heifers.

Least squares means of factors used in estimating retail yield are shown in Table 15 and the analysis of variance and coefficients of determination for each comparison are shown in Table 16. The U.S.D.A. yield grade and predicted percent retail yield are composite estimates based on carcass l. dorsi area; fat thickness; estimated percent kidney,

Table 15. Least Square Means of Carcass Yield Traits

Breed[a]	U.S.D.A. Yield Grade	U.S.D.A. Predicted Retail Cuts (Percent)	Actual Retail Cuts (Percent)	Rib Eye Area (sq. in.)	Carcass Fat Thickness (in.)	Actual[b] KHP Fat (Percent)	Hot Carcass Weight (lb.)
Overall	2.54	50.98	53.46	10.94	0.31	3.79	527.8
H X H	3.07	49.76	51.08	9.58	0.39	4.24	475.8
MA X H	2.77	50.39	50.91	11.45	0.33	4.05	605.2
S X H	2.28	51.58	54.40	10.69	0.25	3.21	507.3
L X H	2.44	51.21	53.32	11.09	0.29	3.38	526.6
C X H	2.57	50.91	54.04	10.83	0.30	4.00	519.3
H X CH	2.73	50.55	52.62	10.66	0.35	3.78	526.2
C X CH	1.90	52.46	55.65	12.30	0.25	3.42	533.3
Steers	2.16	52.74	54.89	11.61	0.27	3.29	538.6
Heifers	2.92	49.22	52.03	10.27	0.35	4.29	517.0

[a]H = Hereford, MA = Maine-Anjou, S = Simmental, L = Limousin, C = Charolais.

[b]Percent kidney, heart and pelvic fat.

Table 16. Analysis of Variance of Carcass Yield Traits

Source[a]	Mean Squares						
	U.S.D.A. Yield Grade	Predicted Percent Retail Cuts	Actual Percent Retail Cuts	Rib Eye Area	Carcass Fat	Actual KHP Fat[b]	Hot Carcass Weight
Breed	7.41**	3.98**	7.79***	3.17***	1.40**	7.00	8495.4***
Comparison 1	8.17*	4.15*	2.80	5.37**	2.61**	5.66	10669.88**
Comparison 2	5.32	3.18	10.05**	1.53	1.10	5.95	34779.31***
Comparison 3	21.92***	11.68***	21.85***	8.53***	3.44**	4.23	161.77
Comparison 4	2.01	1.11	0.52	0.29	0.78	19.81*	983.09
Comparison 5	0.35	0.18	0.26	0.15	0.04	0.66	112.41
Comparison 6	8.50*	4.52*	12.92**	4.75**	0.16	5.89	63.31
Sex of Calf	46.16***	24.37***	15.94***	14.10***	6.03***	78.91***	3616.88
Residual	2.25	1.21	1.74	1.05	0.49	5.88	2365.78
R^2	9.57***	0.57***	0.51***	0.55***	0.48***	0.40**	0.46***

[a]Orthogonal comparisons are described in Table 2, page 24.

[b]Percent kidney, heart and pelvic fat.

*P < .10.

**P < .05.

***P < .01.

heart and pelvic fat and hot carcass weight. Differences in these traits are reflected in the stimates of retail yield. Steer carcasses were significantly ($P < .01$) more desirable than heifer carcasses in all carcass yield traits except hot carcass weight which was not affected by differences in sex.

V. ORGANOLEPTIC, CHEMICAL AND OBJECTIVE EVALUATION OF PALATABILITY

Taste Panel Evaluations

Each 6-7-8th rib roast was scored for desirability with respect to juiciness, flavor and tenderness by a trained 10-member taste panel. Results from these organoleptic evaluations are shown in Tables 17 and 18. Roasts from Hereford carcasses had the lowest mean juiciness score and muscle lipid content. Panel scores for juiciness have been related to muscle lipid content (Cover, Butler and Cartwright, 1956) however; in the current study, variation in these traits was low and their relationship was not significant.

Cooked meat flavor has a great influence on overall desirability (Cole and Badenhop, 1958). Panel members scored all roasts with respect to flavor. Mean flavor scores ranged from 6.80 for the L X H to 7.07 for roasts from H X H carcasses. The analysis of variance indicated that breed was not a significant source of variation with respect to panel scores for flavor. Heifers averaged 7.12 and steers averaged 6.74 with respect to flavor. This difference was significant ($P < .05$).

Panel scores for tenderness ranged from 5.74 (slightly tender) for the L X H to 6.94 (very tender) for the H X H roasts. The overall effect due to breed or sex of calf had no effect on panel scores for

Table 17. Least Square Means of Organoleptic Traits and an Objective Measure of Tenderness

	6-7-8th Rib Roast				12th Rib Steak		
Breed[a]	Panel[b] Juiciness Score	Panel[b] Flavor Score	Panel[c] Tenderness Score	Warner-[d] Bratzler Shear (lb.)	Warner-[d] Bratzler Shear (lb.)	Percent[e] Lipid	Percent Moisture
Overall	6.58	6.93	6.63	22.39	20.50	3.54	74.06
H X H	6.28	7.07	6.88	16.90	17.02	3.20	74.95
MA X H	6.62	6.90	6.32	24.45	21.29	4.17	73.06
S X H	6.62	6.94	6.75	24.44	19.59	3.81	73.80
L X H	6.76	6.80	5.74	24.25	18.70	3.31	74.06
C X H	6.64	6.93	6.93	23.70	26.26	3.50	74.48
H X CH	6.53	6.84	6.94	20.80	19.23	3.38	73.99
C X CH	6.55	7.03	6.85	22.58	21.40	3.44	74.09
Steers	6.53	6.74	6.37	22.75	22.09	3.12	74.57
Heifers	6.63	7.12	6.89	22.03	18.91	3.97	73.54

[a] H = Hereford, MA = Maine-Anjou, S = Simmental, L = Limousin, C = Charolais.

[b] A nine-point hedonic scale, 9 being most desirable.

[c] A ten-point hedonic scale, 10 being most desirable.

[d] Pounds shear force.

[e] Expressed as a percent of raw sample weight.

Table 18. Analysis of Variance of Organoleptic Traits and an Objective Measure of Tenderness

Source[a]	Mean Squares						
	6-7-8th Rib Roast				12th Rib Steak		
	Panel Juiciness Score	Panel Flavor Score	Panel Tenderness Score	Warner-Bratzler Shear	Warner-Bratzler Shear	Percent Lipid ($\times 10^{1}$)	Percent Moisture
Breed	0.088	0.046	1.051	31.315	33.863	6.666	1.640*
Comparison 1	0.385	0.082	0.505	138.439**	51.137	6.104	3.802*
Comparison 2	0.011	0.001	0.091	0.457	0.230	18.201	5.952**
Comparison 3	0.019	0.113	0.046	6.314	15.022	0.150	0.041
Comparison 4	0.027	0.023	0.697	0.824	33.764	6.057	1.097
Comparison 5	0.034	0.034	3.051*	0.643	120.774**	0.749	0.431
Comparison 6	0.003	0.001	1.058	12.931	0.544	2.775	0.007
Sex of Calf	0.067	1.106**	2.138	4.032	78.549*	56.074**	9.846***
Residual	0.326	0.192	0.909	29.574	22.600	1.151	0.833
R^2	0.05	0.21	0.30*	0.17	0.25	0.22	0.39**

[a]Orthogonal comparisons are described in Table 2, page 24.

*P < .10.

**P < .05.

***P < .01.

tenderness. A rank (within cooking group) correlation coefficient of 0.83 ($P < .001$) between rank of panel scores for tenderness and rank of Warner-Bratzler suggested that panel members were able to identify slight differences in variation of tenderness as evaluated by an objective device.

Objective Estimation of Tenderness

The Warner-Bratzler shear device was used to objectively evaluate tenderness of roasts and steaks. Mean shear values of three one-inch cores from all roasts and steaks are reported in Table 17, page 56. Breed mean roast shear values ranged from 16.90 lb. to 24.45 lb. for H X H and MA X H roasts, respectively. Breed influence on Warner-Bratzler shear values was nonsignificant; however, the orthogonal contrast of shear value from H X H roasts with roasts from the F_1 carcasses was significant ($P < .05$).

Results from the analysis of variance of steak Warner-Bratzler shear values were similar to the analysis for the same measure of tenderness in roasts. The overall effect of breed on steak Warner-Bratzler shear values was nonsignificant. The L X H breed group had the least desirable average panel tenderness scores, and the highest average steak shear values. There was a significant ($P < .05$) difference between mean Warner-Bratzler shear scores from the L X H and S X H breed group roasts. No other breed comparison with respect to tenderness as evaluated objectively were significant. Heifers had significantly ($P < .10$) more desirable steak shear values than steers.

Chemical Composition of a Sample from the 1. dorsi Muscle

Mean percent lipid for breed groups is presented in Table 17, page 55. Simple correlations between muscle lipid content and taste panel scores for tenderness, flavor and juiciness and Warner-Bratzler shear values were not significant. However, percent lipid was significantly ($P < .01$) related to both U.S.D.A. marbling score and carcass quality grade ($r = .57$ and $r = .63$, respectively).

Breed variation in percent muscle lipid content was not significant but heifers had higher ($P < .05$) average muscle lipid content than steers (3.97 vs. 3.19 percent). This difference was significant ($P < .05$).

Breed variation in muscle moisture content was significant ($P < .10$) and was inversely related ($P < .01$) to muscle lipid content ($r = -0.88$). Heifers had lower ($P < .01$) muscle moisture content than steers reflecting the effect of intramuscular fat content on other chemical traits.

CHAPTER V

SUMMARY

Performance of 65 steers and heifers from Hereford (H) dams and sired by either a H, Maine-Anjou (MA), Simmental (S), Limousin (L) or a Charolais (C) bull or from Charolais X Hereford (CH) dams and sired by either a H or C bull was evaluated at various intervals from birth to weaning. Calves were born in February and March and nursed the cows without creep feed during the summer grazing season.

Forty-five of these animals were selected at weaning and were fed a daily ration of 6 lb. shelled corn, 3 lb. legume hay and late dent corn silage ad libitum per head (roughage feeding phase). Following the roughage phase, animals were fed a daily concentrate ration consisting of 2 lb. of shelled corn per 100 lb. of weight and 6 lb. of legume hay until the predetermined fat thickness level (0.40 in.) over the longissimus dorsi muscle was attained. Animals then were slaughtered and carcasses evaluated with respect to U.S.D.A. quality and retail yield traits. A representative retail cut from each carcass was subjected to organoleptic and chemical evaluations.

Least squares procedures as described by Harvey (1960) were used to evaluate differences among breed groups with respect to growth rate, carcass traits and meat palatability. Orthogonal contrasts were used for mean separation when significant differences were observed. Three breed comparisons were of primary interest. These contrasts compared H calves to all F_1 calves, MA X H calves to other F_1 calves, and H X CH to C X CH calves.

Hereford calves were fatter ($P < .01$) than F_1 calves at the end of the roughage phase. Mean subcutaneous fat thickness for H calves was 0.36 in. MA X H, S X H and L X H measured about 0.18 in. fat thickness. H X C, H X CH and C X CH were intermediate with respect to fatness and averaged about 0.25 in. after 140-days roughage feeding.

All animals with less than 0.40 in. subcutaneous fat were fed a concentrate ration until an estimated fat thickness of 0.40 in. was attained. H calves attained this predetermined level of fatness at a lighter ($P < .05$) weight, a younger ($P < .05$) age and required fewer ($P < .01$) days on feed than F_1 calves. MA X H calves were heavier ($P < .01$) and had maintained a higher ($P < .01$) lifetime growth rate than the other F_1 calves. No differences were found between F_1 calves with respect to final age. Heifers fattened faster ($P < .01$) than steers and had lower ($P < .01$) total gains on feed.

Differences in carcass dollar value were directly related to carcass weight. No breed or sex differences were found with respect to carcass value per cwt. All breeds were similar with respect to U.S.D.A. carcass quality grade and other quality attributes. Carcasses from MA X H, S X H and C X CH groups graded an average of low choice. All other breeds graded high good.

Differences in estimates of carcass retail yield were associated with differences in carcass fatness and were significant ($P < .01$) between H X CH and C X CH carcasses and between steer and heifer carcasses; however, steers also had larger ($P < .01$) <u>l. dorsi</u> muscle areas and less ($P < .01$) actual kidney, heart and pelvic fat than heifers.

No significant trends were found with respect to palatability or Warner-Bratzler shear of cooked meat from these animals. F_1 crosses were similar to H with respect to organoleptic scores; however, roasts from H carcasses had lower ($P < .05$) Warner Bratzler shear values than roasts from F_1 calves. Sex of calf significantly ($P < .05$) affected percent lipid in a sample of the l. dorsi muscle. Other sources of variation in muscle lipid content were not significant. A significant ($P < .001$) rank correlation of ($r = 0.83$) existed between rank of panel tenderness scores and rank of Warner-Bratzler shear values.

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VITA

Sam K. Winfree, son of Alton J. and Clara Mae (Loftis) Winfree, was born September 12, 1944, at Detroit, Michigan. He was reared at Algood, Tennessee, there attending elementary and secondary schools. He received the FFA State Farmer Degree in 1962. He entered Tennessee Technological University in June, 1962 and graduated with the B.S. degree in Animal Husbandry and a commission in the Army Medical Service Corps. He served as National Vice-President of the honor society, Delta Tau Alpha, and was also selected for membership in Who's Who Among Students in American Colleges and Universities. He also received the college merit trophy award for his work with the Block and Bridle Club.

He began graduate studies at the University of Tennessee in September, 1966 and was granted the M.S. degree in Animal Husbandry in March, 1968. He served in the U. S. Army from 1968 to 1970, part of which time was spent as a Field Medical Officer with the 4th Infantry Division, Pleiku, Vietnam.

He married the former Cynthia L. Loftis on May 1, 1969 and saw their first child Alan J. Winfree born July 17, 1972.

He resumed graduate studies in Animal Science at the University of Tennessee in April, 1970 and received the Ph.D. degree in March, 1973.