Beef Research Program

Progress Report No. 3

Roman L. Hruska
U.S. Meat Animal Research Center

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U.S. MEAT ANIMAL RESEARCH CENTER[1]

1. Overview of Center: The U.S. Meat Animal Research Center (MARC) was authorized by Congress on June 16, 1964, thereby creating a single facility that provides an unusual opportunity for making major contributions to the solution of problems facing the U.S. livestock industry. Development of the 35,000-acre facility started in the spring of 1966 and is continuing at the present time. Phase I construction, consisting of an office-laboratory building for intensive investigations, was completed in January 1971. These facilities provide a physical plant for 42 scientists and about 200 support personnel. Phase II construction, consisting of the Meats Research Laboratory and the Biological Engineering Building, was completed in October 1977 and provides a physical plant for 25 scientists and about 60 support personnel. Phase III construction will provide for an Animal Health Systems Research Laboratory and a Veterinary Service-Training Facility. Both buildings are scheduled for completion in August 1989 and will accommodate 15 professional and 25 subprofessional employees.

Approximately 50 percent of the research program is devoted to beef cattle, 30 percent to swine, and 20 percent to sheep. Current research program objectives require breeding-age female populations of approximately 7,250 cattle (18 breeds), 4,250 sheep (10 breeds), and 600 swine litters (4 lines) to carry out the various experiments.

The research program at the Center is organized on a multidisciplinary basis and is directed toward providing new technology for the U.S. livestock industry by extending investigations into new areas not now being adequately studied. The research program complements research conducted elsewhere by the U.S. Department of Agriculture and is cooperative with the University of Nebraska Agricultural Research Division and other land grant university agricultural experiment stations throughout the country.

On October 10, 1978, the President signed into law a bill renaming the U.S. Meat Animal Research Center the Roman L. Hruska U.S. Meat Animal Research Center. The purpose of the bill was to honor former Nebraska Senator Roman L. Hruska for "his efforts in the establishment of a centralized facility for the research, development, and study of meat animal production in the United States."

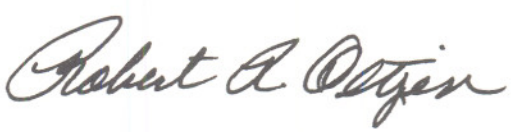
[1]Agricultural Research Service-U.S. Department of Agriculture, the University of Nebraska, and other cooperating land grant universities.

2. Overview of Beef Cattle Research Program: MARC's beef cattle research program places the highest priority on developing technology capable of having an immediate and major impact on the beef cattle industry. Although the program is largely oriented towards fundamental research, emphasis is placed on the generation of technology that can be practically implemented by small farmers and commercial beef cattle producers alike within a relatively short time frame. Because of the uniqueness of the Center's resources, research is being conducted on a "conception to consumption" basis with beef cattle.

Currently, we have 20 scientist "equivalents" conducting research in the beef cattle program at MARC. They are working in 11 primary research thrust areas. In addition, they are coworkers on five major projects away from MARC. Also, MARC has an active postdoctoral and visiting scientist program which supports the beef cattle research program.

This report represents a cross section of our beef cattle research program at the present time. Since some of the projects from which results are reported are still in progress, the preliminary nature of some of the results must be recognized. However, it is our opinion that information useful to the industry should be provided at the earliest possible time. Progress reports of this nature will be released periodically to make current results available to the beef industry.

3. Appreciation: I want to express my appreciation to Margie McAlhany, MARC Information Officer, for serving as editor. I also want to thank Linda Kelly, Secretary to the Director, for proofreading the report. These individuals have contributed many hours to the completion of this report.



Robert R. Oltjen, Director
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U.S. Meat Animal Research Center

Beef Facilities and Management at MARC

Margaret S. McAlhany, W. Gordon Hays, and Gary S. Ross[1]

The Cattle Operations Unit functions as a support service to the research scientists and maintains the animal populations necessary for our livestock research. Indirectly, this also involves responsible land management and herd health procedures. All the facilities and procedures employed in maintaining the extensive cattle herd are determined by research needs. Consequently, while providing a function sometimes indirectly related to research, the operations unit is necessary to provide adequate feedstuffs and healthy animals for research studies.

Facilities

Cow-Calf Polesheds. There are nine polesheds at MARC used for maintenance of the 7,250-cow breeding herd. Each barn functions as a working area, with general-purpose facilities designed for calving, artificial insemination, pregnancy checking, data collection, and routine processing of the cattle herd. These facilities generally include a scale, manual chute, calf-pulling stall, and individual pens (ranging from 10 to 25, depending upon use in cow or heifer calving areas). Individual pens are used primarily in the spring during the main calving season and are used either after assistance to the cow or heifer during calving or to provide assistance to the calf in cases of severe chilling, poor mothering, or sickness. Corrals are used to hold or sort cattle. Each area is equipped with a "hot house," which is a heated office and supply area.

Bull Barn. This area is used for routine processing, semen collection, and special research studies. Pens are available for holding and sorting bulls. A heavily constructed squeeze alley and chute are used for processing and semen collection. A special area is designed for libido evaluation. The hot house includes an office and lab for semen evaluation.

Feedlot. Five thousand five hundred calves and assorted other cattle are fed in the feedlot, primarily in the winter. This number includes animals which will be used in the breeding herd, animals fed for slaughter, cows for reproduction studies, and breeding bulls. Performance and puberty studies are routinely conducted on many of the young calves as part of genetics studies. Approximately 80% of the calves are born in the spring (3,900) and come to the feedlot in the fall at an average age of 6 months. Twenty percent (800) of the calves from the fall calving herd enter the feedlot at approximately 5 months of age.

Multi-Purpose Building. The main processing facility is a pre-engineered metal building, fully lighted and heated, with concrete flooring. The working facility includes a circular squeeze, working alley, scale, and chute. Fifteen pens are used for sorting and holding. There is also an office and lab area. A reproductive physiology lab is a separate, thermally controlled area specifically designed for embryo transfer and other cattle physiology research.

Scalehouse. This is a metal building which functions as the main doctoring area and as office headquarters for the feed-truck drivers. A working alley, scale, and chute are included in this area, as well as sorting pens and sick pens.

Poleshed. This barn functions as a sale and physiology facility. It includes a working alley and chute. There is a heated office and sale ring. Holding pens are used predominantly for embryo transfer donor cows.

Cattle Confinement Area. There are 11 pre-engineered metal buildings with a total animal capacity of 1,500 head. They are used mainly for intensive nutrition, reproduction, or environmental research.

The cattle surgery facility includes a prep room, surgery room, recovery stalls, lab, and office. Four barns are equipped with individual headgates for intensive feeding studies. Two of these accommodate cows with calves and have been used predominantly for cow efficiency studies. The other two are used for postweaning experiments requiring individual feed consumption data.

A specially designed barn includes 12 metabolism crates, used to study animal utilization of nutrients. In addition, 36 stalls equipped with headgates are primarily used for studies requiring frequent collection of blood samples for hormonal determinations. Three hood calorimeters are used for fasting heat production studies. A nursery has been developed for artificial rearing of calves for specific research studies. The barn also contains a lab.

Two self-cleaning buildings are equipped with flushing gutters and are used for total confinement research. Working facilities include an office, lab, crowding area, working alley, scale, chute, and sorting pens.

Laboratory Complex. Of the four buildings in the main office and laboratory complex, one is used frequently for beef cattle studies. The meats complex contains an abattoir and a sensory evaluation (taste panel) area which are used extensively for carcass evaluation studies.

Necropsy Building. This building is equipped with a dissection room, holding cooler, lab, and office area. It is used by MARC veterinary staff for lab analyses and autopsy. Autopsies are conducted routinely to monitor herd health.

Land Management

The land is managed so that 27,000 acres of warm and cool-season grasses are used as pastures. Twenty-five thousand acres are used for the cattle herd. Cows are maintained on pastures year-round and supplemented with hay in the winter. Heifers are supplemented with a haylage-corn silage diet through their first calving. Bulls are on pastures during the summer and are primarily maintained in the feedlot during the winter.

Six thousand acres of land are irrigated for crops and hay production. The two main feedstuffs produced at MARC are alfalfa and corn. The first cutting of alfalfa is chopped for haylage and subsequent cuttings harvested for hay. Corn acreage produces an annual 35-40,000 tons of silage and 200,000 bushels of corn. (All feedstuffs are used for both the sheep flock and the beef herd. Corn is also a major component of the swine diet.) Additional acreage includes irrigated pasture and small grains used for forage and feed.

[1]McAlhany is the information officer; Hays is the cattle operations manager; and Ross is the herd health veterinarian, MARC.

General Management Practices

The cow herd is managed so that 80% of the cows and heifers (4,200 head) will calve during the spring calving season (March through May). Another 1,000 head will calve during the fall season (August through early October). Calf survival each year averages from 92 to 93%.

First-calf heifers are managed to start calving two weeks ahead of cows, so their breeding season begins the end of May. Most of the heifers are bred to yearling bulls during a 45-day mating season. The breeding season for cows starts with 30 days of artificial insemination and ends with a 30-day natural mating period. Average conception rate, combining heifers and cows, is 88%.

A very young cow herd is maintained to meet research objectives. Approximately 40% of the breeding herd is composed of yearlings and 2-yr-old cows. Many prime-aged (3- to 6-yr-old) cows are sold each year in a bred cow sale. Excess breeding bulls are also sold in this manner.

Herd Health Procedures

The following are the vaccination and routine processing procedures for heifers, cows, calves, and bulls.

Heifers. Prior to their first breeding season, yearling heifers are injected with killed BVD-IBR-PI3 (bovine respiratory disease-infectious bovine rhinotracheitis-parainfluenza), 5-way leptospirosis, vibriosis in oil, 7-way blackleg, and Haemophilus vaccines. Approximately 70 days after the end of breeding season, heifers are palpated for pregnancy, injected with ivermectin for parasite control, and vaccinated against *E. Coli* bacteria. Prior to calving, brands are clipped, and heifers are given *E. Coli*, 7-way blackleg, and vitamins A and D.

Cows. After calving and before breeding, cows are given the same injections as heifers. At 70 days postbreeding, they are pregnancy checked and treated for external and internal parasites. Prior to calving, they receive the same treatment as heifers. They become excess for research needs after pregnancy detection if they fail to conceive or are no longer needed for their projects.

Calves from Birth to Maturity. At birth, all calves are identified, weighed, dehorned (paste), and vaccinated against viral scours, and the navel is treated with iodine. Depending upon research projects, some calves may be castrated. Prior to the cow breeding season, the calves are vaccinated with 4-way blackleg, and 5-way leptospirosis, and Haemophilus. At weaning, they are vaccinated a second time with killed BVD-IBR-PI3 and Haemophilus. One month postweaning, brucellosis vaccine is given to heifers. At one year of age, some of the bulls are sold as breeding stock, and the rest of the heifers, bulls, and steers are either used for research studies or are fattened for slaughter.

Bulls. At the end of the growing period (1 yr), bulls are vaccinated with killed BVD-IBR-PI3, 4-way blackleg, and 5-way leptospirosis. Subsequently, they are treated for parasites and vaccinated with 5-way leptospirosis prior to each breeding season.

Germ Plasm Evaluation in Cattle

Larry V. Cundiff, Robert M. Koch, and Keith E. Gregory[1,2]

Introduction

Breed differences in performance characteristics are an important genetic resource for improving efficiency of beef production. Diverse breeds are required to exploit heterosis and complementarity through crossbreeding and to match genetic potential with diverse market requirements and climatic zone-feed resource situations. Genetic variation among breeds can be used to provide an array of beef products that differ widely in fat and caloric content. Diverse feed resources will continue to be used for cow herds among and within different geographical regions of the U.S. Thus, it is important to characterize breeds of cattle representing different biological types for a wide spectrum of bioeconomic traits contributing to beef production. This report presents preliminary results from the first two of five calf crops to be produced in the fourth cycle of the Germ Plasm Evaluation Program (GPE) at MARC.

Procedure

GPE program has been conducted in four cycles. Table 1 shows the mating plan for Cycles I, II, III, and IV. Each cycle has been initiated by mating Hereford and Angus cows by artificial insemination (AI) to sires of diverse breeds. Semen from the same Hereford and Angus bulls has been used throughout to produce a control population of Hereford-Angus reciprocal crosses in each cycle of the program. In addition to the repeated use of semen from control Hereford and Angus bulls, new samples of Hereford, Angus, and Charolais bulls born since 1982 are being added in Cycle IV to evaluate genetic trends within these breeds. New breeds being evaluated in Cycle IV include the Longhorn, Salers, Piemontese, Galloway, Nellore, and Shorthorn. An effort is being made to sample at least 20, and preferably 30, sires to produce about 200 calves per sire breed in five calf crops (1986-1990). Semen from 14 original control Angus, 11 original control Hereford, 16 current Angus, 23 current Hereford (10 horned and 13 polled), 21 Longhorn, 10 Piemontese, 20 Charolais, 24 Salers, 19 Galloway, 18 Nellore, and 21 Shorthorn bulls was used by AI in the 1985 and 1986 breeding seasons to produce the two calf crops included in this report. Following an AI period of about 45 days, two Angus, two Hereford, two Charolais, two Gelbvieh, and two Pinzgauer bulls were used by natural service in single-sire breeding pastures for about 21 days. These breeds are being used in clean-up matings to increase ties to previous cycles and facilitate eventual pooling of results over all four cycles of the program.

Calving occurs in the spring, beginning late March and ending in mid-May. Calves are weighed, tattooed, and tagged for identification. Male calves are castrated within 24 hr of birth. Calves are creep fed whole oats from mid-July until weaning in early October.

Calving difficulty scores are assigned to each calf at birth. The percentage of calves requiring assistance at birth (taken with a calf puller, surgically removed, and abnormal presentation) are presented in this report. Calf survival is the percentage of all calves born that survived until weaning. Birth wt and 200-day weaning wt are also presented in this report.

The data were analyzed by least-squares procedures. The analytical model for calving difficulty, calf survival, and birth wt included effects of breed group (26 sire breed by dam breed groups), sex (steers *vs* heifers), cow age

[1]Cundiff is the research leader, Genetics and Breeding Unit, MARC; Koch is a professor of animal science, University of Nebraska-Lincoln, stationed at MARC; and Gregory is a research geneticist, Genetics and Breeding Unit, MARC.

[2]The authors would like to acknowledge W. Gordon Hays, Richard B. Jones, Darrell E. Light, and others who have assisted with conducting this research.

Table 1—Sire breeds used in the germ plasm evaluation program[a]

Cycle I (1970-72)	Cycle II (1973-74)	Cycle III (1975-76)	Cycle IV (1986-90)
F_1 crosses from Hereford or Angus dams (Phase 2)			
Hereford	Hereford	Hereford	Hereford
Angus	Angus	Angus	Angus
Jersey	Red Poll	Brahman	Longhorn
S. Devon	Brown Swiss	Sahiwal	Salers
Limousin	Gelbvieh	Pinzgauer	Galloway
Simmental	Maine-Anjou	Tarentaise	Nellore
Charolais	Chianina		Shorthorn
			Piemontese
			Charolais
			Gelbvieh
			Pinzgauer
3-way crosses out of F_1 dams (Phase 3)			
Hereford	Hereford		
Angus	Angus		
Brahman	Brangus		
Devon	Santa Gertrudis		
Holstein			

[a]Hereford and Angus sires, originally sampled in 1969, 1970, and 1971, have been used throughout the program. In Cycle IV, a new sample of Hereford and Angus sires produced after 1982 are being used and compared to the original Hereford and Angus sires.

(3- to 10-yr-old), birth yr (1986, 1987), and breed group x sex interaction. The analytical model for 200-day wt was the same, except that birth date was included as a covariate.

Results

Breed group means averaged over Hereford and Angus dams are shown in Table 2 for calving difficulty, birth wt, calf survival, and 200-day wt. Again, it is emphasized that these results are preliminary, involving only the first two of five calf crops to be produced in Cycle IV. Means for traits such as percentage calving difficulty and percentage calf survival should be regarded as especially preliminary because they have large experimental errors (e.g., one calf affects each breed group mean about 1%).

F_1 progeny by current Hereford and Angus sires were heavier at birth (4.9 lb) and weaning (20 lb) than F_1 progeny by original Hereford and Angus sires, indicating that significant genetic change for growth rate has accrued in these breeds between the late 1960's and the early 1980's. This was expected in view of the selection emphasis that seedstock breeders for both of these breeds have placed on growth rate during this period. It is surprising that, in the first two calf crops of Cycle IV, the increase in birth wt for progeny of current *vs* original sires has not been associated with an increase in calving difficulty. However, the Hereford and Angus cows producing these calves were 3 through 10 yr of age. Calving difficulty is not expected to be a serious problem in cows calving at these ages.

Relative to Hereford-Angus crosses, the results for Charolais, Gelbvieh, and Pinzgauer are consistent with those observed in previous cycles of the program for calving difficulty, birth wt, and 200-day wt. Early indications are that progeny sired by Galloway and Longhorn bulls are lighter at weaning than progeny sired by original or current Hereford and Angus bulls while progeny sired by Nellore and Salers bulls are heavier at weaning than progeny sired by original or current Hereford and Angus bulls. Weaning wt of progeny sired by current Hereford and Angus, Shorthorn, and Piemontese bulls were similar.

Table 2—Breed group means for preweaning traits (1986 and 1987 calf crops)

Breed group	No. calves		Calv.	Birth	Calf	200-day wt	
	born	weaned	diff., %[a]	wt., lb	surv., %[b]	lb	ratio[c]
Original HA-x	94	88	3.8	78.7	93.0	438	100.0
Current HA-x	111	101	3.0	83.6	90.4	458	104.6
Charolais	97	86	11.9	87.8	86.7	479	109.4
Gelbvieh	131	123	1.5	86.6	93.5	474	108.2
Pinzgauer	121	115	5.7	88.2	94.9	476	108.7
Shorthorn	83	77	0.0	85.4	92.8	463	105.7
Galloway	84	82	1.3	80.1	97.0	431	98.4
Longhorn	101	91	.9	72.3	90.4	421	96.1
Nellore	92	87	7.2	88.5	94.0	483	110.3
Piemontese	104	100	4.4	84.1	95.6	455	103.9
Salers	90	82	1.0	83.6	91.6	467	106.6

[a]Percentage requiring assistance.
[b]Percentage of calves born that survived to weaning.
[c]Ratio expressed in percentage units relative to the mean for Hereford-Angus F_1 crosses.

Breeding for Lean Beef (Germ Plasm Evaluation Program)

Larry V. Cundiff, Michael E. Dikeman, Robert M. Koch, John D. Crouse, and Keith E. Gregory[1,2]

Introduction

Historically, when steers were finished on pasture, ability to finish at a young age was desirable, particularly when market requirements for fatness were great. However, ability to fatten became a handicap as we shifted to increased use of concentrate feeds in diets of growing-finishing cattle. Consequently, yield grades were added to the USDA grading system to reflect variation in carcass value associated with differences in yield of retail product. Recently, consumer pressure to reduce caloric and fat content of beef and other red meats has intensified because coronary heart disease is believed to be associated with elevated blood-cholesterol levels. Cholesterol levels are, in turn, associated with dietary intake of saturated fat. Dietary control of the type and amount of fat consumed is strongly recommended by members of the medical profession in an attempt to regulate blood-cholesterol levels. The purpose of this paper is to examine genetic variation among and within breeds in the amount and distribution of fat and lean in beef carcasses and to evaluate opportunities to genetically change fat and caloric content of retail product in cattle.

Procedure

Results reviewed are from the first three cycles of the Germ Plasm Evaluation (GPE) Program at MARC (see paper entitled "Germ Plasm Evaluation in Cattle") in which topcross performance of 19 different sire breeds have been evaluated in calves out of Hereford and Angus dams or calves out of F_1 cross dams. Data were pooled over Cycles I, II, and III by adding the avg differences between Hereford-Angus reciprocal crosses (HAx) and other breed groups (2-way and 3-way F_1 crosses) within each cycle to the avg of Hereford-Angus reciprocal crosses (HAx) over the three cycles. Data presented are for 19 F_1 crosses (2-way and 3-way), grouped into seven biological types based on relative differences (X = lowest, XXXXXX = highest) in growth rate and mature size, lean to fat ratio, age at puberty, and milk production (Table 1). Carcass and meat data, obtained in cooperation with Kansas State University under the direction of Dr. Michael E. Dikeman, are presented for 15 F_1 crosses out of Hereford and Angus dams.

[1]Cundiff is the research leader, Genetics and Breeding Unit, MARC; Dikeman is a professor of meat science, Kansas State University, Manhattan; Koch is a professor of animal science, University of Nebraska-Lincoln, stationed at MARC; Crouse is the research leader, Meats Unit; and Gregory is a research geneticist, Genetics and Breeding Unit, MARC.

[2]The authors would like to acknowledge W. Gordon Hays, cattle operations manager, MARC, and C.E. Murphey and others, Agricultural Marketing Service, USDA, who assisted with this research.

Table 1—Breed crosses grouped into seven biological types on the basis of four major criteria[a]

Breed group	Growth Rate & Mature Size	Lean to Fat Ratio	Age at Puberty	Milk Production
Jersey (J)	X	X	X	XXXXX
Hereford-Angus (HA)	XX	XX	XXX	XX
Red Poll (Rp)	XX	XX	XX	XXX
Devon (D)	XX	XX	XXX	XX
South Devon (Sd)	XXX	XXX	XX	XXX
Tarentaise (T)	XXX	XXX	XX	XXX
Pinzgauer (P)	XXX	XXX	XX	XXX
Brangus (Bn)	XXX	XX	XXXX	XX
Santa Gertrudis (Sg)	XXX	XX	XXXX	XX
Sahiwal (Sw)	XX	XXX	XXXXX	XXX
Brahman (Bm)	XXXX	XXX	XXXXX	XXX
Brown Swiss (B)	XXXX	XXXX	XX	XXXX
Gelbvieh (G)	XXXX	XXXX	XX	XXXX
Holstein (Ho)	XXXX	XXXX	XX	XXXXXX
Simmental (S)	XXXXX	XXXX	XXX	XXXX
Maine-Anjou (M)	XXXXX	XXXX	XXX	XXX
Limousin (L)	XXX	XXXXX	XXXX	X
Charolais (C)	XXXXX	XXXXX	XXXX	X
Chianina (Ci)	XXXXX	XXXXX	XXXX	X

[a]Increasing number of X's indicate relatively higher levels of performance and older age at puberty.

Results

Percentage of retail product. Significant genetic variation exists between and within breeds for retail product percentage when comparisons are made at the same age or weight. In Figure 1, F_1 cross means for percentage of retail product at 458 days of age are shown on the lower horizontal axis. The spacing on the vertical axis is arbitrary but the ranking from the bottom to top, generally, reflects increasing increments of mature size. Steers by bulls of breeds with large mature size produced a significantly higher percentage of retail product than steers sired by breeds of small and medium mature size.

In Figure 1, differences have been doubled in the upper horizontal scale to reflect variation among pure breeds relative to a standard deviation change in breeding value [$\sigma g = (\sigma 2p)(h^2) = (3.3)(.63)$] within pure breeds. Frequency curves, shown for Jersey, the avg of Hereford and Angus, and Chianina, reflect the distribution expected for breeding values of individual animals within pure breeds (i.e., 68, 95, or 99.6% of the observations are expected to lie within the range bracketed by the mean ± 1, 2, or 3 standard deviations, respectively). The breeding value of the leanest Jersey is not expected to equal that of the fattest Chianina, and the leanest Hereford and Angus would only equal the fattest Chianina in genetic potential for percentage of retail product at 458 days. The range for mean differences between breeds is estimated to be about 5.2 σg (standard deviations in breeding value) between Chianina and Hereford or Angus steers, and 5.8 σg between Chianina and Jersey steers. Genetic variation, both between and within breeds, is important for percentage of retail product. When both between and within breed genetic variation are considered, the range in breeding value from the smallest Jersey steers to the heaviest Chianina steers is estimated to be about 30%.

Marbling (USDA Quality Grade). In addition to cutability, as reflected by USDA yield grades, USDA quality grade is also considered in the USDA dual-grading system. Degree of marbling (i.e., deposits of fat interspersed in muscle) in the twelfth rib cross-section of the ribeye muscle is currently the primary determinant of USDA quality grade among carcasses of cattle of the same age. Traditionally, marbling has been emphasized because it was believed to be associated with palatability characteristics of meat. Some studies have shown a positive relationship between marbling and palatability characteristics, especially sensory panel ratings for tenderness or Warner-Bratzler shear force, while others have shown a very low or nonexistent relationship.

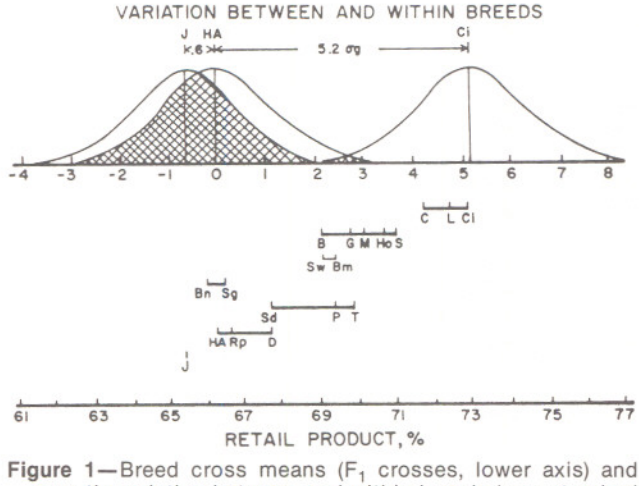

Figure 1—Breed cross means (F_1 crosses, lower axis) and genetic variation between and within breeds (σg, standard deviation in breeding value, upper axis) for retail product percentage at 458 days. See Table 1 for abbreviations.

Table 2—Sensory panel tenderness scores (means and standard deviations) within different degrees of marbling[a]

Marbling	Number	Mean	Standard deviation
Slightly Abundant	13	7.8	.56
Moderate	35	7.7	.60
Modest	95	7.3	.87
Small	180	7.3	.85
Slight	134	7.1	.78
Traces	27	7.0	.83

[a]Taste panel scores: 2 = undesirable, 5 = acceptable, 7 = moderately desirable, 9 = extremely desirable.

In data from Cycle I of the GPE Program, sensory panel tenderness tended to improve about 1 sensory panel score as marbling increased the full range from practically devoid to slightly abundant (Table 2). Marbling accounted for only 10% of the variation in tenderness. Thus, the standard deviation and range in tenderness among cattle with the same marbling score was still almost as large as that found among cattle not grouped by marbling level. Variation in tenderness scores (see standard deviations) was less at high levels of marbling (moderate and slightly abundant) than at intermediate (small and modest) or low degrees of marbling (traces and slight), indicating a greater risk of at least some steaks having less than acceptable tenderness at low degrees of marbling.

Significant genetic variation exists between and within breeds for propensity to deposit marbling (Fig. 2). Again, the range for differences between breeds is about equal to the range for breeding value of individual animals within breeds for marbling. Within breeds, variation in marbling was highly heritable (.40). However, it is much easier to use information on variation among breeds than within breeds for marbling because of the difficulty of measuring marbling levels in live bulls and heifers used for breeding. Also, heritability of breed differences is high (approximately 100%), provided the breed means are estimated with an adequate sample to average out errors of sampling individual animals within breeds. The tendency for progeny from individual animals to regress to their own breed group mean is much greater than any tendency to regress to the mean of all cattle.

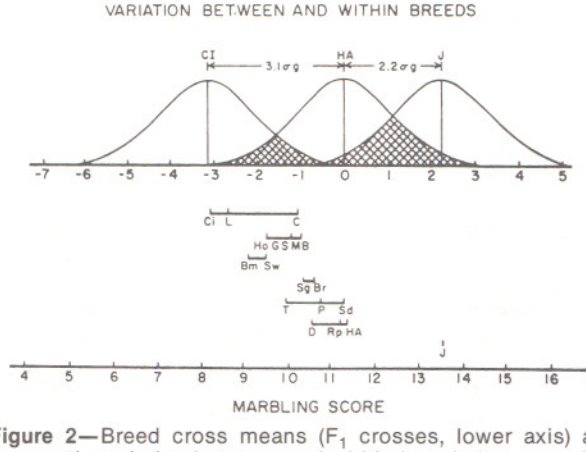

Figure 2—Breed cross means (F_1 crosses, lower axis) and genetic variation between and within breeds (σg, standard deviation in breeding value, upper axis) for marbling score. See Table 1 for abbreviations.

Genetic Antagonism (Retail Product and Marbling). Unfortunately, breeds that rank highest for retail product percentage rank lowest for marbling (Fig. 3). Similarly, high negative genetic correlations have been found within breeds between marbling and retail product percentage. Thus, only limited opportunity exists from between breed selection or from within breed selection for genetically increasing marbling without increasing fat trim and reducing retail product percentage.

Marbling and Palatability. Concern with the antagonism between marbling and retail product percentage is justified to the extent that a certain amount of marbling is required to ensure palatability of the retail product. Sensory panel evaluations of uniformly cooked 10th rib steaks from about 1,230 steers produced in the GPE program are summarized in Table 3. High levels of acceptance were found for steaks from all *Bos taurus* breed groups when the steers were fed and managed alike and slaughtered at 14 to 16 mo of age. Average taste panel scores and Warner-Bratzler shear determinations for tenderness did tend to improve as marbling increased when comparisons were at the same age, but the change was very small. Although breed groups differed significantly in avg marbling scores and in percentage of carcasses that had adequate marbling to grade USDA Choice or better, avg sensory panel evaluations of flavor and juiciness were acceptable for all breed groups.

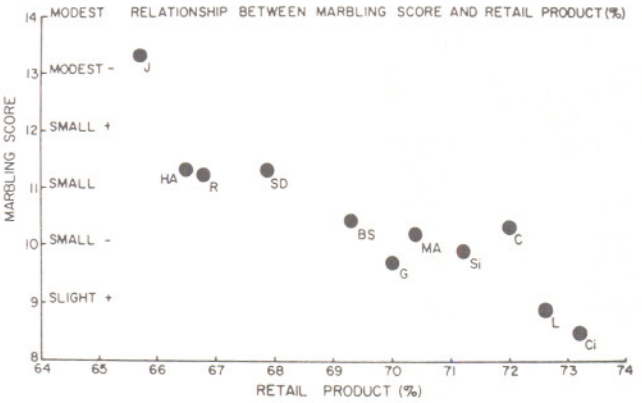

Figure 3—Breed cross means for retail product percentage *vs* marbling score at 458 days of age. See Table 1 for abbreviations.

Caloric Density of Retail Cuts. Breed group means for calories originating from the lean, intra-muscular fat, and inter-muscular fat components of 100 gram (3.5 oz) uncooked portions of retail product are presented in Table 4. External and inter-muscular fat (averaging 20.6% over all breeds) accounted for a much greater proportion of total fat in the retail product than intra-muscular (i.e., marbling) fat (averaging 4.0%). Variation among breeds was important for both percentage of external and intramuscular fat (range 2.6 percentage units) and for percentage of inter-muscular fat (range of 3.2%).

On the average, a 100 gram portion of uncooked retail product containing a total of 280 kcal, would have 83 kcal originating from protein (29.7%), 34 kcal from intramuscular fat (12.2%) and 163 kcal from external and intermuscular fat (58.3%). Fat content of retail product is markedly reduced by total trimming of visible fat. Caloric content of totally-trimmed portions (lean and intramuscular fat only) contained an avg of 117 kcal. For totally-trimmed retail product, the range among F_1 breed groups was 14 kcal (111 for Chianina crosses to 125 kcal for Jersey crosses). Since topcross comparisons estimate only half of the difference between breeds, estimates of the range between F_1 crosses can be doubled to estimate the range between pure breeds—28 kcal or from about 99 kcal for Chianina to 127 kcal for Jersey steers.

Dairy processors have developed and effectively marketed products with a similar range in caloric content to that found between Chianina and Jersey steers. Low fat milk (2% fat content) contains 20% fewer calories per one cup serving than regular milk (3.5% fat content). Similar ranges can be achieved in beef products by fabrication and marketing of totally-trimmed retail cuts. The key to production of low calorie beef products is total trimming.

Table 3—Breed cross means for factors identified with meat quality

Breed group	Marbling[a]	Percent USDA Choice	Warner-Bratzler shear[b] (lb)	Sensory panel scores[c]		
				Tenderness	Flavor	Juiciness
Chianina-X	8.3	24	7.9	6.9	7.3	7.2
Limousin-X	9.0	37	7.7	6.9	7.4	7.3
Brahman-X	9.3	40	8.4	6.5	7.2	6.9
Gelbvieh-X	9.6	43	7.8	6.9	7.4	7.2
Sahiwal-X	9.7	44	9.1	5.8	7.1	7.0
Simmental-X	9.9	60	7.8	6.8	7.3	7.3
Maine-Anjou-X	10.1	54	7.5	7.1	7.3	7.2
Tarentaise-X	10.2	60	8.1	6.7	7.3	7.0
Charolais-X	10.3	63	7.2	7.3	7.4	7.3
Brown Swiss-X	10.4	61	7.7	7.2	7.4	7.2
Pinzgauer-X	10.8	60	7.4	7.1	7.4	7.2
South Devon-X	11.3	76	6.8	7.4	7.3	7.4
Hereford-Angus-X	11.3	76	7.3	7.3	7.3	7.3
Red Poll-X	11.5	68	7.4	7.3	7.4	7.1
Jersey-X	13.2	85	6.8	7.4	7.5	7.5

[a]Marbling: 8 = slight, 11 = small, 14 = modest, 17 = moderate.
[b]Shear force required for a 1 in core of cooked steak.
[c]Taste panel scores: 2 = undesirable, 5 = acceptable, 7 = moderately desirable, 9 = extremely desirable.

Table 4—Breed cross means for caloric content of retail product (3.5 oz uncooked portion)

Breed group	Lean protein, kcal	intra-musc. fat, kcal	External & inter-musc. fat, kcal	Total kcal	Lean & intra-musc. fat only, kcal
Jersey-X	79	46	180	305	125
Hereford-Angus-X	81	42	172	294	123
Red Poll-X	80	40	177	297	120
South Devon-X	82	39	167	287	121
Tarentaise-X	84	33	159	276	117
Pinzgauer-X	83	39	160	281	122
Sahiwal-X	84	30	161	275	114
Brahman-X	84	30	164	276	113
Brown Swiss-X	83	32	164	280	116
Gelbvieh-X	84	33	160	277	117
Simmental-X	84	33	156	273	117
Maine-Anjou-X	83	32	164	280	115
Limousin-X	86	26	154	266	111
Charolais-X	84	33	156	274	117
Chianina-X	86	25	155	265	111
Range (R)	7	21	26	40	14

Table 5—Composition and caloric content of *longissimus* (ribeye) muscle with different degrees of marbling (1 oz uncooked portion)

Quality grade	Marbling	Chem. fat[a] %	Chem. fat[a] kcal	Protein[b] %	Protein[b] kcal	Total kcal
	Fat free	0	0	27.0	31.5	31.5
Standard	Practically devoid	.7	1.9	26.8	31.3	33.2
Standard	Traces	2.2	5.8	26.4	30.7	36.5
Select	Slight	3.7	9.8	26.0	30.2	40.0
Choice	Small	5.2	13.7	25.6	29.6	43.3
Choice	Modest	6.7	17.8	25.2	29.1	46.9
Choice	Moderate	8.2	21.7	24.8	28.5	50.2
Prime	Slightly abundant	9.7	25.7	24.4	27.9	53.6
Prime	Moderately abundant	11.2	29.7	24.0	27.4	57.1
Prime	Abundant	12.7	33.7	23.6	26.8	60.5

[a]Chemical fat, % = -.3 + .5(M) where M = 5 for traces, 8 for slight, ..., and 17 for moderate degrees of marbling and fat contains 9.3 kcal per gram.
[b]Lean is 27% protein and protein contains 4.1 kcal per gram.

Caloric content of totally-trimmed beef varies depending on the level of intramuscular fat (marbling) in the lean. Composition and estimates of caloric content in 1 oz portions of uncooked longissimus (ribeye) muscle with different USDA quality grades and degrees of marbling are shown in Table 5. Muscle with a slight degree of marbling (USDA Select quality grade) is about 3.7% fat and contains about 40 kcal per oz. Muscle from carcasses grading USDA Choice range from about 4.7 to 9.3% fat and contain about 43 to 51 kcal per oz. Muscle from carcasses in the USDA Prime grade range from about 9.2 to 12.7% fat and contain 52 to 60 kcal per oz. Total trimming will favor production of carcasses with a higher percentage of retail product and less fat trim. Cattle with the greatest genetic potential for retail product growth and reduced fat trim levels also excel in feed efficiency from weaning to slaughter at age or wt end points.

Conclusions

The variation that exists in biological traits of economic importance to beef production, including carcass leanness, is vast and under a high degree of genetic control. Genetic variation found between breeds is comparable in magnitude to that found within breeds for most growth and carcass traits. Thus, significant genetic change can result from selection both between and within breeds.

Between breed differences are more easily exploited than genetic variation within breeds because they are more highly heritable. Also, use of genetic variation within breeds is complicated by difficulties of estimating carcass characteristics in live animals used for breeding or by the increased generation interval and other costs associated with progeny testing.

The genetic variation both between and within breeds can be used to provide an array of beef products that differ widely in fat and caloric content. Cattle with the greatest retail product growth potential produce carcasses with lower levels of marbling and totally-trimmed retail cuts with lower fat and caloric content. These cattle are especially well suited for marketing opportunities for low fat or low caloric beef with acceptable palatability characterisitics. Cattle with greater marbling potential are more suited to marketing opportunities for the gourmet food trade, where the risk of occasional steaks with unacceptable tenderness must be minimized.

Germ Plasm Utilization in Beef Cattle

Keith E. Gregory, Larry V. Cundiff, and Robert M. Koch[1]

Introduction

Heterosis achieved through well-organized crossbreeding systems can be used to increase weight of calf weaned per cow exposed to breeding by about 20%. Comprehensive programs of breed characterization have revealed large differences among breeds for most biological traits of economic importance.

A high percentage of beef cattle in the U.S. and globally are in herds too small to use well organized crossbreeding systems on a self-contained basis. Further, there is wide fluctuation in breed composition between generations in rotational crossbreeding systems. Thus, there is need for experimental evaluation of the potential of composite populations as an alternative, or, as a supplement to continuous crossbreeding systems to use heterosis, and, as a procedure to use genetic differences among breeds to optimize such biological characters as growth rate and mature size, milk production level, lean-to-fat ratio, and climatic adaptability. The primary objective of achieving and maintaining optimum breed composition is to synchronize cattle genetic resources with the production environment most favored by economic and technological factors and with market requirements.

The situation. More than 55% of the national beef breeding herd, involving 92% of the farms and ranches that have beef breeding cows, is represented by herds that have 100 or fewer cows. Organized crossbreeding systems favor herd size of 100 or more cows. The problem of achieving and maintaining the most optimum contribution by each breed used in rotational crossbreeding systems is reflected by the fact that in a two-breed rotation system, in each generation, 66.7% of the genes are from the breed of the sire and 33.3% of the genes are from the breed of the maternal grandsire at equilibrium (7 generations); and in a three-breed rotation system, in each generation, 57% of the genes are from the breed of the sire, 29% of the genes are from the breed of the maternal grandsire, and 14% of the genes are from the breed of the maternal great grandsire at equilibrium (7 generations). If the optimum contribution to achieve maximum adaptability to the production situation should be 25% for a specific breed, the optimum is approached infrequently in rotational crossbreeding systems.

Retention of initial heterozygosity following crossing (F_1) and subsequent random mating within the crosses (*inter se'*) is a function of the number of breeds and the proportion each breed contributes to a composite population. Retention of initial (F_1) heterozygosity is proportional to $1 - \sum_{i}^{n} P_i^2$, where P_i is the fraction of each of *n* breeds in the pedigree of a composite population; e.g., three-breed composite formed from 3/8 breed A, 3/8 breed B, and 1/4 breed C $= 1 - [(3/8)^2 + (3/8)^2 + (1/4)^2] = .656$. Where the breeds contribute equally to the foundation of a composite population, retention of initial heterozygosity following crossing can be computed $\frac{n-1}{n}$, where *n* is the number of breeds contributing *equally* to the foundation of a composite population; e.g., four-breed composite formed from 1/4 breed A, 1/4 breed B, 1/4 breed C, and 1/4 breed D, $= \frac{n-1}{n} = 3/4 = .75$. The loss of heterozygosity occurs between the F_1 and F_2 generations in populations mated *inter se'*. Thus, for maternal traits, performance of F_2 generation dams is evaluated in their F_3 generation progeny.

Computations of heterozygosity retained in different mating types and estimates of the increase in weight of calf weaned per cow exposed to breeding as a result of heterosis are presented in Table 1. These estimates of heterosis are appropriate *if* retention of heterosis is proportional to retention of heterozygosity in composite populations. As indicated by Table 1, the percentage of F_1 generation heterozygosity retained in composite populations based on approximately equal contribution by either three or four breeds equals or exceeds the percentage of F_1 generation heterozygosity retained in a continuous two-breed rotational crossbreeding system after equilibrium is reached. A primary objective of this project is to determine experimentally if retention of heterosis in composite populations is proportional to retention of heterozygosity.

Research results from rotational crossbreeding systems have shown that retention of heterosis is approximately equal to retention of heterozygosity. Thus, production increases as a result of heterosis can be estimated with precision for different crossbreeding systems if the level of heterosis for the traits of interest is known.

Research objectives. Specific research objectives of the Germ Plasm Utilization Project are: (1) Determine the percentage of initial heterosis (F_1) that is retained in composite populations; i.e., to what extent is retention of heterosis proportional to retention of heterozygosity; (2) Determine the additive genetic variance, particularly for traits contributing to reproductive performance, in composite populations relative to parental purebred populations contributing to the composites; i.e., *is* selection for male and female reproductive traits more effective in composite populations than in the contributing purebreds; (3) Develop effective selection criteria and procedures to improve both male and female reproductive performance in beef cattle; (4) Determine the feasibility of developing new populations of beef cattle based on a multi-breed (composite) foundation as an alternative to rotational and other crossbreeding systems to utilize heterosis; and (5) Determine the feasibility of using genetic differences among breeds for making more rapid progress toward optimizing such biological characters as (a) climatic adaptability, (b) growth rate and mature size, (c) carcass composition, and (d) milk production.

The three combinations of breeds that contribute to the three composites (MARC I, MARC II, and MARC III) were identified with the intent of producing composite populations of different biological type (e.g., bioeconomic traits) using a series of breed combinations. Results obtained involving several breed combinations affects the inferences that can be made in application of the principles being investigated (i.e., research objectives) by the experiment.

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Table 1—Heterozygosity of different mating types and estimated increase in performance as a result of heterosis

Mating type	Heterozygosity percent relative to F_1	Est. increase in calf wt wnd per cow exposed[a] (%)
Pure breeds:	0	0
Two-breed rotation at equilibrium	66.7	15.5
Three-breed rotation at equilibrium	85.7	20.0
Four-breed rotation at equilibrium	93.3	21.7
Two-breed composite:		
F_3 - 1/2A, 1/2B	50.0	11.6
F_3 - 5/8A, 3/8B	46.9	10.9
F_3 - 3/4A, 1/4B	37.5	8.7
Three-breed composite:		
F_3 - 1/2A, 1/4B, 1/4C	62.5	14.6
F_3 - 3/8A, 3/8B, 1/4C	65.6	15.3
Four-breed composite:		
F_3 - 1/4A, 1/4B, 1/4C, 1/4D	75.0	17.5
F_3 - 3/8A, 3/8B, 1/8C, 1/8D	68.8	16.0
F_3 - 1/2A, 1/4B, 1/8C, 1/8D	65.6	15.3
Five-breed composite:		
F_3 - 1/4A, 1/4B, 1/4C, 1/8D, 1/8E	78.1	18.2
F_3 - 1/2A, 1/8B, 1/8C, 1/8D, 1/8E	68.8	16.0
Six-breed composite:		
F_3 - 1/4A, 1/4B, 1/8C, 1/8D, 1/8E, 1/8F	81.3	18.9
Seven-breed composite:		
F_3 - 3/16A, 3/16B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G	85.2	19.8
Eight-breed composite:		
F_3 - 1/8A, 1/8B, 1/8C, 1/8D, 1/8E, 1/8F, 1/8G, 1/8H	87.5	20.4

[a]Based on heterosis effects of 8.5% for individual traits and 14.8% for maternal traits and assumes that retention of heterosis is proportional to retention of heterozygosity. These estimates of heterosis were obtained in a crossbreeding experiment involving the Angus, Hereford, and Shorthorn breeds that was started at the Fort Robinson Beef Research Station and completed at MARC.

Table 2—Germ Plasm Utilization Project - approximate number of calving females[a]

Breed group	Year					
	1986	1987	1988	1989	1990	1991
MARC I—1/4C, 1/4B, 1/4L, 1/8H, 1/8A						
F_1	152	116	99	84	71	60
F_2	132	110	100	100	100	111
F_3	18	44	82	120	120	120
MARC II—1/4S, 1/4G, 1/4H, 1/4A						
F_1	115	92	78	66	56	48
F_2	120	110	100	80	79	87
F_3	48	104	120	120	120	120
MARC III—1/4R, 1/4H, 1/4P, 1/4A						
F_1	155	150	127	100	84	71
F_2	76	128	120	120	120	120
F_3		16	44	80	120	133
Composite total	816	870	870	870	870	870
Hereford (H)	110	90	90	90	90	90
Angus (A)	91	90	90	90	90	90
Limousin (L)	109	90	90	90	90	90
Brown Swiss (B)	91	90	90	90	90	90
Charolais (C)	103	90	90	90	90	90
Gelbvieh (G)	94	90	90	90	90	90
Simmental (S)	93	90	90	90	90	90
Red Poll (R)	91	90	90	90	90	90
Pinzgauer (P)	80	90	90	90	90	90
Purebred total	862	810	810	810	810	810
Grand total	1,678	1,680	1,680	1,680	1,680	1,680

[a]Females exposed to breeding will be 2,400; i.e., 1,680 calving females and 720 yearling heifers. After 1985 breeding season, open females have not been retained.

Procedure

The calving schedule shown in Table 2 involving Composites (MARC I, MARC II, and MARC III) F_1 generation, F_2 generation, F_3 generation, and purebred females will provide the basic data essential for: (1) estimating linearity of association of heterosis with heterozygosity in composite populations; (2) estimating genetic and phenotypic parameters in order to determine selection response, particularly for traits contributing to fitness, in both composite and purebred populations; and (3) developing selection criteria and procedures for both male and female reproductive phenomena. As indicated by Table 2, F_1 generation, F_2 generation, F_3 generation, and contributing purebreds produce calves in the same seasons.

These contrasts provide the basis for estimating heterosis and for determining heterosis retention from the F_1 generation to the F_2 generation and to the F_3 generation for reproductive and maternal traits by comparing F_1, F_2, and F_3 generations and their F_2, F_3, and F_4 generation progeny with each other and with appropriate parental purebreds.

Composite populations were formed from the same genetic base that is represented in the contributing purebreds, i.e., males and females used to establish each composite population were used as foundation in the contributing purebreds.

Matings through 1990 (Table 2) will be consistent with the procedures that have been followed in this project; i.e., yearling heifers are mated by natural service to yearling bulls for about 45 days and females 2 yr old and older have a breeding season of about 56 days; about one-half of the breeding season is by artificial insemination and one-half is by natural service in individual sire breeding pastures. All females born are retained for breeding and excess females in each population are removed based on nonperformance criteria; i.e., age, color, atypical anatomy, etc. Open females have not been retained subsequent to the 1985 breeding season.

The intent of the mating plan is to obtain 10-20 female progeny per sire for estimating genetic parameters for the characters of primary interest. Close matings are avoided in all populations to reduce rates of inbreeding.

In 1988, 1989, and 1990, male calves produced in the nine purebreds and the F_3 generation from each of the three composite populations (12 breed groups), except those needed for breeding, will be castrated at weaning and fed diets of two energy densities to two slaughter end points. There will be two pens for each breed group—one pen for each dietary energy density for each of the three yr. Feed consumption data will be recorded on a pen basis to permit estimation of feed efficiency for each breed group-energy density sub-class.

The right side of each carcass will be processed into boneless, closely trimmed (.3 in. outside fat) and further into boneless, fully trimmed (0 outside fat) product. Fat in a cross section of the longissimus muscle will be estimated by chemical analysis. Samples of cooked meat from the longissimus muscle will be used to obtain sensory evaluations (tenderness, flavor, and juiciness) and shear force values to estimate tenderness.

All female calves will be retained for breeding during this period, as has been done throughout the experiment, and all male calves will be left intact and fed in the standard mode again for the 1991 calf crop.

For calf crops born in 1989 and 1990, and, if needed in 1991, milk production/consumption will be recorded on 24, 3-, 4-, and 5-yr-old females in each yr from each of the nine purebreds, and from the F_2 generation of each of the three composite populations (12 breed groups). Three evaluations of milk production/consumption will be recorded in each yr on 24 cow/calf pairs using the weigh-nurse-weigh procedure. Milk production/consumption estimates will be made on the following schedule: (1) immediately before start of breeding season, about June 15, when calves avg about 2 mo of age, (2) end of breeding season, about August 15, when calves avg about 4 mo of age, and (3) after preconditioning, about September 15, when calves avg about 5 mo of age.

Table 3—Germ Plasm Utilization Project · Matings made to establish composites, retention of heterozygosity, and expected retention of heterosis

	Composites			
	MARC I	MARC II	MARC III	Mean
Matings to Produce F_1's[a]	(C x LH) x (B x LA) or (C x LA) x (B x LH) Reciprocals	(GH) x (SA) or (GA) x (SH)	(PA) x (RH) or (PA) x (HR) Reciprocals	
Matings to produce F_2's	$F_1 \times F_1$	$F_1 \times F_1$	$F_1 \times F_1$	
Matings to produce F_3's	$F_2 \times F_2$	$F_2 \times F_2$	$F_2 \times F_2$	
Breed composition of F_1 and subsequent generations	.25B,.25C,.25L,.125H,.125A	.25G,.25S,.25H,.25A	.25P,.25R,.25H,.25A	
F_1 Heterozygosity[b]	.94	1	1	.98
F_2 Heterozygosity	.78	.75	.75	.76
F_3 Heterozygosity	.78	.75	.75	.76
F_1 Heterosis[c]	$.94\ H^i + 1\ H^m$	$1\ H^i + 1\ H^m$	$1\ H^i + 1\ H^m$	$.98\ H^i + 1\ H^m$
F_2 Heterosis	$.78\ H^i + .94\ H^m$	$.75\ H^i + 1\ H^m$	$.75\ H^i + 1\ H^m$	$.76\ H^i + .98\ H^m$
F_3 Heterosis	$.78\ H^i + .78\ H^m$	$.75\ H^i + .75\ H^m$	$.75\ H^i + .75\ H^m$	$.76\ H^i + .76\ H^m$
F_4 Heterosis	$.78\ H^i + .78\ H^m$	$.75\ H^i + .75\ H^m$	$.75\ H^i + .75\ H^m$	$.76\ H^i + .76\ H^m$

[a]Composites established from same animals used in purebred foundation where C = Charolais, L = Limousin, H = Hereford, B = Brown Swiss, A = Angus, G = Gelbvieh, S = Simmental, P = Pinzgauer, and R = Red Poll.

[b]In populations mated *inter se'*, loss of heterozygosity occurs between the F_1 and F_2 generations and, if inbreeding is avoided, subsequent loss of heterozygosity does not occur.

[c]H^i denotes individual heterosis expressed by progeny and H^m denotes maternal heterosis expressed by dam of progeny and assumes retention of heterosis is proportional to retention of heterozygosity.

All females have been retained for breeding, and excess females have been removed from each population on nonperformance criteria. The same criteria have been used to identify males for use in all populations, e.g., color in composite populations and avoidance of extremes in all populations in regard to wt and skeletal and muscular anatomy. The same basic criteria have been used in all breed groups (purebred and composites) in identifying males to use and in the removal of females excess to the needs of the project.

The specific mating plan used to produce the F_1, F_2, and F_3 generations of the three composite populations and their breed composition is provided by Table 3. Heterozygosity for the F_1, F_2, and F_3 generations and expected heterosis for both individual and maternal traits is given in Table 3. Values given for heterosis for both individual (H^i) and maternal (H^m) traits assumes retention of heterosis proportional to retention of heterozygosity. Loss of heterozygosity in *inter se'* mated populations occurs between the F_1 and F_2 generations and, if inbreeding is avoided, further loss of heterozygosity is not expected. Because heterosis for maternal traits is expressed in progeny, heterosis for maternal traits is expressed in F_3 generation progeny of F_2 generation dams (Table 3).

In Composite MARC I, the F_1 generation was produced from 1978 through 1983, the F_2 generation was produced starting in 1980, and the F_3 generation was produced starting in 1982. In Composite MARC II, the F_1 generation was produced from 1978 through 1982, the F_2 generation was produced starting in 1980, and the F_3 generation was produced starting in 1982. In Composite MARC III, the F_1 generation was produced from 1980 through 1984, the F_2 generation was produced starting in 1982, and the F_3 generation was produced starting in 1984. Purebred contemporaries have been maintained since 1978 for all except the Pinzgauer. For the Pinzgauer breed, the first 3/4 Pinzgauer were produced in 1980, 7/8 Pinzgauer (purebred in females) were produced in 1982, and 15/16 Pinzgauer (purebred in males) have been produced since 1984. The Brown Swiss breed averages about 7/8 dual-purpose type from Europe (Braunvieh) and was established by using semen from nine Braunvieh sires from Switzerland and Germany (Bavaria), starting with a female foundation of typical dairy-type Brown Swiss females obtained as heifer calves in Wisconsin and Minnesota in 1967 and 1968. The grading toward the European dual-purpose type of Brown Swiss started in 1969.

The current phase of this experiment will be completed with the production and growing out through yearling age of the calf crop to be born in 1991.

Results

Growth traits. Breed group means and standard errors for the nine purebreds and for the F_1, F_2, and F_3 generations of each of the three composite populations for birth, weaning, and yearling wt are presented in Tables 4 and 5 for bulls and heifers, respectively. These data were analyzed as individual traits. Differences are small among the Charolais, Simmental, Gelbvieh, Pinzgauer, and Brown Swiss breeds for these wt traits. The Limousin breed is intermediate in growth traits; the Angus and Red Poll breeds are similar to each other; and the Hereford breed is lightest in weaning and yearling wt. The three composite populations are closer in wt traits to the higher gaining purebred parents than they are to the lower gaining purebred parents.

Heterosis estimates for the F_1, F_2, and F_3 generations for each composite population and mean heterosis for the F_1, F_2, and F_3 generations for the three composite populations for birth, weaning, and yearling wt are presented in Tables 6 and 7 for bulls and heifers, respectively. The numbers on which these estimates are based are provided in Tables 4 and 5 for bulls and heifers,

Table 4—Breed group means and standard errors for birth, weaning, and yearling weight of bulls - Germ Plasm Utilization Project - 1978-1985

Breed group	N[a]	Birth wt (lb)	SE[b]	200-day wt (lb)	SE	368-day wt (lb)	SE
Mean	5,086	93	.4	512	1.5	972	2.7
Red Poll (R)	348	84	.9	470	4.0	880	7.0
Brown Swiss (B)	367	100	.8	540	3.5	1,005	6.1
Hereford (H)	382	80	.9	406	4.0	831	7.1
Angus (A)	666	75	.7	436	2.9	866	5.1
Simmental (S)	364	97	.8	547	3.3	1,034	5.7
Limousin (L)	363	90	.8	470	3.7	902	6.4
Charolais (C)	324	103	.9	531	4.0	1,025	7.1
Gelbvieh (G)	284	97	1.0	558	4.1	1,021	7.2
Pinzgauer (P)	143	107	1.4	547	5.8	1,019	10.1
MARC I F_1[cd]	238	94	1.1	522	4.6	1,001	8.1
F_2	245	96	1.1	529	4.7	1,005	8.2
F_3	55	98	1.8	520	8.0	986	13.8
MARC II F_1[cd]	341	91	1.0	551	4.4	1,010	7.8
F_2	365	93	1.0	525	4.1	1,005	7.3
F_3	156	92	1.2	527	5.0	999	8.6
MARC III F_1[cd]	237	91	1.2	505	5.0	961	8.8
F_2	190	91	1.3	509	5.4	979	9.5
F_3	18	92	3.0	522	12.9	988	21.9

[a]N = Number observations.
[b]SE = Standard Error.
[c]MARC I is 1/4B, 1/4L, 1/4C, 1/8H, 1/8A; MARC II is 1/4H, 1/4A, 1/4S, 1/4G; MARC III is 1/4R, 1/4H, 1/4A, 1/4P.
[d]F_1, F_2, F_3 is first, second, and third generation of matings to produce animals of the same breed composition, i.e., *inter se'* mating.

Table 5—Breed group means and standard errors for birth, weaning, and yearling weight of heifers - Germ Plasm Utilization Project - 1978-1985

Breed group	N[a]	Birth wt (lb)	SE[b]	200-day wt (lb)	SE	368-day wt (lb)	SE
Mean	5,090	87	.3	481	1.4	739	2.2
Red Poll (R)	349	79	.8	432	3.7	653	5.9
Brown Swiss (B)	353	93	.7	512	3.3	765	5.2
Hereford (H)	382	75	.8	379	3.9	608	6.2
Angus (A)	663	70	.6	412	2.8	666	4.4
Simmental (S)	379	90	.7	516	3.1	774	4.8
Limousin (L)	360	84	.7	441	3.5	686	5.4
Charolais (C)	373	96	.8	503	3.5	776	5.5
Gelbvieh (G)	303	92	.8	529	3.9	774	6.1
Pinzgauer (P)	148	98	1.2	522	5.6	772	8.8
MARC I F_1[cd]	237	91	1.0	503	4.4	778	7.0
F_2	203	91	1.0	505	4.6	783	7.3
F_3	50	96	1.7	514	7.6	798	11.6
MARC II F_1[cd]	332	84	.9	496	4.2	743	6.8
F_2	372	86	.9	487	4.0	754	6.5
F_3	126	86	1.1	498	5.0	763	7.6
MARC III F_1[cd]	251	85	1.0	465	4.8	728	7.6
F_2	185	84	1.1	476	5.2	739	8.1
F_3	24	84	2.3	472	10.4	739	15.7

[a]N = Number observations.
[b]SE = Standard Error.
[c]MARC I is 1/4B, 1/4L, 1/4C, 1/8H, 1/8A; MARC II is 1/4H, 1/4A, 1/4S, 1/4G; MARC III is 1/4R, 1/4H, 1/4A, 1/4P.
[d]F_1, F_2, F_3 is first, second, and third generation of matings to produce animals of the same breed composition, i.e., *inter se'* mating.

Table 6—Heterosis for birth, weaning, and yearling weight of bulls[a] - Germ Plasm Utilization Project - 1978-1985

Contrast	Traits: Birth wt (lb)	200-day wt (lb)	368-day wt (lb)
MARC I			
F_1 minus Purebreds	1.5	31	55
F_2 minus Purebreds	2.9	37	62
F_3 minus Purebreds	5.7	29	40
MARC II			
F_1 minus Purebreds	3.5	62	73
F_2 minus Purebreds	5.7	37	66
F_3 minus Purebreds	4.8	40	62
MARC III			
F_1 minus Purebreds	4.4	40	62
F_2 minus Purebreds	4.2	44	82
F_3 minus Purebreds	5.5	57	88
Mean Heterosis			
F_1 minus Purebreds	3.1	44	64
F_2 minus Purebreds	4.2	40	70
F_3 minus Purebreds	5.3	42	64

[a]See footnotes in Table 4.

Table 7—Heterosis for birth, weaning, and yearling weight of heifers[a] - Germ Plasm Utilization Project - 1978-1985

Contrast	Traits: Birth wt (lb)	200-day wt (lb)	368-day wt (lb)
MARC I			
F_1 minus Purebreds	4.6	40	62
F_2 minus Purebreds	4.8	40	66
F_3 minus Purebreds	10.4	48	82
MARC II			
F_1 minus Purebreds	2.2	35	37
F_2 minus Purebreds	4.4	29	48
F_3 minus Purebreds	4.4	40	57
MARC III			
F_1 minus Purebreds	4.4	29	51
F_2 minus Purebreds	3.7	40	64
F_3 minus Purebreds	4.2	35	64
Mean Heterosis			
F_1 minus Purebreds	3.7	35	51
F_2 minus Purebreds	4.4	35	60
F_3 minus Purebreds	6.4	42	68

[a]See footnotes in Table 5.

respectively. Heterozygosity for F_1, F_2, and F_3 generations and expected heterosis for both individual and maternal traits for F_1, F_2, F_3, and F_4 generations are presented in Table 3 for each composite population and for the mean of the three composite populations.

Because of limited numbers, the estimates of heterosis for the F_3 generation for these growth traits should be interpreted with some degree of caution. These early results for growth traits are based on data from calf crops born through 1985. The approximate additional numbers of F_2, F_3, and F_4 generation progeny out of F_1, F_2, and F_3 generation dams expected from 1986 through 1991 are given in Table 2. Even though additional numbers of the F_2 generation will be produced, the number (Tables 4 and 5) of the F_2 generation on which these estimates of heterosis are based are sufficiently large to indicate that retention of heterosis is proportional to retention of heterozygosity for individual growth traits. The F_2 generation is expected to reflect about three-fourths of the F_1 generation level of heterosis for individual traits and all of the F_1 generation level of heterosis for maternal traits, whereas, the F_3 generation is expected to reflect about three-fourths of the F_1 generation level of heterosis for both individual and maternal traits; i.e., further loss of heterosis is not expected (Table 3).

Based on these early results, we conclude that level of heterosis in the F_1 generation is high for birth, weaning, and yearling wt in all three composite populations, is reasonably uniform among the three composite populations, and, on a percentage basis, is greater in females than in males (Tables 6 and 7). The level of heterosis in the F_2 generation averages approximately the same as in the F_1 generation for birth, weaning, and yearling wt even though the F_2 generation is expected to have less heterosis for individual traits than the F_1 generation because expected loss of heterozygosity has already occurred. The F_3 generation reflects expected loss of heterosis for both individual and maternal traits (Table 3). The level of heterosis observed for birth, weaning, and yearling wt in the F_3 generation is approximately the same as observed for these traits in the F_1 and F_2 generations for both males and females (Tables 6 and 7), but, as stated previously, the heterosis estimates for the F_3 generation should be interpreted with some degree of caution because of limited numbers of F_3 generation included in these analyses (Tables 4 and 5).

Reproduction and maternal traits. Breed group means for the nine purebreds and for the F_1 and F_2 generations of composite populations for some reproduction traits and for some reproduction and maternal traits combined are presented in Tables 8 and 9, respectively. These data were analyzed as traits of the dam. The results presented in Tables 8, 9, 10, and 11 are based on analyses of observations of F_1 and F_2 generation females, and, when calf traits are involved, their F_2 and F_3 generation progeny. The production of F_2 generation progeny by F_1 generation dams is expected to reflect about three-fourths of F_1 generation level of individual heterosis and all of the F_1 generation level of maternal heterosis, whereas, the production of F_3 generation progeny by F_2 generation dams is expected to reflect about three-fourths of F_1 generation level of both individual and maternal heterosis; i.e., further loss of heterosis is not expected (Table 3).

Large differences were observed among the purebreds for most reproduction traits. Composite populations generally were equal to, or exceeded, the superior contributing purebred parents for reproduction traits (Table 8). When reproduction and maternal traits are combined (e.g., 200-day wt per cow exposed or actual calf wt weaned per cow exposed), even larger differences among the purebreds were observed, and composite populations generally equalled or exceeded the superior contributing purebred parents (Table 9).

Heterosis estimates for the F_1 and F_2 generations for each composite population and mean heterosis for the F_1 and F_2 generations for the three composite populations are presented in Tables 10 and 11, respectively, for some reproduction traits and for some reproduction traits combined with maternal traits. The effects of heterosis were significant in both the F_1 and F_2 generations for all reproduction and maternal traits except calving difficulty (%) and calving difficulty score (Table 10). Even though the effects of heterosis on birth wt was about 5 lb, it did not result in increased calving difficulty (Tables 10 and 11).

The numbers on which these estimates of heterosis are based are provided in Tables 8 and 9. Heterozygosity for F_1 and F_2 generation females producing F_2 and F_3 generation progeny and expectations for heterosis for both individual and maternal traits are presented in Table 3 for each composite population and for the mean of the three composite populations. Because these data were analyzed as traits of the dam when calf traits were involved (F_2 and F_3 generation progeny of F_1 and F_2 generation dams), the F_1 generation is expected to reflect about three-fourths of the F_1 generation level of heterosis for individual traits and all of the F_1 generation level of heterosis for maternal traits, whereas, the F_2 generation is expected to reflect about three-fourths of the F_1 generation level of heterosis for both individual and maternal traits (Table 3).

Table 8—Breed group means for reproduction traits · Germ Plasm Utilization Project · 1979-1986

Breed group	N[a]	Puberty[b] (%)	Adjusted age at puberty[b] (days)	Concept. rate, yearling[b] (%)	Concept. rate, all ages (%)	Calf crop wnd, all ages[c] (%)	Calving diff.[d] (%)	Calving diff. score[e]
Mean	17,402	89.8	376	78.3	85.7	76.9	17.2	1.6
Red Poll (R)	1,325	93.2	364	81.5	87.3	78.3	13.7	1.4
Brown Swiss (B)	1,333	95.7	343	82.2	84.5	73.8	27.0	2.0
Hereford (H)	1,396	67.6	435	61.6	77.9	72.7	13.5	1.4
Angus (A)	2,385	85.0	411	77.1	84.3	73.4	7.7	1.2
Simmental (S)	1,364	93.4	365	83.1	83.5	72.5	21.8	1.8
Limousin (L)	1,525	62.2	434	48.9	73.4	70.0	14.4	1.5
Charolais (C)	1,390	82.1	402	73.2	83.6	75.7	18.2	1.6
Gelbvieh (G)	991	96.0	347	86.1	85.5	78.6	20.3	1.7
Pinzgauer (P)	722	98.4	350	88.0	89.0	79.2	22.9	1.8
MARC I F_1[f,g]	1,003	94.6	377	79.5	89.6	79.0	17.6	1.6
F_2	485	97.8	368	85.6	91.1	80.5	17.2	1.6
MARC II F_1[f,g]	1,447	92.9	349	73.8	87.0	79.7	17.9	1.6
F_2	838	94.9	361	84.5	87.9	79.9	20.4	1.7
MARC III F_1[f,g]	886	96.5	364	83.1	91.6	82.2	12.7	1.4
F_2	312	97.5	372	86.1	88.7	77.4	12.8	1.4

[a]N = Number observations for conception rate all ages.
[b]Number of heifers per breed group = 178 to 573, % reaching puberty by end of breeding season, and *adjusted* age at puberty includes heifers that had not reached puberty by end of breeding season.
[c]Based on females of all ages exposed to breeding.
[d]Calving difficulty = % requiring assistance.
[e]Calving difficulty score—1 = no assistance, 2 = minor hand assistance, 3 = little difficulty with calf jack, 4 = slight difficulty, 5 = moderate difficulty, 6 = major difficulty, 7 = caesarean birth.
[f]MARC I is 1/4B, 1/4L, 1/4C, 1/8H, 1/8A; MARC II is 1/4H, 1/4A, 1/4S, 1/4G; MARC III is 1/4R, 1/4H, 1/4A, 1/4P.
[g]F_1 and F_2 are females from the first and second generation of the same breed composition producing F_2 and F_3 progeny.

Table 9—Breed group means for maternal traits and reproduction traits combined with maternal traits - Germ Plasm Utilization Project - 1979-1986

Breed group	N[a]	Birth wt (lb)	200-day wt (lb)	200-day calf wt per cow exposed (lb)	Actual calf wt wnd per cow exposed (lb)
Mean	13,347	90.8	495	384	356
Red Poll (R)	948	83.5	456	358	336
Brown Swiss (B)	988	98.2	527	390	356
Hereford (H)	1,064	79.2	397	292	266
Angus (A)	1,680	74.3	428	317	300
Simmental (S)	965	93.8	535	390	363
Limousin (L)	1,126	86.4	457	325	292
Charolais (C)	1,032	98.5	516	393	365
Gelbvieh (G)	790	95.1	540	427	391
Pinzgauer (P)	551	102.3	533	427	401
MARC I F_1[bc]	895	95.5	515	410	377
F_2	407	94.9	503	409	381
MARC II F_1[bc]	1,235	91.1	505	406	378
F_2	624	90.9	515	418	390
MARC III F_1[bc]	765	89.0	493	408	383
F_2	277	88.8	491	382	357

[a]N = Number observations.

[b]MARC I is 1/4B, 1/4L, 1/4C, 1/8H, 1/8A; MARC II is 1/4H, 1/4A, 1/4S, 1/4G; MARC III is 1/4R, 1/4H, 1/4A, 1/4P.

[c]F_1 and F_2 are females from the first and second generations of the same breed composition producing F_2 and F_3 progeny.

These early results indicate that level of heterosis is high for most reproduction and maternal traits (Tables 10 and 11). The level of heterosis for most reproduction and maternal traits averages almost as great for the F_2 generation females as for the F_1 generation females (e.g., F_2 and F_3 generation progeny out of F_1 and F_2 generation dams for traits included in Tables 9 and 11). Because expected loss of heterosis has occurred in F_2 generation females, and in F_3 generation progeny produced by F_2 generation dams, these results indicate that loss of heterosis is not greater than loss of heterozygosity for reproduction and maternal traits in *inter se'* mated composite populations.

A note of interpretation is in order for the lack of heterosis observed for conception rate in F_1 generation yearling heifers for Composite MARC II (Table 10). The F_1 generation in Composite MARC II was produced by mating *mature* (6- to 12- yr-old) Simmental x Angus and Simmental x Hereford cross females to Gelbvieh x Hereford and Gelbvieh x Angus cross males, respectively (Table 3). Even though these records were adjusted as appropriate for the effects of differences in age of dam, these adjustments do not remove the negative association that exists for maternal effects between generations; i.e., a highly favorable maternal environment, as provided by *mature* crossbred cows, may result in physiological damage that may reduce level of performance in some reproductive and maternal traits in their daughters. We think it is likely that the relatively low conception rate (73.8%) of the F_1 generation yearling heifers in Composite MARC II (Table 8) may be the result of the favorable maternal environment provided by their *mature* Simmental x Angus or Simmental x Hereford crossbred dams. There was a normal age distribution in the dams of the contributing purebred contemporaries to which they were compared. The relatively low conception rate of the F_1 generation Composite MARC II yearling heifers accounts for the lack of heterosis in this trait and is not consistent with the relatively high estimate of heterosis for conception rate observed in the F_2 generation of Composite MARC II yearling heifers (Table 10).

We do conclude, however, that, based on results obtained through 1986 breeding (1987 calving), heterosis retained in composite populations for reproduction and maternal traits is likely not less than retained heterozygosity of the F_2 generation relative to the F_1 generation. If inbreeding is avoided, further loss of heterozygosity does not occur subsequent to the F_2 generation. Collection of additional data on reproduction and maternal traits involving F_2, F_3, and F_4 generation progeny out of F_1, F_2, and F_3 generation dams (Tables 2 and 3) on calf crops to be born through 1991 will estimate more precisely the relationship between retained heterosis and retained heterozygosity in composite populations of cattle.

Table 10—Heterosis for reproduction traits[a] · Germ Plasm Utilization Project · 1979-1986

Contrast	Puberty (%)	Adjusted age at puberty (days)	Concept. rate, yearling (%)	Concept. rate, all ages (%)	Calf crop wnd. (%)	Calving diff. (%)	Calving diff. score
			MARC I				
F_1 minus Purebreds	15.6	-23	11.1	9.0	5.9	-.004	-.006
F_2 minus Purebreds	18.7	-32	17.2	10.4	7.4	-.411	-.029
			MARC II				
F_1 minus Purebreds	7.4	-41	-3.1	4.2	5.4	2.048	.062
F_2 minus Purebreds	9.4	-29	7.5	5.1	5.6	4.568	.157
			MARC III				
F_1 minus Purebreds	10.4	-26	6.1	7.0	6.3	-1.756	-.085
F_2 minus Purebreds	11.4	-18	9.0	4.1	1.6	-1.681	-.071
			Mean Heterosis				
F_1 minus Purebreds	11.1	-30	4.7	6.7	5.9	.096	-.010
F_2 minus Purebreds	13.2	-26	11.2	6.5	4.9	.825	.019

[a]See footnotes in Table 8.

Table 11—Heterosis for maternal traits and reproduction traits combined with maternal traits[a] · Germ Plasm Utilization Project · 1979-1986

Contrast	Birth wt (lb)	200-day wt (lb)	200-day calf wt per cow exposed (lb)	Actual calf wt wnd per cow exposed (lb)
		MARC I		
F_1 minus Purebreds	5.5	37	56	53
F_2 minus Purebreds	5.0	25	56	56
		MARC II		
F_1 minus Purebreds	5.5	30	49	48
F_2 minus Purebreds	5.3	40	61	60
		MARC III		
F_1 minus Purebreds	4.1	39	60	58
F_2 minus Purebreds	3.9	38	33	31
		Mean Heterosis		
F_1 minus Purebreds	5.0	35	55	53
F_2 minus Purebreds	4.7	34	50	49

[a]See footnotes in Table 9.

Individual Heterosis Effects on Mature Size and Maternal Heterosis Effects on Preweaning Traits and Postweaning Growth and Carcass Traits

Keith E. Gregory, Delwyn D. Dearborn, Larry V. Cundiff, and Robert M. Koch[1,2]

Introduction

The Brown Swiss, Red Poll, Hereford, and Angus breeds and their 12 reciprocal crosses from a four-breed diallel crossing experiment were evaluated for production and carcass characters. Estimates of average heterosis and breed maternal and additive direct effects were reported earlier for preweaning traits, growth rate and puberty in females, growth traits of steers, and carcass traits of steers. This report provides results from the second phase of this experiment for maternal performance data on the females, including estimates of heterosis and breed maternal and additive direct effects on cow size and on preweaning traits, postweaning growth, and carcass traits of their progeny.

Procedure

This study included data collected on 549 females produced in a four-breed diallel crossing experiment at MARC. These females were born in 1973 and 1974 and were developed and maintained at the Research Center until 1982. The numbers representing each breed group are presented in Table 1.

Breeding females in this experiment were fed alfalfa haylage and corn silage during the winter prior to and immediately after their first calving as 2-yr-olds. A mixture of alfalfa and bromegrass hay was fed *ad libitum* during each of the following winters. Cool season pastures composed of a mixture of bromegrass and alfalfa were used from mid-April until mid- to late June and from early September until late October or early November. Warm-season pastures composed of mixtures of switchgrass, Indian grass, and big bluestem were used during the summer months and again in the late fall. The initiation of hay feeding each winter was dependent on the availability of grass and the severity of weather.

Each breeding season was 63 days in length, starting the last wk in May. However, the breeding season for yearlings started 2 wk earlier. The yearlings were bred by artificial insemination (AI) for 42 days and then exposed to bulls for 21 days. During their second and subsequent breeding seasons, all females were bred natural service to 3/4, 7/8, or 15/16 Simmental bulls produced at the Research Center. Females were removed from the project only if they failed to calve 2 yr in succession.

Body weight, hip height, and condition score (nine-point scale, 2 = thin, 5 = intermediate, and 8 = fat) were taken on all females four times each year: (1) prior to calving, approximately February 1; (2) before start of breeding season, approximately May 20; (3) end of breeding season, approximately August 1; and (4) pregnancy palpation time following weaning, approximately October 25. Weight, height, and condition scores analyzed for each yr were the average of four measurements recorded for each cow.

Results reported on preweaning traits are for cows calving as 3-, 4-, 5-, 6-, and 7-yr-olds while raising calves by 3/4, 7/8, or 15/16 Simmental sires. As yearlings, the females were mated to Santa Gertrudis, Brangus, Hereford, and Angus sires. Because female breed group effects could not be estimated without some confounding with sire breeds, the progeny of 2-yr-old females are not included in this report. Average birth date of calves was April 1. Calves were not creep fed. Calves were weaned near mid-October at an average age of about 200 days.

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[2]The authors would like to acknowledge W. Gordon Hays, cattle operations manager, for his assistance with this project.

Table 1—Number of females by breed group and number of observations or matings, calves born, calves weaned, and milk consumption

Breed group of females[a]	Females	Matings	Number observations: Calves born	Calves weaned	Milk consumption
RR	26	125	110	97	10
RB	8	28	25	22	3
RH	42	211	198	156	17
RA	53	278	246	199	17
BR	17	94	81	74	12
BB	27	145	126	114	9
BH	64	356	309	265	17
BA	62	343	304	266	18
HR	21	113	108	103	11
HB	12	70	68	64	8
HH	38	209	193	166	18
HA	50	281	262	223	18
AR	21	112	103	94	10
AB	14	71	60	56	7
AH	39	203	165	133	17
AA	55	282	263	236	17
Totals	549	2,921	2,621	2,268	209

[a]R = Red Poll; B = Brown Swiss; H = Hereford; A = Angus (breed of sire is designated first).

To estimate milk consumption, calves were penned with their dams at about 4 p.m. and separated 2 hr later; at 6 a.m. the following morning, calves were individually weighed, allowed to nurse, and reweighed. The difference between post- and prenursing weights of each calf was an estimate of milk consumption. This procedure was followed three times each yr when the dams were 3-yr-olds, at intervals of 4 wk beginning in July.

Postweaning growth and carcass data on 360 steers and 329 heifers produced in 1979 and 1980 were analyzed. Dams were 5-, 6-, and 7-yr-olds in 1979 and 1980 when they produced progeny on which postweaning growth and carcass data were recorded in this study. After an adjustment period of about 28 days following weaning, both heifers and steers were fed a growing diet composed of corn silage, corn, and protein supplement with mineral [2.61 megacalories of metabolizable energy (ME)/kg of dry matter (DM) and 12.75% crude protein] for about 96 days and fed a finishing diet composed of the same feed ingredients in different proportions (3.04 ME/kg of DM and 10.93% crude protein) for an average of 120 days in each yr. Cattle were slaughtered in a commercial facility, and carcass data were obtained 24 hours after slaughter. Cattle were slaughtered in two groups in both yr; interval between slaughter dates was 5 to 6 wk for each year-sex subclass. Average age at slaughter was 444 days for both steers and heifers.

Results

Mature size and condition of cows. Beef females representing Brown Swiss, Red Poll, Hereford, and Angus breeds and the 12 reciprocal crosses among them were studied to estimate heterosis and breed maternal and additive direct effects on wt, hip height, and condition score at succeeding ages through maturity. Heterosis was important for wt at all ages and for hip height from 2 through 6 yr of age. Adjustment of wt for the effects of condition score decreased the magnitude of heterosis, though it was still important. These results indicate that most of the heterotic effect for avg wt and height present at yearling age continues through maturity. Breed mean heterosis differences for wt were significant only at 2 yr, but the same trend continued through maturity. Brown Swiss and Hereford tended to exhibit more heterosis for wt in crosses with other breeds than Red Poll; Angus was intermediate. Brown Swiss and Red Poll exhibited a larger breed maternal effect for avg wt at each age than Hereford or Angus. Likewise, Brown Swiss exhibited larger breed maternal effect for hip height than the three other breeds, which ranked Red Poll > Hereford > Angus. Most of the increased wt observed at 2 yr of age due to breed maternal effect was maintained through maturity. The additive direct effects for avg wt ranked the four breeds Angus > Brown Swiss > Hereford > Red Poll. Adjusting avg wt for condition score changed the ranking with Brown Swiss ranking highest and Hereford lowest. A large part of the Angus additive direct effect for avg wt was associated with higher condition. Estimates of direct effects for avg hip height ranked Brown Swiss > Red Poll > Hereford = Angus.

Preweaning traits of progeny. Crossbred progeny sired by 3/4, 7/8, and 15/16 Simmental sires from the 16 breed groups of females, 3 yr old and older, were evaluated to estimate breed mean maternal heterosis for each breed, maternal heterosis for specific breed cross females, avg maternal heterosis for all crosses, and breed grandmaternal effects for preweaning calf traits. Estimates of avg maternal heterosis for all crosses were important for birth date and wt, 200-day wt, and 200-day wt/cow exposed. Even though calves with crossbred dams weighed more at birth, they did not differ from calves with straightbred dams in frequency of calving assistance. The estimates of maternal heterosis for specific breed cross females were similar for most crosses and most traits, except 200-day wt and 200-day wt/cow exposed. The largest heterotic advantage was exhibited by progeny of Brown Swiss-Hereford reciprocal cross females, which exceeded crossbred progeny from straightbred Brown Swiss and straightbred Hereford females for 200-day wt/cow exposed by 79 lb. The smallest heterotic effect was exhibited by crossbred progeny of Red Poll-Angus reciprocal cross females. Progeny with Red Poll maternal granddams exhibited a higher percentage of live calves born and weaned than progeny with Hereford maternal granddams. Progeny with Brown Swiss maternal granddams were born later in the calving season than progeny with Red Poll maternal granddams. Progeny with Angus maternal granddams exhibited a lower frequency of calving assistance than progeny with Hereford maternal granddams, and progeny with Hereford maternal granddams were heavier at 200 days than progeny with Red Poll maternal granddams.

Postweaning growth and carcass traits of steer and heifer progeny. Crossbred steer and heifer progeny of 7/8 and 15/16 Simmental sires born in 1979 and 1980 from 5-, 6-, and 7-yr-old dams were evaluated for postweaning growth and carcass traits to estimate breed mean maternal heterosis, maternal heterosis for specific breed cross females, avg maternal heterosis for all crosses, breed grandmaternal effects, and net breed effects in crosses. Average maternal heterosis was not significant for final wt in either heifers or steers. The effects of maternal heterosis on postweaning growth were not important. Differences among breeds in mean maternal heterosis values were small for growth-related traits. Breeds did not differ in grandmaternal effects for growth-related traits; Brown Swiss tended to be highest, Red Poll lowest, with Hereford and Angus intermediate. Differences in net breed effects in crosses favored Brown Swiss over the three other breeds and were generally significant for growth traits. Average maternal heterosis, though generally positive, was not significant for carcass traits on either an age-constant or weight-constant basis. Differences among breeds were small in grandmaternal effects, specific heterosis, and net breed effects in crosses for carcass traits associated with both wt and composition; generally the Brown Swiss breed was favored in carcass traits associated with wt on an age-constant basis and generally had a higher lean-to-fat ratio than the three other breeds on both an age-constant and weight-constant basis.

Heterosis, Breed Maternal, and Breed Direct Effects in Red Poll and Hereford Cattle

Keith E. Gregory, Delwyn D. Dearborn, Donald D. Lunstra, Larry V. Cundiff, and Robert M. Koch[1,2]

Introduction

Breed differences, heterosis, and reciprocal cross differences from beef cattle crossbreeding experiments have been summarized in prior reports from MARC and reports from other research stations.

However, there have been only limited reports to characterize the Red Poll breed relative to other breeds. This report summarizes results from an experiment where reciprocal crosses and straightbreds were produced to estimate heterosis, breed maternal effects, and breed effects for growth rate of the Red Poll and Hereford breeds.

Procedure

This study was conducted in 1978 and 1979 at MARC. Numbers of animals classified by sex, breed of sire, and breed of dam subclass are presented in Table 1. Ten Red Poll and eleven Hereford sires were used. Most sires were used by both artificial insemination and natural service, and most produced both straightbred and crossbred progeny. Sires and dams of each breed were sampled from the same population of purebreds maintained at MARC. Age of dam distribution was similar in both breeds. Dams of each breed were randomly assigned to breed of sire and to sires within breed, except matings that would result in more than modest levels of inbreeding (> 6%) were avoided.

Dams were maintained on improved pasture (April to November) and fed a mixture of grass and legume hay on pasture during the winter. Calves were born during a calving season of approximately 65 days extending from mid-March to mid-May; the avg calving date was April 13. All calves were identified and weighed within 24 hr of birth. Male calves were left intact. Calves were raised by their dams on pasture without creep. They were weaned at an avg age of 181 days.

During the 168-day postweaning period, female calves received a diet of corn silage and alfalfa haylage averaging 11.8% crude protein (CP) and 2.18 Mcal of metabolizable energy (ME)/kg of dry matter (DM). The diet for male calves for the 168-day postweaning period included corn silage, rolled corn, and soybean oil meal and was 12.9% CP and 2.69 Mcal of ME/kg of DM. Weight at 368 days of age was estimated by adding 168-day postweaning gain to adjusted 200-day wt.

Bulls and heifers were measured for height, and bulls were measured for scrotal circumference at an avg age of 349 days.

Results

Individual heterosis, differences between breeds in maternal ability, and growth rate were estimated (Table 2). Important heterosis effects, expressed as a percent of the straightbred mean, were 8.0% for birth wt and 7.9% for both preweaning avg daily gain and 200-day wt. Heterosis effects on postweaning growth traits of females were 15.7% for 168-day gain, 12.0% for 368-day wt, and 2.9% for 368-day height. Heterosis effects on postweaning growth traits of intact males were 9.1% for 168-day gain, 6.5% for 368-day wt, 2.3% for 368-day height, and 9.6% for scrotal circumference.

Based on comparison of reciprocal crosses, breed maternal effects were significantly greater for calves with Red Poll dams for birth wt, preweaning avg daily gain, 200-day wt, and for postweaning gain of female calves receiving a high silage diet. However, bull calves from Hereford dams grew more rapidly postweaning than bull calves from Red Poll dams; bull calves received a diet of higher energy density than the heifer calves. Estimates of Red Poll breed effects exceeded Hereford breed effects for survival, preweaning avg daily gain, 200-day wt, and 368-day height. However, Hereford breed effects exceeded Red Poll breed effects for calving difficulty, birth wt, and 168-day postweaning gain in both heifers and bulls. Breed maternal effects were higher for the Red Poll, while breed effects for traits of the individual (e.g., growth rate) were higher for the Hereford.

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[2]The authors would like to acknowledge W. Gordon Hays, cattle operations manager, for his assistance with this project.

Table 1—Number born, weaned, and completing postweaning growth period classified by sex, breed of sire, and breed of dam

Breed of dam	Sex of calf	Breed of sire: Red Poll B[a]	Red Poll W[b]	Red Poll P[c]	Hereford B	Hereford W	Hereford P
Red Poll	Male	19	19	19	40	34	33
	Female	32	26	23	46	45	45
Hereford	Male	114	106	104	74	61	60
	Female	124	118	117	90	75	73

[a]B = no. born.
[b]W = no. weaned.
[c]P = no. completing postweaning growth period.

Table 2—Estimates of breed group means for economic traits

Item[a]	Calving[b] difficulty, %	Survival to 72 hr, %	Survival to weaning, %	Birth wt, lb	200-day wt, lb	Heifers: 368-day wt, lb	Heifers: Height,[c] in	Bulls: 368-day wt, lb	Bulls: Height,[c] in	Bulls: SC,[cd] cm
Breed group means										
RR	16.8	89.1	85.0	74	430	621	45.3	820	47.0	30.2
HH	19.8	86.4	79.8	74	378	589	43.5	818	44.9	30.4
RH	16.6	93.8	88.9	78	420	650	45.6	880	47.0	33.3
HR	23.3	86.7	83.6	83	452	705	45.9	865	47.0	33.2

[a]R = Red Poll, H = Hereford; sire breed listed first.
[b]% requiring assistance.
[c]Estimates of height and scrotal circumference are based on measures at the end of the 168-day postweaning feeding period at an average age of 349 days.
[d]SC = scrotal circumference.

Investigation of the Major Histocompatibility Complex in Cattle and Its Association with Economically Important Traits

Noelle E. Muggli, Michael J. Stear, and Roger T. Stone[1]

Introduction

Efficiency of animal production could be increased by reducing losses due to diseases. Therefore, disease resistance is an obvious trait to include in a selection program. However, how to incorporate this trait into the program is a difficult question. While it has been experimentally shown that selection for resistance against specific diseases is effective, it would be impossible to select for resistance to all potential diseases. Also, selection studies in mice show that increasing resistance to one disease can result in increased susceptibility to other diseases. This may be because antagonistic relationships exist among the mechanisms of the immune system. Thus it would be preferable to use general resistance to disease as the selected trait in cattle.

As for any selected trait, disease resistance must meet three criteria. First, there must be a reasonable economic weight placed on disease resistance. There is little doubt that disease costs can be extremely high because of reduced production due to mortality, morbidity, and subclinical infections. Second, genetic variation must exist. Several experiments have established that there is significant genetic influence on disease resistance. Finally, the selection procedure must be accurate in estimating the breeding potential of selected animals. While an accurate method of assessment would be to infect all animals and select those that survive, it would be very costly. A preferred, indirect method of selection would include the use of genetic markers that are associated with, or closely linked to, the genes influencing disease resistance. Potentially, a newborn animal could be tested for these markers and evaluated for lifetime resistance, since an animal's genetic potential is not altered throughout life.

A set of genetic markers that is associated with disease resistance or susceptibility has been identified in humans and laboratory species. These markers are genes that belong to the major histocompatibility complex (MHC). The MHC is a cluster of tightly linked genes discovered in the late 1930's in mice. It was first implicated as the genetic basis for rejection or acceptance of tissue and organ transplants. In 1963, it was also demonstrated that the MHC determines the degree of response made by the immune system against foreign molecules or pathogens. The MHC spans a short segment of chromosome and contains genes that code for variable or polymorphic class I and class II proteins. Class I proteins, found on almost all nucleated cells, are involved in rejection or acceptance of grafts as well as tumor rejection and elimination of virus-infected cells. Class II proteins, found predominantly on cells of the immune system, are involved in regulation of antibody production by the immune system. The MHC of cattle is called BoLA.

Because of the previously defined association of the MHC with disease resistance, a project at MARC is investigating the possibility of using BoLA polymorphisms as genetic markers for assessing disease competence in cattle. To accomplish this objective, several studies of this genetic region are necessary. First, definition of class I and class II proteins or genes coding for these proteins is required. Secondly, the associations with diseases must be defined. Finally, before decisions can be made on which markers to include in a selection program, the associations with economically important traits must be estimated. If an antagonistic relationship exists between a desired MHC marker and a production trait, severity of the associated disease must be assessed before the marker would be included in the selection program.

Procedure

In all studies, class I proteins were defined by serology. To develop antibodies used in class I serology, white blood cells are first isolated from a blood sample of a donor cow and injected into a recipient cow. An immune response is mounted by the recipient against cell surface proteins that differ from its own, primarily against class I proteins. Antibodies specific to the donor's class I proteins are isolated from serum of the recipient. By using various combinations of donors and recipients, a panel of antisera recognizing 37 different protein determinants has been developed. In family studies, these determinants behave as alleles of a single class I locus. The antisera are used in a microcytotoxicity assay to determine the class I proteins for each animal tested. To do this, white blood cells from an animal are combined with each of the antisera and with rabbit complement, a series of blood proteins that causes cell death in the presence of an antibody-protein complex. If the test cells have class I proteins that are recognized by the antisera, an antibody-protein complex is formed, and the complement responds by killing the cells. Thus, if an animal is positive for a particular class I protein, its cells are killed after incubation with the corresponding antisera and complement.

Because class II proteins are found on a limited number of cells, generating class II antisera is technically difficult. Therefore, an alternative method of detection has been developed which detects differences in DNA sequences of the genes coding for class II proteins. These differences appear as variation in length of DNA fragments when total DNA from each animal is digested with restriction enzymes, separated by gel electrophoresis, and hybridized with radioactive probes made from the genes of interest. These fragments can be identified as codominant alleles.

To test for differences in cattle class I proteins and class II genes, blood samples were taken from straightbred cattle of the Germ Plasm Utilization (GPU) population at MARC. These animals were born in 1984 and 1985 and included Angus, Brown Swiss, Charolais, Gelbvieh, Hereford, Limousin, and Simmental breeds. Blood samples were also obtained from 1984- and 1985-born male calves of a MARC population selected for increased twinning rate. Class I types were determined for these males.

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Results

Striking differences were found between breeds in the presence or absence of certain class I alleles, and the combinations of class I proteins found within each breed were unique. In Table 1, the numbers of animals tested for each breed are given, as well as the numbers of class I alleles identified within each breed. The Hereford and Simmental cattle tested were more homogeneous than the other breeds, as shown by the proportion of homozygotes found within each breed. Two Hereford cows were more likely to have the same combination of class I proteins than two cows of the other breeds, but the probability is low.

The associations of class I alleles and growth traits, specifically birth weight, preweaning gain, and postweaning gain, were investigated in a subset of these animals including 139 Angus, 109 Charolais, 111 Herefords, and 107 Simmentals. The mean growth trait values for animals with a particular class I allele were compared to the mean growth trait values for animals without the allele. Significant differences are given in Table 2. Since breeds differed in allele frequency, the allele effects on these growth traits were examined breed by breed. No allele was associated with more than one growth trait.

The relationships of class I alleles with reproduction traits were also examined. In the first study, class I protein types were determined for 243 GPU bull calves including 85 Angus, 47 Charolais, 58 Herefords, and 53 Simmentals. Also, paired testicular volume (an indicator of sexual potential) was measured on these same males at approximately 1 yr of age. Of the 11 alleles present in sufficient numbers of animals for statistical analyses, only W6 was significantly associated with paired testicular volume. Those bulls with W6 had a mean paired testicular volume 85.2 cm^3 less than bull calves without W6. This allele was present in 21.3% of the Charolais. In addition, the class I types of 102 male calves from the MARC twinning herd were examined for association with expected breeding value (EBV) for twinning. Males with the W6 class I allele had a significantly higher mean EBV for twinning than those without the W6 allele. The associations with reproductive traits are being examined further by testing cattle born in subsequent years.

To begin the investigation of genes coding for class II proteins, DNA sequences were determined for the coding regions of two cattle genes. Comparisons with the published sequence of a human class II DRβ gene indicate that the bovine and human DNA sequences are very similar. A specific coding region in the two bovine genes has a 90% identity with the corresponding region in the human sequence. Other regions have an average identity of 76%. One of the bovine genes contains several errors in its sequence that render it nonfunctional, while the second appears to be functional. Using portions of the two cattle genes as radioactive probes, 185 GPU cattle (50 Angus, 31 Charolais, 58 Hereford, and 46 Simmental) have been characterized for differences in size of fragments containing these genes. Only one Charolais had a different fragment size for the nonfunctional gene. More variation was found for the functional gene, but variation was dependent on the breed. All Herefords had one fragment size, while two sizes were found in Angus, Charolais, and Simmental.

Table 1—Number of alleles and proportion of homozygotes for class I proteins detected in breeds of the Germ Plasm Utilization Project

Breed	No. animals	No. alleles present	Observed proportion of homozygotes	Probability of two cattle having the same genotype
Angus	139	14	.17	.05
Brown Swiss	51	13	.20	.06
Charolais	109	20	.09	.03
Gelbvieh	56	15	.11	.02
Hereford	111	10	.34	.12
Limousin	58	12	.19	.04
Simmental	107	13	.34	.11

Table 2—Allele effects[a] on growth traits measured on cattle of the Germ Plasm Utilization project

Trait	Class I allele	Breed	Effect (kg)[b]
Birth weight	CA5	Angus	-.8
	CA45	Angus	+.5
	Eu12	Hereford	+3.2 (1984)[c]
			-2.7 (1985)[c]
	W10	Simmental	-3.0
	CA12	Simmental	+3.4
Preweaning gain	W5	Hereford	+12.1
	W8.1	Simmental	-11.9 (1984)[c]
Postweaning gain	CA40	Charolais	+18.5

[a]Allele effects were calculated as the differences for mean growth traits of cattle with the class I protein minus mean growth traits of cattle without the class I protein.
[b]All differences were significant (probability < .05).
[c]Birth year.

Inheritance of Active and Passive Immunity in Beef Calves

Noelle E. Muggli, Bill D. Hohenboken, Larry V. Cundiff, and Don E. Mattson[1,2]

Introduction

Disease is caused by successful invasion of pathogenic organisms (e.g., viruses, bacteria, parasites). The immune system is responsible for the protection of an individual against these invasions. This system is complex, with interconnective parts composed of many stimulators, inhibitors, effectors, and consequences. Immunity that is dependent upon antibodies or immunoglobulins can be either active or passive in origin. In active immunity, the body produces protecting antibodies in response to a naturally occurring infection or to vaccination against a pathogenic organism. Vaccination will prime the animal's immune system for a faster and more effective response to later infections. In passive immunity, temporary protection against infection results because of the transfer of immune products from a resistant to a susceptible individual. Passive immunity occurs between mother and young via transfer of immunoglobulins across the placenta to the developing fetus and/or by ingestion of immunoglobulin-containing colostrum. In ruminants, placental transfer of maternal antibodies does not occur due to the complexity of the placenta. The animal is born with a negligible level of immunoglobulins unless fetal infection has occurred. However, this is compensated for by absorption of large protein molecules, including immunoglobulins, from colostrum across the intestinal wall of the neonate. The absorptive mechanism is short-lived, lasting only 24 to 36 hr after birth, and absorption capacity decreases over time. Catabolism of these proteins eventually occurs in the body. Therefore, we believe maternal immunoglobulins are gone by 3 to 4 mo of age. As level of maternal antibodies declines, the animal's own immune system takes over the role of protection. Responses to natural infection and vaccination begin. Thus, both types of immunity are necessary for the well-being of the ruminant animal.

One approach to reducing losses due to disease is to increase genetic disease resistance. Improvement of genetic resistance requires identification of genetically superior animals and dissemination of their genes by preferential mating. However, before a clear definition of immune superiority is possible, factors that affect immune traits must be defined.

The first part of this study investigated the ability of calves to acquire and absorb colostral antibodies. The second part of this study investigated the animals' active immunity, specifically the vaccination response to infectious bovine rhinotracheitis virus (IBRV). Factors affecting these immune traits were examined, and heritabilities of these traits were estimated.

Procedure

Two beef cattle populations were included in the study. The first group was 367 Selection Experiment Herefords, including three selection lines and an unselected control line (CNL). The selection lines sampled were a weaning weight line (WWL), a yearling weight line (YWL), and a line selected for an index of yearling weight and muscling score (IXL). The second population was the Germ Plasm Utilization (GPU) Project. Straightbred Angus (79), Herefords (40), and Red Polls (46) were sampled. Three sets of blood samples were collected from each animal. The first set was taken from calves between 24 and 48 hr of age. Level of IgG_1, a specific class of immunoglobulin, was quantified in these samples in a single radial immunodiffusion (SRID) assay. The second set was taken from these same animals at time of vaccination for IBRV, and the third set was taken 60 days postvaccination. The second and third set of samples were quantified for antibody titers specific to IBRV by a kinetics-ELISA assay and are referred to as prevaccination and postvaccination titers, respectively.

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[2]The full report of this work was published in J. Anim. Sci. 64:385-393, 1987.

Table 1—Least-squares means for lines of the Selection Experiment Hereford population and breeds of the Germ Plasm Utilization population

Group	No.	IgG_1 level (mg/ml) at 24 to 48 hr	Prevaccination IBRV titer	Postvaccination IBRV titer
SEH[a] overall	367	26.0	4.8	13.8
Line[b]				
WWL	86	25.7[de]	4.5[de]	12.4[d]
YWL	88	22.4[d]	4.7[de]	13.9[de]
IXL	69	26.8[de]	4.4[d]	15.1[e]
CNL	124	28.9[e]	5.4[e]	13.7[de]
GPU[c] overall	165	33.6	4.6	8.8
Breed				
Angus	79	38.9[d]	4.3	8.9
Hereford	40	28.4[e]	5.2	8.9
Red Poll	46	33.4[e]	4.4	8.6

[a]Selection Experiment Hereford population.
[b]Line abbreviations are: weaning weight (WWL), yearling weight (YWL), index of yearling weight and muscling score (IXL), and randomly selected control line (CNL).
[c]Germ Plasm Utilization population.
[de]Means within the same trait and group with no superscript in common differ (probability < .05).

Table 2—Least-squares means for sex and age of dam effects in Selection Experiment Hereford calves

Effect	No.	IgG_1 level (mg/ml) at 24 to 48 hr	Prevaccination IBRV titer	Postvaccination IBRV titer
Sex				
Male	190	25.3	4.8	13.9
Female	177	26.6	4.7	13.7
Age of dam				
2 yr	97	20.3[a]	4.3[a]	17.1[a]
3 yr	92	26.6[b]	4.6[a]	14.4[b]
4-9 yr	178	31.0[c]	5.4[b]	9.9[c]

[abc]Means within the same trait and effect with no superscript in common differ (probability < .05).

Table 3—Least-squares means for sex and age of dam effects in Germ Plasm Utilization calves

Effect	No.	IgG_1 level (mg/ml) at 24 to 48 hr	Prevaccination IBRV titer	Postvaccination IBRV titer
Sex				
Male	89	33.3	4.5	8.3
Female	76	33.8	4.8	9.3
Age of dam				
3 yr	56	33.4	4.0	9.9[a]
4-7 yr	109	35.2	5.0	8.0[b]

[ab]Means within the same trait and effect with no superscript in common differ (probability < .05).

Table 4—Heritability estimates (h^2) for immune traits pooled across Selection Experiment Hereford and Germ Plasm Utilization populations

Trait	h^2
IgG_1 level (mg/ml) at 24 to 48 hr	.09
Prevaccination IBRV titer	.21
Postvaccination IBRV titer	-.06

Results

The traits measured in this study were IgG_1 level at 24 to 48 hr of age, prevaccination IBRV titer, and 60-day postvaccination IBRV titer. In Table 1, least-squares means of these traits are given for the Selection Experiment Hereford lines and for Angus, Hereford, and Red Poll calves of the GPU population. There were no consistent differences among lines or breeds for the traits measured. While the CNL line was highest in mean IgG_1 level and prevaccination titer, it was intermediate for postvaccination titer. Angus calves were higher in mean IgG_1 level than Hereford and Red Poll calves. At the time of 24 to 48 hr sampling, the Angus calves were observed to be more active than calves of the other two breeds. It may be that the time from birth to colostrum ingestion was less in Angus calves and so greater absorption of immunoglobulins occurred.

The effects of sex and age of dam on each trait were also examined. These effect means are given in Table 2 and Table 3 for the Selection Experiment Herefords and the GPU calves, respectively. No differences between sexes were found for any trait. However, interesting differences were found for the age of dam effect. The mean IgG_1 level was lower for calves of younger dams (2 and 3 yr of age) than for calves of older dams (4 yr and older). It may be that the younger dams (or their calves) experienced more pain at parturition, causing them to ignore or reject any teat-seeking advances (or attempts) by the newborn calf. Any delay in colostrum ingestion will cause a decreased protein absorption in the newborn's intestine, resulting in a decrease in serum immunoglobulin levels. Also, mammary gland development may not be complete in these younger dams, and the quantity of available immunoglobulins, including those specific to IBRV, may have been less. Calves of younger dams had a lower mean prevaccination titer than calves of older dams. It is possible that less maternal IBRV-specific antibodies were present in the prevaccination samples because less colostral antibodies were available to these calves of younger dams. A lower mean postvaccination titer was found for calves of older dams than for calves of younger dams. Any remaining IBRV-specific antibodies at time of vaccination would neutralize the vaccine before the calf's own immune system could respond. Therefore, calves with higher prevaccination titers (calves of older dams) would have lower responses measured 60 days later. Calves from younger dams would have lower levels of passive immunity, less maternal antibodies at time of vaccination, a greater response to the vaccination, and more antibodies measured 60 days later.

Heritability estimates for IgG_1 level at 24 to 48 hr of age, prevaccination IBRV titer, and 60-day postvaccination IBRV titer are given in Table 4. These estimates are pooled over the two populations, resulting in a single value for each trait. All estimates were low and nonsignificant, indicating that improvement of these traits through genetic selection would be difficult.

The effect of these immune traits on survival rate was examined for IgG_1 level at 24 to 48 hr of age. Fourteen Selection Experiment Hereford calves died during the calving season. The mean level for these calves (16.1 mg IgG_1/ml of serum) was significantly lower than the overall mean level for the Selection Experiment population (26.0 mg/ml). One Angus calf of the GPU population died during the calving season, and its IgG_1 level was 16.7 mg/ml. Seven additional Selection Experiment calves died between the end of calving and weaning. Their mean IgG_1 level was 23.7 mg/ml, and this was not significantly different from the overall mean. Thus, there was an increased risk of death associated with lower colostral immunoglobulin level, but this risk was evident only during the first 30 days of life.

Inheritance of Vertical Fiber Hide Defect

Larry V. Cundiff, Matthew P. Dahms, Mary V. Hannigan, Alfred L. Everett, and Peter E. Buechler[1, 2, 3]

Introduction

Cattle leather with vertical fiber hide defect (VFHD) breaks when stretched and, consequently, is not suitable for production of shoe uppers. Typical tensile strength of VFHD leather is only 50% of normal leather. VFHD is caused by a structural defect of collagen fiber orientation in the corium layer of cattle hides. The defect was first described by Amos, an Australian research chemist, in 1958. Economic losses to the leather industry were estimated to exceed $10 million in 1973. The cost can be high because the defect is often not detected until after the expense of tanning has been incurred. The defect does not occur uniformly throughout the hide, but tends to be localized in the upper rear quarter (rump area). Often it may extend forward and downward to involve 75% of the trimmed hide.

Biopsy procedure

Scientists at the Animal Bio-Material Laboratory at the Eastern Regional Research Center (ERRC), ARS, USDA, Philadelphia have been conducting research on this defect since the 1960's. At that time, they developed a biopsy and histological examination procedure which can be used to diagnose VFHD either on hide samples taken by biopsy on live animals or from hide samples taken after slaughter. We have used this procedure in all of our joint experiments on inheritance of VFHD. Biopsy samples 1 inch in diameter were taken from the rump area of each animal at a point about 10 inches in front of the tail and 10 inches down from the mid-line with an automatic biopsy gun. Each biopsy specimen was put into a tube containing a 10% formalin solution and sent to the ERRC for histological evaluation. The fiber bundle structures are designated as:

Normal (N) = Compact with bundles interweaving at an angle of approximately 50 to 60 degrees;

Vertical (V) = Mostly vertical with little or no interweaving and usually very loose in appearance; and

Intermediate (I) = Loosely interwoven with variable upright angle of weave and vertical appearance in localized areas.

Unfortunately, it has not been practical to adopt this procedure outside of the research laboratory on a routine basis in the tanning industry because the histological examination is time consuming and requires a high level of skill.

Inheritance of VFHD

In early studies, VFHD was diagnosed in the progeny of certain sires but not others, suggesting that VFHD was heritable. In addition to a heritable component, early indications were that the condition was associated with carcass fatness. Thus, biopsy samples were studied from Hereford and Holstein identical and fraternal twin sets fed either high or low energy diets in experiments conducted at the University of Wisconsin in the early 1970's. Thirteen cases of the defect were found in fifteen pairs of Herefords, with matching occurrence in identical pairs but not always in fraternal pairs. The defect was not found in any of the Holstein twin pairs. Diet had no effect on expression of the defect. There was some indication that cows with the condition had lower reproductive performance than those without the condition.

This observation eventually led to a larger experiment at MARC in which 604 biopsies were evaluated from 465 Herefords and 139 Angus ranging from 4 mo to 9 yr in age. Incidence of VFHD was not associated with reproduction rate of females or other performance characters. VFHD was found in 13.3% of the Herefords but in no Angus. The Herefords were progeny of 65 sires. Sire effects were significant, and estimates of heritability were very high (84%).

The high heritability suggested that the condition was primarily, if not completely, under genetic control. The data set on 465 Herefords included 44 offspring-dam pairs. Examination of offspring and parental frequency distributions indicated that inheritance of the condition was not due to a single autosomal additive or dominant gene, but possibly was due to an autosomal recessive.

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[2]Full report of this work was published in J. Am. Leather Chem. Assoc. (1983) 78:178-187 and J. Heredity (1987) 78:24-28.

[3]The authors would like to acknowledge Mr. Ray Sampson, former cattle operations assistant, and Dr. W. G. Kvasnicka, former herd health veterinarian, for herd management and biopsy sampling.

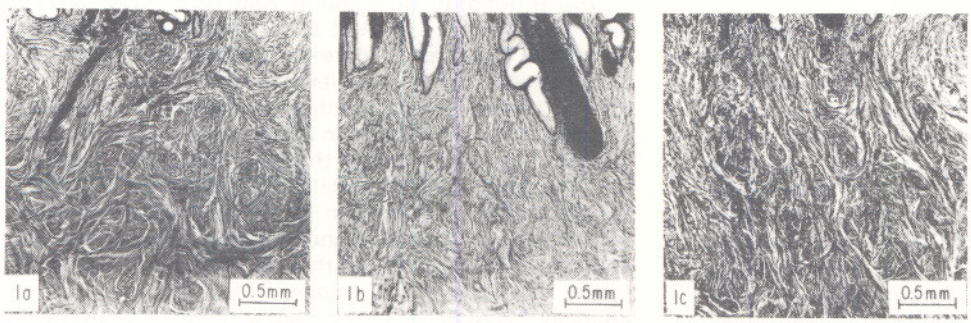

Figure 1—Cross sections of upper corium of three biopsy samples illustrating the three fiber types of fiber structure: A—normal; B-vertical; C—intermediate (Bars in A-C = .02 in).

At about the same time in 1983, Australian workers studied frequency distributions in 365 Herefords grouped according to sires and dams. They also concluded that VFHD was likely due to an autosomal recessive gene. However, this hypothesis could not be confirmed conclusively because no matings were available where known VFHD sires had been mated to known VFHD dams. In 1984 we mated a Hereford bull with a known VFHD phenotype to Hereford cows with known VFHD phenotypes and to Angus cows not showing the defect. Angus were chosen because the defect had never been observed in the breed. All offspring (5) resulting from the VFHD x VFHD matings expressed the defect, while no (12) offspring out of VFHD x non-VFHD (Angus) matings expressed the defect, confirming that VFHD was inherited as an autosomal recessive trait.

Results also indicated that the vertical (V) and intermediate (I) phenotypes represented two degrees of expression for the same genotype, rather than extra intensity of expression associated with one *vs* two copies of the same allele. Perhaps degree of expression for VFHD varies like that for hornedness in *Bos taurus* cattle. In *Bos taurus* breeds, presence or absence of horns is determined by genotype for a simple autosomal recessive gene, but degree of expression varies both within and especially between breeds from short to very long, presumably due to effects of other genes (at other loci) affecting expression of the trait.

Since the condition had only been diagnosed in Herefords and one Hereford x Holstein cross, an additional experiment was conducted to evaluate the frequency of VFHD in other breeds of cattle. Hide biopsies were taken in November of 1985 on 35 Pinzgauer, 55 Red Poll, 47 Brown Swiss, 52 Charolais, 69 Gelbvieh, 55 Simmental, and 45 Limousin heifers produced at MARC. The defect was found in only one Simmental heifer. The sire and dam of this heifer were both 1/16 Hereford. Simmental are registered as purebreds if they are 15/16 or more Simmental. Thus, we do not know whether or not the VFHD gene originated from "full blood" Simmental originally imported from Europe or from Herefords contributing to foundation of the breed in North America. Incidence of the condition in European breeds of cattle has not been studied in Europe. The defect is likely to be present in North American Simmental and other breeds including Pinzgauer, Gelbvieh, and Limousin, at least at a low frequency, if for no other reason than that it was present in Herefords or possibly other breeds used as foundation stock to grade up to purebreds of each breed. However, to date, indications are that the gene, if present, is only present at low frequencies in all breeds evaluated except the Hereford.

Estimates of phenotypic frequency and frequency of the VFHD gene in populations to date are shown in Table 1. In our data, 13.3% of the Herefords were affected, suggesting a gene frequency (q) of 0.37. It was also found in progeny of sires representing diverse lines of the Hereford breed. In Australian data, the phenotypic frequency and gene frequency were even higher than in our data. The Herefords in our study were all horned, but in Australia, both polled and horned Herefords were included in their sample. It is not known why the frequency of the gene is so much higher in Herefords than in other breeds.

To the extent that the VFHD gene is present at a high frequency only in Herefords and either not present or present only at a low frequency in other beef or dairy breeds, it would appear that the problem should be diminishing in importance and costs to the tanning industry with increased use of crossbreeding during the last 20 years. If the defect is present at a frequency V in only one breed:

For n breeds used in rotation, phenotypic frequency of the recessive defect would be reduced to $[(1/n)(1/2^{n}-1)(V)]$. For example, if V = .133 and n = 2 as in a two breed rotation, (e.g., Hereford and one other breed) 2.2% of the cattle would express VFHD, and in a three breed rotation only .6% of the cattle would express VFHD.

In a composite population, the frequency would be $Pv^2(V)$, where Pv is the fraction contribution of breed v to the composite population. For example, if V = .133 and Pv = 1/2 (e.g., 1/2 Hereford), 3.3% of the cattle would express VFHD; if Pv = 3/8, 1.9% of the cattle would express VFHD; and if Pv = 1/4, only 0.8% of the cattle would express VFHD.

Thus, incidence of the recessive defect will be very low in the total cattle population if systematic crossbreeding programs or composite populations are used for commercial production. It is estimated that about 70% of the calves produced in the U.S. are crossbreds. Considering the expense and technical difficulty of evaluation, intensive selection against VFHD is not justified, especially if the condition is present in only one breed.

Table 1—Estimates of incidence (phenotypic frequency) and gene frequency for vertical fiber hide defect (VFHD) by breed

Breed	Number sampled	Number with VFHD	Frequency of phenotype q^2, %	Frequency of gene q, %
Pinzgauer (MARC)	35	0	0	0
Red Poll (MARC)	55	0	0	0
Brown Swiss (MARC)	47	0	0	0
Charolais (MARC)	52	0	0	0
Gelbvieh (MARC)	69	0	0	0
Simmental (MARC)	55	1	1.8	13
Limousin (MARC)	45	0	0	0
Angus (MARC)	139	0	0	0
Holstein (Wisconsin)	15	0	0	0
Hereford (MARC)	465	62	13	37
Hereford (Australia)	362	83	23	48

Bison, Hereford, and Brahman Growth and Carcass Characteristics

Robert M. Koch, John D. Crouse, and Steven C. Seideman[1]

Introduction

Bison, Hereford, and Brahman represent three species of the bovine family that evolved under different environmental conditions. There has been much interest in these species and hybrids among them to find animal types that are better adapted to the climatic conditions of the U.S. northern temperate zones down to the subtropical areas. There has been considerable research on growth and carcass characteristics of crosses among British, European, and Brahman cattle types, such as studies at MARC. However, there is little experimental documentation of the growth and carcass merit of Bison or their crosses. The three species differ distinctly in conformation, and Bison normally have 14 ribs instead of 13. The experiment described here addresses the differences in growth and carcass characteristics between Bison and two cattle types.

Procedure

Brahman calves, born in January and February, were obtained from the Subtropical Agricultural Research Station, Brooksville, Florida. The Hereford calves, born in March and April, were from the MARC herd. Bison calves, born in May, June, and July were obtained from the Fort Niobrara Wildlife Refuge, Valentine, Nebraska. The period from late September until January 28 was used to adjust the Bison, Hereford, and Brahman groups to the pens and diet to be used during a 224-day feeding trial. Animals were placed in pens of 5 or 6 animals and fed the following diet: corn silage (66%), corn (22%), and a soybean and mineral supplement (12%), on a dry matter basis. All animals were castrated and dehorned.

The Hereford and Brahman groups were slaughtered in two groups based on the time when Hereford reached an avg wt of 1,150 lb. The Bison were younger, smaller, and varied greatly in wt and rate of gain when placed on feed so were slaughtered when the pen groups attained an avg wt of 900 lb. This wt was thought to be comparable in stage of maturity to the Hereford and Brahman groups.

Detailed carcass evaluation, retail cutout, and taste panel (sensory) evaluations were obtained on all carcasses. The right side was broken into wholesale cuts. Primal cuts were trimmed to an avg of .3 in fat cover and boned out. After aging 7 days, loins were frozen and, at a later date, cut into steaks for sensory evaluation. A trained taste panel of 10 persons evaluated three samples from each loin for variation in juiciness, ease of fragmentation, amount of connective tissue, tenderness, and flavor. The 9-10-11 rib cut was removed from the left side and separated into bone and soft tissue for chemical analysis of the soft tissue. The left loins were used for chemical analysis, fiber type analysis, and shear force determination.

Results

Growth and carcass characteristics are presented in Table 1. Rate of gain for the 224-day test period indicate Hereford > Brahman > Bison. Daily feed intake followed the same pattern. Feed intake as a percentage of avg body wt on test was lowest for Brahman and highest for Hereford with Bison not significantly lower than Hereford. Feed per unit of gain was lowest for Bison and highest for Brahman. Part of the low feed requirement

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Table 1—Growth and carcass characteristics of Bison, Hereford, and Brahman

Item	Bison	Hereford	Brahman
Number	10	12	10
Initial wt, lb	408	550	672
Range in initial wt	266-494	490-642	547-804
Wt after 224 days on feed	787	1,093	1,110
Avg daily gain, 224 days, lb	1.7	2.5	1.9
Feed/day, lb	14.0	21.6	19.4
Feed/avg wt, %	2.4	2.6	2.2
Feed/gain, lb	8.2	8.6	10.3
Avg days to slaughter	336	239	239
Slaughter wt, lb	903	1,149	1,114
Carcass wt, lb	561	701	697
Dressing percentage	62.2	61.0	62.5
Forequarter percentage	53.5	51.4	50.4
Retail product[a], %	70.6	62.1	63.4
Total fat trim[b], %	13.3	22.2	21.3
Bone, %	16.1	15.7	15.3
Fat thickness, in	.87	.53	.46
Fat, 9-10-11 rib cut, %	38.8	40.5	37.6

[a]Retail product is amount of trimmed, boneless lean relative to side wt.
[b]Fat in excess of .3 in was trimmed from the surface of cuts and added to the kidney and pelvic fat.

of Bison was associated with a lower avg wt during the 224-day period. When adjusted for differences in avg wt on test, Bison and Hereford were similar (8.1 and 8.2) and lower than Brahman (11.3). The increased efficiency of gain of Bison, in spite of a lower rate of gain, may have been due to a lower basal metabolic rate and maintenance requirement. Growth contrasts in these data should be interpreted with caution, even though a long adjustment period was used before starting the test. Confinement to pens and a moderate density diet is an abnormal situation for Bison, which are not domesticated animals. The Brahman cattle came from Florida and may not have adapted well to the cold winter but should have had a compensating advantage during the hot summer months.

Brahman and Bison had similar dressing percentages and exceeded Hereford. The forequarter percentage differed significantly among all species with Bison the highest and Brahman the lowest. The amount of trimmed, boneless retail product was higher and fat trim was lower for Bison than Brahman and Hereford. Surprisingly, the Bison had more fat over the rib than Hereford or Brahman (Fig 1). This was due to an unusual distribution of the subcutaneous fat with a disproportionate amount being concentrated over the rib portion of the carcass (Fig. 2). The percentage of fat in the 9-10-11 rib cut has often been used as a good indicator of total fat in the carcass of British breeds. Hereford had the highest percentage of fat in the 9-10-11 rib cut and the highest percentage of fat trim. However, the relative discrepancy of 9-10-11 rib fat and total fat trim for Bison and Brahman suggests a differential pattern of fat distribution among the three species.

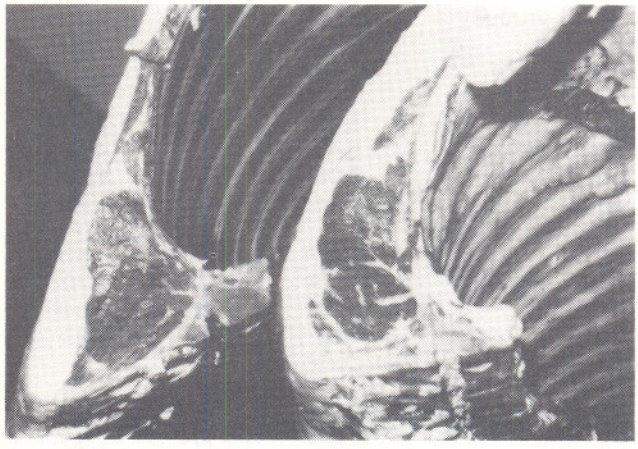

Figure 1—Rib section of Bison (left) and Hereford (right) showing increased fat thickness of Bison *vs* Hereford.

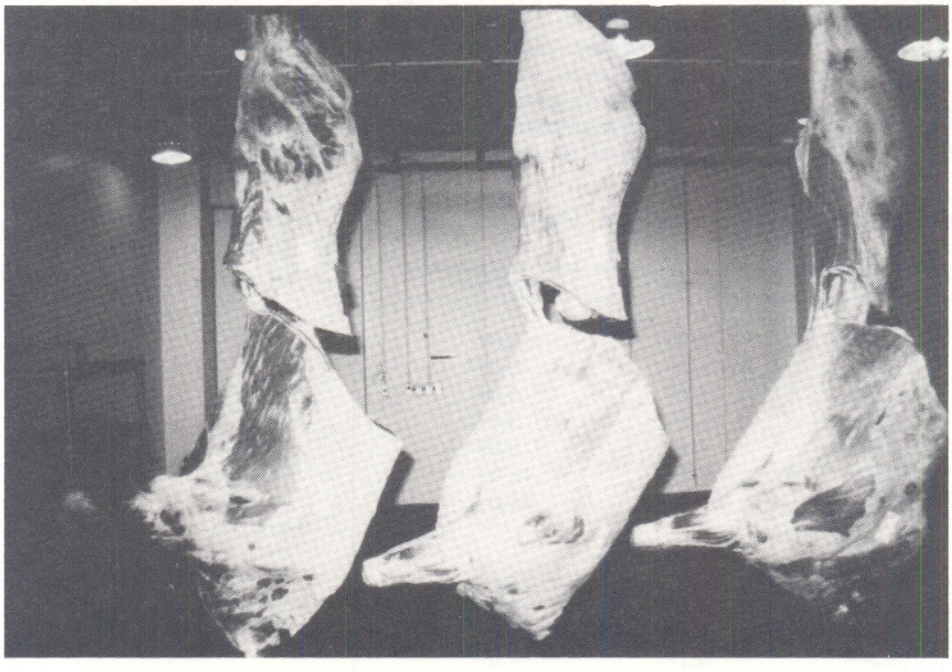

Figure 2—Side of Bison (left), Hereford (middle) and Brahman (right) showing relative fat cover.

Wholesale cut composition as a percentage of side wt is shown in Table 2. Bison had more chuck than Brahman or Hereford. Part of the difference in chuck retail product among species was associated with the hump (rhomboid muscle) of Bison (.54%) and Brahman (1.11%).

Table 2—Wholesale cut composition, as a percentage of side weight

Item	Bison	Hereford	Brahman
Chuck	30.82[b]	26.80[c]	27.36[c]
Retail product	23.39[b]	18.59[d]	20.26[c]
Fat trim	2.83[b]	4.26[c]	3.09[b]
Bone	4.60[b]	3.94[c]	4.01[c]
Rib	8.93[b]	7.86[c]	7.40[c]
Retail product	5.43[b]	7.82[c]	4.57[c]
Fat trim	2.06[b]	1.54[c]	1.38[c]
Bone	1.44	1.49	1.45
Loin	13.95[b]	15.33[c]	14.57[d]
Retail product	10.55[b]	9.90[c]	9.70[c]
Fat trim	1.41[b]	3.46[d]	2.94[c]
Bone	1.99	1.97	1.93
Round	24.19	23.56	24.23
Retail product	19.23[b]	16.71[d]	17.65[c]
Fat trim	.82[b]	2.77[c]	2.55[c]
Bone	4.13	4.08	4.03
Minor cuts[a]	18.95[b]	23.51[d]	22.32[c]
Retail product	11.99[b]	12.06[b]	11.20[c]
Fat trim	2.98[b]	7.22[c]	7.22[c]
Bone	3.98[c]	4.23[c]	3.90[b]
Kidney knob	3.17[b]	2.94[b]	4.12[c]

[a]Minor cuts include flank, shank, brisket, and plate.
[b c d]Values with superscripts that do not have a common letter differ (probability < .05).

Bison had a higher percentage of retail product and fat trim in the rib cut than Brahman or Hereford, but, in all other cuts, Bison had less fat trim. Bison may have evolved this extra fat over the rib as an energy storage depot or as protection from a cold environment. Hereford had the largest loin percentage, but this was due to more fat trim. Bison, with the lowest percentage of whole loin, had the highest percentage of loin retail product. The whole round did not differ significantly across species, but it did differ in percentages of retail product and fat trim. Bison had more round retail product and less fat trim than Brahman or Hereford, which might not be expected from a casual appraisal of their conformation. The percentage of minor cuts was lowest in Bison due to low fat trim percentage. The lower percentage of minor cuts for Brahman compared to Hereford was due to less retail product and bone. Hereford had the lowest and Brahman the highest percentage of kidney knob.

Meat and sensory panel characteristics of Bison, Hereford, and Brahman are presented in Table 3. Bison meat had a darker and coarser texture than Hereford or Brahman. The ranking of species for intramuscular fat (marbling score and longissimus muscle fat) was Hereford > Brahman > Bison. Bison also had less total and soluble collagen in the loin than Hereford or Brahman. Brahman had more soluble collagen than Hereford. The cholesterol content of the longissimus muscle, trimmed of all external fat, did not differ significantly among species. Most of the observed differences could be accounted for by intramuscular fat.

Even though Bison had the least amount of intramuscular fat, their shear force values and sensory panel scores for tenderness, ease of fragmentation, and amount of connective tissue were similar to Hereford. Shear force is inversely related to tenderness. Brahman had the highest shear force and lowest tenderness scores. Bison had the highest and Brahman the lowest juiciness scores. The sensory panel detected a stronger and different flavor for Bison as compared to Hereford or Brahman. The taste panel described this as a more intense ammonia, metallic, and gamey flavor.

Table 3—Meat and sensory panel characteristics of Bison, Hereford, and Brahman

Item	Bison	Hereford	Brahman
Meat characteristics[a]			
Color score	4.8[c]	6.0[d]	5.6[d]
Texture score	5.7[c]	6.7[d]	6.2[cd]
Marbling	3.2[c]	5.4[d]	4.4[e]
Longissimus fat, %	2.7[d]	5.3[c]	3.4[d]
Collagen, mg/g	3.0[c]	4.1[d]	3.9[d]
Soluble collagen, %	8.6[c]	10.1[d]	12.0[e]
Cholesterol (lean), mg/100g	50.6	51.9	51.0
Sensory characteristics[b]			
Shear force, lb	11.0[cd]	10.1[c]	12.8[d]
Tenderness	5.4[d]	5.4[d]	5.0[c]
Ease of fragmentation	5.4[d]	5.3[d]	5.0[c]
Amount of connective tissue	5.3[de]	5.1[d]	4.9[c]
Juiciness	5.3[de]	5.1[d]	4.9[c]
Flavor	2.3[c]	3.0[d]	3.1[d]

[a]Color scores: 1 = dark, 8 = light; texture scores: 1 = coarse, 8 = fine; marbling scores: 1 = devoid, 5 = small, 10 = abundant.
[b]Tenderness scores: 1 = extremely tough, 8 = extremely tender; ease of fragmentation: 1 = extremely difficult, 8 = extremely easy; amount of connective tissue: 1 = abundant, 8 = none; juiciness scores: 1 = extremely dry, 8 = extremely juicy; flavor scores: 1 = intense, 4 = none.
[c d e]Values with superscripts that do not have a common letter differ (probability < .05).

Twinning in Cattle

Keith E. Gregory, Sherrill E. Echternkamp, Gordon E. Dickerson, Larry V. Cundiff, and Robert M. Koch[1,2]

Introduction

Why an interest in twinning in cattle?

- More than one-half of the feed units used by the national beef herd are needed to meet *maintenance requirements* of the reproducing female population.
- The beef cow is capable of producing about *.7* of her body weight per year in progeny market weight.
- The sow is capable of producing more than *8* times her body weight per year in progeny market weight.
- The meat type hen is capable of producing more than *70* times her body weight per year in progeny market weight.
- The channel catfish female is capable of producing more than *1,000* times her body weight per year in progeny market weight.

Research objectives of this project are: (1) Determine the effectiveness of selection for multiple births in cattle and estimate genetic correlations between twinning rate and other bioeconomic traits; (2) develop selection criteria and procedures for multiple births in cattle; (3) accumulate data that will contribute to an economic assessment of multiple births in cattle for varying production resource situations; (4) establish nutritional and other managerial requirements for herds of cattle that have a high twinning frequency; (5) determine the relative importance of multiple ovulation and embryo survival in contributing to multiple births in cattle in both spring and fall breeding; and (6) determine the usefulness of cows with high twinning frequency as "models" to gain understanding of biological factors that relate to ovulation and embryo survival for both single and multiple births in cattle.

Procedure

About 50 females/year with highest estimated breeding value (EBV) are superovulated (25 in May and 25 in September). Embryos are collected and transferred into recipient females with low EBV. The intent is to produce from 125 to 150 progeny/yr from high EBV cows mated to high EBV bulls.

Barring the identification of a gene with a major effect on twinning frequency, we do not expect much progress *unless* an effective selection criterion is identified that can be used at an early age. Therefore, starting at puberty, ovaries of all heifers are palpated per rectum to determine ovulation rate (number of corpora lutea) for 6 to 9 mo (8 to 12 estrous cycles) and are bred first at about 19 mo of age. Palpation of fall-born heifers starts in July and continues until April, and, for spring-born heifers, palpation starts in March and continues until October. Fall-born females are bred in their second spring and spring-born females are bred in their second fall.

Females are palpated per rectum to determine ovulation rate during the artificial insemination (AI) breeding season (spring and fall). Multiple ovulating cows are paired with contemporary single ovulating cows, and both are laparoscoped to validate rectal palpation results. It is important to know the relative effects of ovulation rate and embryonic loss on twinning frequency. Embryonic migration between uterine horns seldom occurs in cattle. Therefore, the effect of bilateral and unilateral multiple ovulations on embryonic loss and twinning frequency is of considerable interest. Spring and fall breeding seasons are about 60 days; 40 days are by AI and 20 days are by natural service in individual sire breeding pastures. Calves are weaned at the end of the AI breeding period.

Cows in the twinning project are weighed and scored for condition five times each yr; i.e., (a) before calving, (b) before breeding, (c) end of AI breeding period, (d) end of breeding season, and (e) when palpated for pregnancy. Height at hooks is taken at each period except at the end of the AI period.

Heifers are weighed at birth, weaning (about 100 days), and about 200 days of age. They are weighed, measured, and scored at about 12 mo and again at end of ovulation rate evaluation cycle (about 19 mo) or when they go, as appropriate, to either (a) breeding, (b) donor use, or (c) recipient use.

All females in the twinning project are fed consistent with requirements to maintain them in optimal breeding condition. It is recognized that the nutritive requirements are affected by age, lactation status, number of nursing progeny, breed, etc. Thus, the nutritive environment is varied consistent with nutritive requirements.

Pelvic area on males and females in the twinning project is measured at 11 to 12 mo of age. Libido evaluations are taken on spring born males retained for breeding but not on fall born males. Males are weighed at birth, at weaning (about 100 days), at about 200 days, and are weighed, measured (including scrotal circumference), and scored at about 1 yr of age. Thereafter, weights, measures (including scrotal circumference), and scores are taken two times each yr (May and September) as long as bulls remain in the herd.

About 15% of the females with highest EBV for twinning are mated to proven sires (ovulation rate of daughters in 8 to 12 estrous cycles) to produce replacement bulls. About 20 to 25 young males with highest EBV for twinning are retained each year and mated to the females not bred to proven sires. The intent is to obtain 10 to 12 daughters by each young sire. Semen is collected and stored on each young sire. Ovulation rate of these daughters (8 to 12 estrous cycles) is the primary criterion for identification of bulls to use on high EBV females to sire males for the next generation. Progeny tests for ovulation rate are completed when sires are about 4 yr old. In order to control rate of inbreeding, a minimum of 6 males from the 20 to 25 young males selected and used each year are used subsequently in matings with highest EBV cows.

Matings are planned to limit the contribution of a single breed to 50% or less in any individual in early

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[2]The authors would like to acknowledge W. Gordon Hays, cattle operations manager, Steven M. Kappes, cattle operations assistant, and Darrell E. Light, statistical coordinator, for their assistance with this project.

generations and to 30% or less in the longer term. Breeds represented in the project are: (1) Holstein, (2) Simmental, (3) Charolais, (4) Brown Swiss, (5) Pinzgauer, (6) Gelbvieh, (7) Swedish Friesian, (8) Norwegian Red, (9) Shorthorn, (10) Hereford, and (11) Angus. Breeding (calving) occurs in both spring and fall.

Results

A total of 96 cows with records of two or more twin calvings were acquired from industry in 1976-77 (46), and in 1981-82 (50). Prior records averaged 3.83 parturitions per cow and 1.73 progeny per parturition. Subsequent records have averaged 2.47 parturitions per cow and 1.20 progeny per parturition. A total of 208 females with a record of twinning in other projects at the Research Center were transferred into the twinning project. Prior to transfer, these averaged 2.59 parturitions per cow and 1.39 progeny per parturition. Subsequently, they have averaged 2.92 parturitions and 1.15 progeny per parturition. Semen from three Swedish Friesian sires and two Norwegian Red sires whose daughters had produced twins at a high frequency was introduced in 1983 and in 1984, respectively.

Parturition records (1,194) were analyzed for 578 females born in the project from 316 dams and 51 sires. In this population, mean twinning rate was 8%; estimated heritability was .06 from paternal- and .07 from maternal half-sib correlations; and repeatability was .12. Twinning rate was 1.05, 1.08, 1.08, and 1.11 for 2-, 3-, 4- and 5 + year olds, respectively, and 1.06 *vs* 1.10 for spring *vs* fall calving.

Records (1,730) of ovulation rate were analyzed for 289 heifers, 12 to 20 mo of age, from 222 dams and 37 sires. These heifers averaged 6 cycles/heifer and 1.09 ovulations/cycle, with paternal half-sib heritability of .07 and repeatability of .07. Heritability of ovulation rate predicted for means of 6 and 10 estrus cycles/heifer from estimated heritability and repeatability of single-cycle data, was .31 and .43, respectively.

Precision of ovulation rate determination by rectal palpation in 330 postpartum cows was evaluated by laparoscopy with results as follows: Correctly identified 147 of 165 single ovulations (89%) and 125 of 165 multiple ovulations (76%).

Conception rate in postpartum cows was .58 (607 observations) and .67 (99 observations) with single and multiple ovulations, respectively. Embryonic survival was .58 (607 observations) and .49 (205 observations) for single and multiple ovulations, respectively. Embryonic survival was .55 (93 observations) and .44 (112 observations) for bilateral and unilateral multiple ovulations, respectively.

Ovulation rate in yearling females for 8 to 12 estrous cycles appears to offer a useful selection criterion for identifying replacements and for selection among bulls based on progeny test of 8 to 12 daughter progeny per sire.

Differences between singles (2,537) and twins (438) were important for calf survival ($P < .01$); i.e., survival to 72 hr was .96 and .78 and to weaning was .91 and .72 for singles and twins, respectively.

Twinning and Efficiency of Beef Production

Gordon E. Dickerson, Pedro Guerra-Martinez, Gary Anderson, and Ronnie D. Green[1]

Introduction

Twinning is relatively rare in most breeds of beef cattle — less than 1 to 2% of calvings and less frequent for immature females. Twin calving has generally been considered undesirable because of the smaller calf size, higher calf mortality, infertility of females born twin with a male, more retained placentas, and possible delayed rebreeding experienced with twin calvings when observed under feeding and management that is geared to single calving. However, costs for just maintaining the breeding herd account for over one-half of the total costs of beef production. Thus genetic twinning may offer a means of increasing total beef output much more than input costs, especially if genetic selection and appropriate feeding and management changes would reduce some of the undesirable effects of twinning.

Procedure

Data from a 4-yr bilateral embryo-transfer experiment, conducted by Dr. Anderson at the University of California-Davis, was analyzed to provide further information on the net changes in cow and calf performance and in the costs and output to be expected from cows producing twin calves. All embryos transferred were Hereford x Angus crosses. Recipient females were Hereford, Angus, or Hereford x Angus heifers and cows, and Holstein x Hereford heifers. Females were fed *ad libitum* chopped oat hay until the last trimester, when the chopped diet was 50% oat hay and 50% alfalfa, plus mineral supplement. In 1977, calves were weaned at 180 days and in feedlot from 180 to 400 days of age. In 1978-80, calves were grown on forage from 180 to 350 days and in feedlot from 350 to 490 days. Comparisons of twin and single calvings were made within yr, breed, and age of recipient females, and within sex for calf traits.

Results

Reproduction. Although all recipient females received two embryos, percent pregnant at 45-60 days of gestation was 68 for heifers and 74 for cows (Table 1). Percent calving was 61 and 71%, respectively. Proportion of single *vs* twin births was about 40 *vs* 60%. Dystocia was more common for heifers than cows (28 *vs* 10%), and was less for twin than single births in heifers (22 *vs* 37%) but not in cows, probably because easier calving of smaller twin calves was more critical in heifers. Retained placentas were definitely more frequent for twin births (35 *vs* 12% in heifers and 24 *vs* 0% in cows). Abortions were rare and were not higher for twins. Stillbirths and early calf mortality were slightly higher for twins (20 *vs* 12% in heifers and 16 *vs* 13% in cows), but total embryo losses were similar for heifers and cows (26 and 25%).

Cow performance. The 60% of recipient females in which both embryos survived tended to be heavier at conception than those losing one embryo in both heifers (5%) and cows (13%); but wt gain during gestation was

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[2]Full report of this work by Pedro Guerra-Martinez. 1986. Potential effect of twinning on efficiency of meat and milk production in beef cattle. M.S. Thesis, Univ. Nebraska-Libr., 181 pp.

Table 1—Pregnancy and calving rates plus embryo and calf survival from bilateral embryo transfers

	Heifers			Cows		
Traits	Single	Twin	All	Single	Twin	All
No. recipient females			241			84
No. pregnant	66	98	164	15	47	62
%[a]	27.4	40.7	68.1	17.9	55.9	73.8
No. calved	59	88	147	23	37	60
%[a]	24.5	36.5	61.0	27.4	44.0	71.4
No. dystocia	22	19	41	2	4	6
%[b]	37.4	21.6	27.9	8.7	10.8	10.0
No. retained placenta	7	31	38	0	9	9
%[b]	11.8	35.2	25.8	0	24.3	15.0
No. fetuses	66	196	262	15	94	109
Abortions, %[c]	3.0	4.3	3.8	0	0	0
Other fetal loss, %[c]	---	---	6.5	---	---	11.0
No. calves born	59	176	235	23	74	97
Stillborn, %[d]	3.4	7.9	6.8	8.7	5.4	6.2
Early mortality, %[d]	8.5	11.9	11.1	4.3	10.8	9.3
Total lost fetuses, %[c]	---	---	26.3	---	---	24.8

[a]Of all recipient females.
[b]Of all females calving in each parity and type of birth.
[c]Of total fetuses at 45 to 60 days, in each parity and type of pregnancy.
[d]Of all calves born for each parity and type of birth.

less for twin bearing females, and wt after calving differed little between twin and single pregnancies (Table 2). During the last trimester of pregnancy, metabolizable energy (ME) intake was actually 5 or 6% less for twin than for single-bearing females, presumably because of reduced rumen capacity. But the requirements for twin fetuses increased by 53% in heifers and 70% in cows. Thus, the twin bearing females lost empty body wt (energy stores) during late pregnancy in order to supply their total energy requirements. Use of higher energy feed could prevent this loss of body energy stores. Total 180-day milk yield was higher for twins than singles by 29% in heifers and 21% in cows. However, both heifers and cows nursing twins were able to increase their feed intake enough (6 and 17%) to meet the increased lactation requirements (23 and 49%) and still maintain body wt. The interval from calving to first ovulation was lengthened after twin births in 1977. However, this delayed conception only in heifers, and the increase in calving interval in 1977 and 1978 data was only 1 or 2 wk and not statistically reliable.

Calf performance. Calf birth weights were lower for twins than for singles by about 15% for heifers and 11% for cows, as expected from the smaller body size of heifers (Table 3). Preweaning gains also were lower for twins than singles of both sexes, by about 18% in wt but by only 3 or 4% in growth as percentage of wt (relative growth). Weights at 180-day weaning were 17 to 18% lighter for twins than singles. During the 220-day feedlot period in 1977, twin calves gained as much wt as singles but about 11% faster relative to their size. Twins were still 9% lighter at 400 days, but their feed cost per lb of gain was about 5% less.

Table 2—Performance of twin (T) *vs* single (S) calving heifers and cows[a]

	Heifers		Cows	
Traits	S	T/S,%	S	T/S,%
Gestation period:				
Wt at conception, lb[b]	740	105	890	113
Gestation wt gain, lb/day[b]	.73	88	.53	67
Wt after calving, lb[b]	944	101	1,036	106
Gestation length, day	280	99	280	99
Last trimester:				
Change in empty body wt, lb/day	.01	-7,300	.20	-631
ME intake/kg$^{.75}$, Kcal/day	187	94	179	95
ME maintenance/kg$^{.75}$, Kcal/day	144	95	135	118
ME, pregnancy/kg$^{.75}$, Kcal/day	44	153	38	170
(MEI-MEM-MEP)/kg$^{.75}$, Kcal/day	-1	2,800	6	-900
Lactation, 180 days:				
Wt gain, lb/day	1.01	104	.79	105
Wt at weaning, lb	1,148	101	1,204	104
ME intake/kg$^{.75}$, Kcal/day	289	106	264	117
ME maintenance/kg$^{.75}$, Kcal/day	193	100	196	102
ME lactation/kg$^{.75}$, Kcal/day	71	123	57	149
(MEI-MEM-MEL)/kg$^{.75}$, Kcal/day	25	108	11	209
Total milk yield, lb	1,233	129	1,075	121
Peak milk yield, lb/day	19.4	130	17.9	115
Persistency, total/peak	132	101	128	96
Calving to 1st ovulation, day[c]	50	134	62	113
Calving to conception, day[d]	68	128	88	98
Calving interval, day[c]	356	102	368	105

[a]Data from all females calving, 1977 through 1980, except as noted.
[b]Data from 159 calvings in 1977 through 1979.
[c]Data from 56 females calving in 1977.
[d]Data from 83 females calving in 1977 and 1978.

Table 3—Performance of twin (T) and single (S) calves from heifers and cows, by sex of calf[a]

		Males		Females		All
Traits	Dam	S	T/S,%	S	T/S,%	T/S,%
Wt at birth,	heifer	75.0	82	59.9	88	85
lb,	cow	59.7	94	74.3	83	89
Preweaning 180 days:						
Wt gain, lb/day	heifer	1.92	82	1.83	81	81
	cow	2.09	83	2.01	82	83
Relative growth, %/day	heifer	.77	97	.82	94	96
	cow	.82	94	.79	100	97
180-day wt, lb	heifer	420	82	401	82	82
	cow	454	84	434	83	83
Postweaning 220 days:						
Wt gain, lb/day		2.80	95	2.27	106	100
Relative growth, %/day		.37	111	.35	111	111
Feed/gain, lb/lb		6.4	97	6.7	94	95
400-day wt, lb		1,071	87	899	96	91

[a]For 272 calves from 1977 through 1980, except postweaning feedlot data for only 60 calves from 1977.

In 1978 to 1980, calves were grown on forage for 170 days before a 140-day period in the feedlot. During the 170-day "backgrounding" period, twins gained wt 18% faster than singles, which averaged 36% faster in growth relative to their smaller size (Table 4). Thus at 350 days of age, the twins were only 9 or 10% lighter than singles. During the 140-day feedlot period, twins gained about 5% less in wt but at about the same rate relative to their size, with final 490-day weights only 8 or 9% below the single calves. Twins required 5% less feed/gain in the feedlot for heifers but no less for steers. The "compensatory gain" advantage in efficiency of growth for twins occurred during the 170-day backgrounding period, when feed intake was not measured.

Input/output efficiency. The foregoing effects of twin *vs* single calving on cow and calf performance and on feed and other inputs were used to predict net effects on input/output efficiency of beef production for a herd at age equilibrium producing all twin *vs* all single births. The assumptions used concerning prices for feed, labor, veterinarian , and other inputs, and the increase in non-feed costs for managing a twin *vs* a single calving herd are somewhat arbitrary for the example shown in Table 5. However, the assumed 40% increase in non-feed inputs per cow for a twinning herd seemed adequate to avoid overestimating potential effects on efficiency.

For marketing calves at 180-day weaning, the twinning increase in cow inputs would be 11% in feed, 32% in other, and 20% in total. Increase in outputs would be 79% in weaned calves sold, 11% in cull cow sales, and 56% in total wt output of weaned calf equivalent. Since increase in output exceeded that for input, the net effect was reduced total input/output (120/156 or 77%). The reduction in cost/lb output was greater for feed (29%) than for non-feed (15%) inputs and 23% for total inputs.

For an integrated cow-calf feedlot production system, increase in cow inputs would be the same, but feedlot inputs would more than double. Output of 400-day-old slaughter cattle would nearly double (97%), but cull cow output would still increase only 11%. In such an integrated operation, the reduction in cost/lb of output would be only slightly greater for feed (26%) than for non-feed (20%) inputs. The net effect would be a 24% reduction (136/178 or 76%) in input cost per lb of slaughter animal equivalent marketed.

Conclusions

Although more information is needed, these results suggest that input costs per unit of beef output could be reduced 20 to 30% for that proportion of a herd producing twin instead of single calves. The frequency of twin births would need to be large enough to justify identification of twin bearing cows in mid-pregnancy and providing the additional feed and management required.

Table 4—Postweaning performance of 208 twin (T) and single (S) calves during backgrounding (180 to 370 day) and feedlot (370 to 490 day) periods

	Steers		Heifers	
Trait	S	T/S,%	S	T/S,%
180 to 350 days:				
Wt gain, lb/day	.67	118	.66	118
Relative growth, %/day	.139	133	.142	139
350-day wt, lb	543	91	516	90
350 to 490 days:				
Wt gain, lb/day	3.51	93	3.20	97
Relative growth, %/day	.43	100	40	107
490-day wt, lb	1,014	91	935	92
Feed/gain lb/lb	5.85	100	6.19	95

Table 5—Predicted herd input/output ($/lb) *per cow calving* for 100% twin (T) *vs* single (S) births and marketing calves at 180 or at 400 days of age[a]

	180-day marketing		400-day marketing	
Variable	S	T/S,%	S	T/S,%
Inputs ($)				
Cow — feed	246	111	246	111
— other	175	132	175	132
— all	422	120	422	120
Feedlot — feed	---	---	70	203
— other	---	---	30	210
Totals — feed	---	---	316	132
— other	---	---	205	143
— all	---	---	522	136
Outputs (lb)				
Calves sold	289	179	638	197
Cull cows (calf equivalent)	151	111	174	111
Total	440	156	812	178
Cost/lb output ($)				
Feed	.56	71	.39	74
Other	.39	85	.25	80
Total	.95	77	.64	76

[a]Assuming feed costs per lb of 1.36¢ for oat hay or mineral supplement, 1.81¢ for oat + alfalfa hay, 2.72¢ for feedlot diet; non-feed costs of $109.75/cow for single births, 40% more for twins, plus 10% for overhead costs; age equilibrium; replacement rates of 19.5, 21.0, 22.9, and 24.0% for heifer S and T and cow S and T, respectively; $333.50 cost/replacement from weaning to breeding age; cow mortality of 2% for S and 2.5% for T, calf mortality for S *vs* T of 11.8 *vs* 19.9% from heifers and 13.0 *vs* 16.2% from cows; cull cows valued at 65% of weaned calves or 75% of slaughter calves, per 100 lb.

Effects of Dietary Energy Density on Carcass Composition and Beef Palatability Characteristics

Gary L. Bennett[1]

Introduction

Currently there is increased emphasis on production of lean beef with desirable palatability characteristics. Changes in both the type of animal produced and the feeding and management of these animals may be needed to efficiently produce this product. One change in feeding that could be made is the energy density of the feed, measured as megacalories of metabolizable energy per pound (Mcal ME/lb). At low energy densities, the amount of feed that can be consumed limits the animal's intake of metabolizable energy.

Over the past two decades, several experiments at MARC have examined a number of factors, including energy density, that can affect carcass composition and palatability. The purpose of this report is to review these experiments and summarize the effects of energy density on carcass composition and palatability traits.

Experiments

Essential features of seven experiments comparing effects of dietary energy on carcass composition or meat palatability are shown in Table 1. More than 1,800 cattle were used in the seven experiments. Energy densities ranged from 1.09 Mcal ME/lb (77% corn silage, 20% alfalfa haylage) to 1.45 Mcal ME/lb (83% corn, 11% corn silage). Energy density was varied primarily by changing the proportions of corn silage and either corn or other grain. Most cattle used were steers. Several experiments used breeds with a range in mature size. This allowed the researchers to see if the effects of energy density were the same for different growth potentials.

Results

Percentage differences in daily wt gain, daily feed intake, and feed conversion (lb of feed per lb of gain) between the highest and lowest energy density rations are shown in Table 2. Higher energy rations resulted in higher rates of gain in every experiment. Higher energy rations also tended to increase daily intake of ME and reduce the lb of feed needed per lb of gain. Results from one experiment (VII) suggested that larger type cattle increased growth rate and ME intake more than smaller types when energy density was increased, while results from another (II) suggested the opposite.

Carcass measurements were compared at equal carcass wt, equal time on feed, or at equal percentage fat in the rib section (Table 3). Higher energy rations resulted in higher percentages of fat in the rib or greater fat depth when compared at either the same carcass wt or days on feed. Experiment VII compared carcasses at the same percentage of fat in the rib section and showed that carcasses from higher energy rations were lighter, while experiment VI showed no difference in carcass wt. Higher

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Table 1—Essential features of seven experiments comparing energy densities of rations

	Experiments						
	I[a]	II[b]	III[c]	IV[c]	V[c]	VI[d]	VII[e]
No. animals	387	150	385	444	248	72	162
Breeds or mature sizes	Small Large	Hereford X Angus, Chianina, Charolais	Small Medium Large	Small Large	Small	Red Poll, Chianina & Gelbvieh crosses	Angus Simmental
Sex	steers	steers	steers	steers	steers	steers	steers bulls
Initial age, mo	8.5	8.5	post-weaning	post-weaning	post-weaning		8.0
Initial wt, lb	567	586	456	505	536	689	
Days on feed	266-315	232-308	244	287	194	174-238	270
Energy densities, Mcal ME/lb	1.09 1.29	1.32 1.41 1.45	1.21 1.26 1.33	1.22 1.33	1.26 1.31 1.34	1.26 1.44	1.14 1.37
Variable ration components	Corn & corn silage	Corn & corn silage	Grain & corn silage	Grain & corn silage	Grain & corn silage	Corn & corn silage	Corn & corn silage

[a]Smith, G. M., J. D. Crouse, R. W. Mandigo and K. L.Neer. 1977. J. Anim. Sci. 45:236-253.
[b]Prior, R. L., R. H. Kohlmeier, L. V. Cundiff, M. E. Dikeman and J. D. Crouse. 1977. J. Anim. Sci. 45:132-146.
[c]Ferrell, C. L., R. H. Kohlmeier, J. D. Crouse and H. Glimp. 1978. J. Anim. Sci. 45:255-270.
[d]Ferrell, C. L., and J. D. Crouse. 1978. J. Anim. Sci. 47:1167-1173.
[e]Crouse, J. D., C. L. Ferrell and L. V. Cundiff. 1985. J. Anim. Sci. 60:1219-1227 and Crouse, J. D., H. R. Cross and S. C. Seideman. 1985. J. Anim. Sci. 60:1228-1234.

Table 2—Percentage differences in daily gain, daily intake of ME, and feed conversion between the highest and lowest energy densities

	Experiment[a]						
	I	II	III	IV	V	VI	VII
Avg daily gain	16	14	10	13	8	9	16
Daily ME intake	29	5	20	2	4	12	25
Feed/Gain	-5	-9	0	-18	-9	-9	-9

[a]See Table 1.

Table 3—Percentage differences in carcass measurements and retail yields between highest and lowest energy densities

Experiment[a]	Measured at equal	Measurement	High-low, %	Measurement	High-low, %
I	Wt	Rib fat %	14	Retail prod. %	-5
II	Wt	Rib fat %	8	Retail prod. %	-3
III	Days	Fat thk	20	Est. cutability	-3
IV	Days	Rib fat %	16	Est. cutability	-4
V	Wt	Rib fat %	8	Est. cutability	-2
VI	Rib fat %			Carcass wt	0
VII	Rib fat %			Carcass wt	-2

[a]See Table 1.

Table 4—Differences in carcass quality traits and taste panel scores between the highest and lowest energy densities

	Experiment[a]		
	I	II	VII
Compared at equal:	Wt	Days	Rib fat %
Marbling[b]	.7	2.3	.8
Mechanical tenderness[c]	-.4	.1	.4
Taste panel tenderness[d]	.1	.0	-.3
Taste panel juiciness[d]	.0	.0	-.1

[a]See Table 1.
[b]A difference of 1 equals ⅓ of a degree of marbling.
[c]Warner-Bratzler shear force.
[d]Score 1 to 7 (I & II) or 1 to 8 (VII); higher scores are more desirable.

energy density resulted in lower percentage of trimmed retail product or estimated cutability (experiments I, II, III, IV, V).

Experiment I also compared deferred feeding to putting cattle directly into the feedlot. These cattle were fed a low energy ration (0.99 Mcal ME/lb) for 134 days, grazed for 134 days, and then fed higher energy rations in the feedlot. The deferred cattle had 5 to 10% more retail product than steers put directly into the feedlot when compared at the same carcass wt.

Sequential slaughter dates and analyses of experiments I and II allowed for interpretation of changes in trimmed retail weights. In experiment I, the gain in trimmed retail wt was .57 lb/day for the lowest energy density and .60 lb/day for the highest energy density. The difference in carcass growth rate was much greater than this and leads to the conclusion that much of the increased growth rate was due to faster deposition of fat. In experiment II, the avg difference of 60 lb soft tissue wt between carcasses from high and low energy rations was composed of 49 lb fat and only 11 lb protein and water. This result also suggests that much of the increase in growth rate from high energy rations is due to additional increase in fat. Experiments III and IV, evaluated at the same number of days on feed, also showed little difference in nonfat carcass wt between higher and lower density rations.

Taste panel scores and mechanical tenderness of beef were evaluated in three of the experiments (Table 4). There was little difference in taste panel scores or tenderness of beef produced by high and low energy density rations. When compared at the same age, beef produced on high energy rations had higher marbling, but this did not correlate with better taste panel scores.

Discussion

It is clear from these experiments that increased energy density of a ration resulted in faster growth rate. It also appeared that a disproportionate amount of this extra growth is fat and not retail meat. However, a large proportion of carcass wt gain is fat even when lower energy rations are fed. Experiments need to be conducted with large numbers of cattle in order to consistently detect this difference. Taste panel scores of beef produced from lower energy rations were not different from those fed higher energy rations, if the lower energy rations did not greatly restrict change in weight of retail meat.

The pricing of beef carcasses and grain will ultimately be the determining factor in deciding the energy density of rations. Lower energy densities will be economically viable when payment is based on retail product wt rather than on carcass wt. Pricing of the carcasses is an important consideration because increasing the energy density of rations in these experiments increased carcass wt but did not appreciably increase wt of retail product.

Current work in the Production Systems Unit is directed toward incorporating results from several areas of research into computer simulation models of growth, carcass composition, and palatability. Computer models will then be used to determine the best ways to efficiently produce lean beef with desirable eating characteristics.

Breed and Heterosis Utilization in Rotational and Composite Crosses

Gary L. Bennett and Michael D. MacNeil[1,2]

Introduction

Rotational crossbreeding systems breed heifers sired by one breed to bulls from another breed. Heifer offspring are then bred to the next breed in the rotation, etc. Composite systems result in a "new" breed consisting of fixed proportions of "old" breeds. Both systems produce their own replacement heifers rather than requiring the purchase of F_1 heifers or special matings. Both systems have potential advantages for producers of slaughter beef because a high level of heterosis (hybrid vigor) is present in cows and calves. High levels of heterosis increase efficiency and reduce the cost of producing beef.

The level of heterosis in rotational crossbreeding systems and composites increases as the number of breeds increases. All available breeds would be used if the level of heterosis was the only factor considered. However, not all breeds are equally efficient in a given beef production situation. A producer with a straightbred herd should use the most efficient breed. Likewise, the two breeds with highest efficiency would generally be used in a two-breed rotation or composite, the three best breeds in a three-breed rotation or composite, etc. Increasing the number of breeds has the advantage of increased heterosis, but at the cost of decreased average efficiency of the breeds in the rotations or composites.

Two problems may arise in adapting rotational crossbreeding systems to farm and ranch management. Bulls from all breeds in the rotation will need to be available each yr so that cows can be bred to the appropriate breed. Also, cows will need to be identified for their breed of sire so that the next breed they are bred to is known. These conditions are not too restrictive when artificial insemination is used. However, only one or two bulls may be needed by small herds using natural service sires. This makes it costly to maintain extra bulls and breeding pastures. In extensive production situations, identification and sorting of cows and having extra breeding pastures available can pose management problems, making it difficult to use rotational crossbreeding.

[1]Bennett is a research geneticist and MacNeil is a research animal scientist, Production Systems Unit, MARC.

[2]The full report of this work was published in J. Anim. Sci. 65:1471-1476, 65:1477-1486, 65:1487-1494, 1987; and Theor. Applied Genet. 74:837-840, 1987.

Results

Rotational and composite crossbreeding systems that use some breeds proportionately more than others were studied as a way of using higher percentages of genes from better breeds. Examples of the first ten generations of some of these types of rotations are shown in Table 1. The capital letters A, B, and C represent three arbitrary breeds. The shortest repeatable sequence, or cycle, of sire breeds is used to identify each of the rotations. For instance, AB and ABC identify conventional two- and three-breed rotations.

Illustrated in Figure 1 is the average level of heterosis for each of the rotations defined in Table 1 and the conventional two- and three-breed rotations. Also shown is the percentage of genes from each breed averaged over a cycle. It is easy to see that the avg percentage of genes from a breed can be varied from as little as 25 to as much as 75 in two-breed rotations, and from as little as 17 to as much as 60 in three-breed rotations. Of course, heterosis is greatest when each breed is used equally in conventional two- and three-breed (AB and ABC) rotations. Similarly, the amount of heterosis in a composite with the same breed percentages as the rotations is shown in Figure 1.

Increasing the percentage of genes from the best breed can sometimes be an advantage even though it results in less heterosis. Important reasons for deciding when to increase the use of a breed in a rotation or composite are (1) the differences between breeds in life-cycle efficiency of beef production, and (2) the effect of

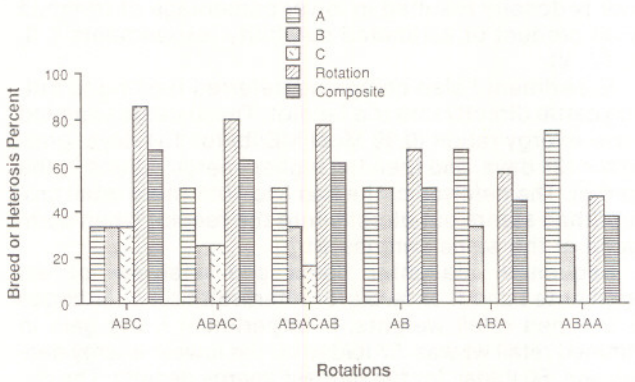

Figure 1—Average heterosis and breed percentages for several rotations and heterosis for a composite of the same breed percentages.

Table 1—Sire breed use by generation in rotations that use breeds unequally. Capital letters A, B, and C represent three arbitrary breeds. An '*' marks the end of each complete cycle

Rotation designation	Generations											
	1	2	3	4	5	6	7	8	9	10	11	12
ABA	A	B	A *	A	B	A *	A	B	A *	A	B	A *
ABAA	A	B	A	A *	A	B	A	A *	A	B	A	A *
ABAC	A	B	A	C *	A	B	A	C *	A	B	A	C *
ABACA	A	B	A	C	A *	A	B	A	C	A *	A	B
ABACAB	A	B	A	C	A	B *	A	B	A	C	A	B *

heterosis on efficiency. The ratio of breed differences to heterosis effect for efficiency can be used to determine rules for selecting among the rotations. If this ratio is less than .6 for two breeds, then the best two-breed rotation is the conventional two-breed (AB) rotation. If this ratio falls between .6 and 1.2, then an ABA rotation (A being the better breed for efficiency) is best. An ABAA rotation is best if the ratio falls between 1.2 and 1.8. Straightbred A would be better than any of the two-breed rotations when the ratio exceeds 1.8. Similarly, only one set of breed percentages maximizes the efficiency of composites for any given set of breed differences. Figure 2 shows the relative differences among some two- and three-breed rotations and optimal composites for three sets of differences among the three breeds. When these differences are small, the best rotation uses the three breeds equally (ABC), and there are similar percentages of each breed in the optimal composite. As breed differences increase relative to heterosis, ABAC and ABACAB rotations and composites that reduce the percentages of the less efficient breeds (B and C) are more efficient than conventional rotations and composites.

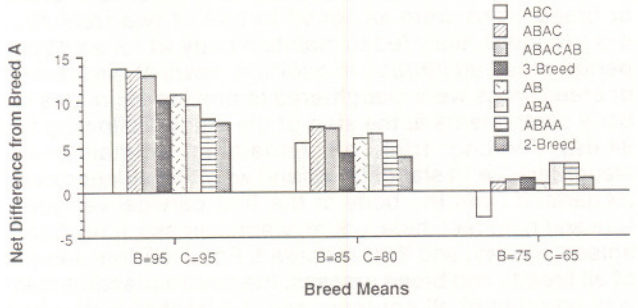

Figure 2—Differences among two- and three-breed rotations and optimal composites relative to breeds A, B, and C. Heterosis is assumed equal to 20 and breed A is assumed equal to 100.

The previous results assume that cows were correctly identified for the breed of their sire and that cows were always mated to the next breed in the rotation. Small herd size and other management constraints often make this impossible for rotations, but not for composites. It does seem likely that the bull breed could be rotated regularly, ignoring the breed of the cows, in almost all management situations. In small herds, a convenient management scheme is to replace bulls after 2 yr of use. This prevents the occurrence of close inbreeding. Only rotating the breed of sire does not change the percentage of genes from each breed compared to a full rotation. However, heterosis will not be as high as a full rotation of sire and dam breeds. Figure 3 shows the amount of heterosis expected from a full rotation of bull and cow breeds compared with a rotation of sire breeds, and with composites of the same breed percentages. It is assumed that a bull in the sire-breed rotation is used for 2 yr and then replaced with a bull from the next breed in the rotation. Sire-breed rotations reduced heterosis by 3 to 13% compared to full rotations. This loss of heterosis needs to be weighed against the costs and feasibility of using a full rotation. In either case, substantial amounts of heterosis can be maintained by two- and three-breed rotations. Sire-breed rotations maintain more heterosis than composites of the same breed proportions. However, this comparison does not include the absence of heterosis in herds needed to produce purebred bulls for rotations.

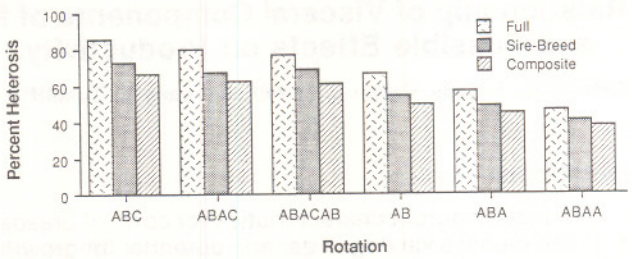

Figure 3—Expected heterosis when a full rotation of bull and cow breeds is used, when only bull breeds are rotated, and for composites of the same breed percentages.

Rotations to produce replacement heifers combined with the use of a bull breed with high growth rate and desirable carcass qualities on older cows has previously been suggested as a method of increasing efficiency of producing beef. This method can combine desirable qualities from breeds with good reproduction and desirable qualities from breeds with high growth rate and desirable carcass composition. The management of these systems can be simplified by rotating only the bull breed to produce the replacement heifer. Four breeds of bulls need to be available each yr to use a full three-breed rotation for replacement heifers and terminal breed to produce slaughter beef. Use of sire-breed rotations or composites to produce replacement heifers and mating excess cows to a terminal breed results in only two bull breeds needed each yr. Furthermore, replacement heifers only need to be identified by yr of birth if the terminal breed color or pattern marks their calves. This modification of the rotational-terminal crossbreeding system not only is simpler to use, but also allows the system to be used in smaller herds needing only two bulls. Figure 4 shows the percentages of heterosis for cows and calves in composite- or rotational-terminal systems breeding cows 5 yr and older to a terminal breed. Differences between full and sire-breed rotations range from 13 to 5% heterosis for cows and from 7 to 3% heterosis for calves. Differences between composites and full rotations range from 17 to 20% heterosis for cows and from 10 to 11% heterosis for calves.

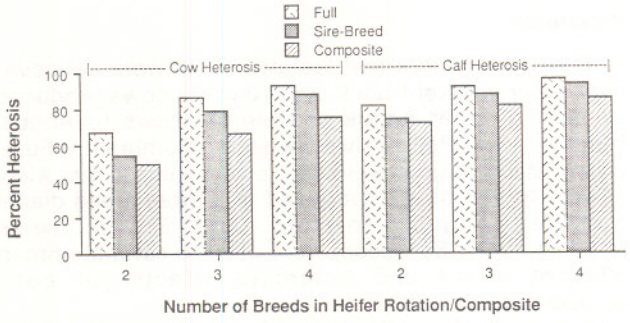

Figure 4—Percentage of heterosis for cows and calves when full rotations, sire-breed rotations, or composites of two, three, or four breeds are used to produce replacement heifers and a terminal breed is mated to cows 5 or more yr of age.

Conclusions

Composites and rotations offer ways to make optimal use of breed differences and heterosis. When herd size or management practices make a full rotation unfeasible, sire-breed rotations and composites can still make good use of breed differences and heterosis to improve the efficiency of beef production.

Relationship of Visceral Components of Mature Cows as Related to Lactation Potential and Possible Effects on Productivity

Thomas G. Jenkins, Calvin L. Ferrell, and Larry V. Cundiff[1,2]

Introduction

Production output characteristics for cows of breeds or breed crosses varying in genetic potential for growth rate, mature size, and lactation have been previously reported. These differences among breeds were reported for characteristics associated with output potential (e.g., gestation length, calving difficulty, calf crop weaned, and for wt at birth, weaning, and at puberty). We have reported differences among nonpregnant, nonlactating mature cows of breed crosses varying in genetic potential for mature size and lactation yield for dry matter required for weight stasis and metabolizable energy (ME) required for zero body energy change. We have reported significant differences among various breed crosses for energetic efficiency (wt gain of the calf/total ME intake of the cow and calf) during a 138-day lactation period, thus documenting the need for consideration of variation in energy requirements among germ plasm resources that vary in mature size or lactation yield potential.

Variation exists among breeds of beef cattle in energy requirements for maintenance or fasting heat production during the postweaning interval. The trend observed in reviewing this literature was that a positive relationship appears to exist between genetic potential for rate of postweaning avg daily gain and fasting heat production. Researchers have reported that rate of gain as mediated through dietary energy intake affected fasting heat production (maintenance) and mass of metabolically active organs such as the liver, empty gastrointestinal tract, and the kidneys. The relationships between visceral organs and postweaning avg daily gain was documented with rams of similar genetic potential for growth receiving feed *ad libitum*. Results from this study indicated that the rate of protein accretion for an aggregate of the visceral components such as the gastrointestinal tract, kidneys, and liver was most closely related to the rate of gain.

Procedure

Body component and lactation data were collected over a 2-yr interval from 9- and 10-yr-old cows produced by mating either Angus or Hereford cows to Angus, Hereford, Red Poll, Brown Swiss (predominantly European), Maine-Anjou, Gelbvieh, or Chianina sires. Also, cows 6 to 9 yr of age produced in a three-breed diallel involving Angus, Hereford, and Brown Swiss (predominantly European) were used to estimate breed additive direct and heterosis effects for body components.

Lactation information was collected by weigh-suckle-weigh techniques at 6-wk intervals from approximately 10 days postpartum until the calves were weaned at approximately 200 days of age. In an open-front poleshed, cows and calves were maintained in small pens with concrete flooring during the trial. At the time of measurement, 24-hr milk production was estimated by separating each calf from its dam for approximately 16 hr, weighing the calf, allowing the calf to suckle for approximately 45 min, then reweighing the calf. Calves remained separated from the dams for an additional 7 hr, then the procedure was repeated. The sum of the differences between the presuckling and postsuckling calf wt from each suckling event was used as an estimate of the 24-hr milk yield. This was used to estimate parameters descriptive of lactation curves and to predict time of peak lactation, milk yield at time of peak lactation, and total yield of milk for individual cows during the lactation following procedures reported previously. During the lactation period, cows were individually fed to maintain body wt.

Following weaning, representative cows of each breed or breed cross were assigned to one of two treatment groups: individually fed to maintain body wt for an 84-day period or fed *ad libitum*. In addition, cows of each breed or breed cross were slaughtered to provide estimates for body components at the start of the study. Following the 84-day feeding trial, all remaining animals were slaughtered with slaughter wt and wt of the skinned head (separated from the body at the first cervical vertebra), fore and hind feet, hide, udder, warm carcass, lung, heart, spleen, kidney, and liver recorded. For a random sample of all breeds and breed crosses, the gastrointestinal tract was emptied of all contents and the tract and attached mesenteric fat were weighed. Components of the body for individual cows were expressed relative to slaughter wt for analysis.

Results

Lactation performance. Significant differences attributable to the effect of breed or breed cross were observed for total yield of milk during the lactation period and for milk yield at time of peak lactation. Mean lactation curves for each breed and breed cross are presented in Figures 1 and 2, respectively. Among the straightbreds, the Brown Swiss had a greater total milk yield and daily yield at time of peak lactation. Herefords had the lowest yield for both traits, with the Angus intermediate. The Angus x Hereford (reciprocal crosses pooled) and Chianina-x (x denotes Hereford and Angus dams combined) had earlier peak yields and lower total milk yield than the Brown Swiss-x, Gelbvieh-x, and Maine-Anjou-x. Although not measured directly, the decline in lactation appeared to be greater for the breed or breed crosses with relatively high total milk yield than for breeds or breed crosses with lower total milk yield, which is consistent with observations previously reported. Time of peak lactation ranged from 8.2 to 9.4 wk but was not significantly affected by breed or breed cross.

Body components. The effect of breed or breed cross was significant for body components relative to slaughter wt (Table 1). Breeds or breed crosses that had higher levels of total milk production or daily yield at time of peak lactation tended to have higher percentages of visceral organs. Among the breed crosses, the correlations between the breed cross means for percentages of

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[2]The full report of this work was published in Anim. Prod. 43:245-254, 1986.

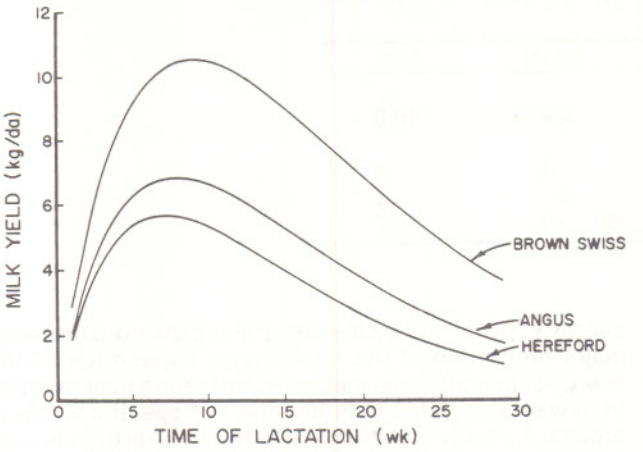

Figure 1—Lactation curves for mature straightbred Angus, Brown Swiss, and Hereford.

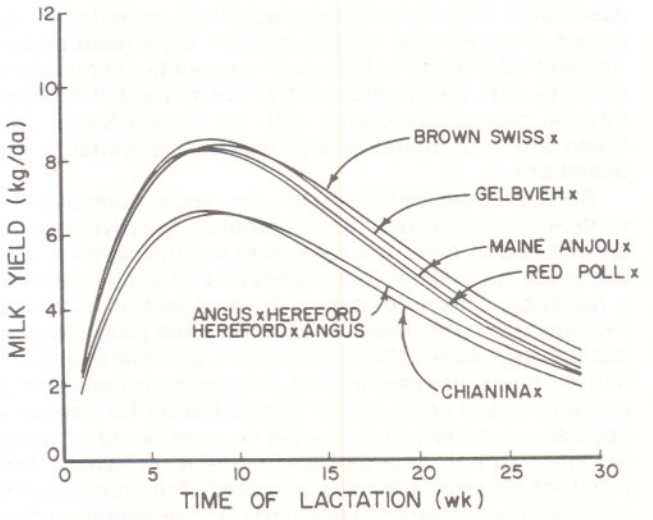

Figure 2—Lactation curves for mature crossbred cows that were produced by mating Angus, Brown Swiss, Chianina, Gelbvieh, Hereford, Maine-Anjou, and Red Poll sires to either Angus or Hereford dams.

lung, heart, spleen, kidney, and liver with breed means for milk yield were .79, .49, .69, .51, and .52, respectively. This provides an indication that a greater fraction of visceral components is associated with higher levels of milk production.

Estimates of direct and heterosis effects. Differences in body components among Angus, Hereford, Brown Swiss, and crosses among these breeds were observed for all visceral organs reported (Table 2). Among the straightbreds, the Brown Swiss had a greater relative amount of liver and lung compared with the Angus and Hereford. In general, the Hereford tended to have the smallest relative amounts of internal organs.

The least-squares means for the relative amounts of visceral components of the breeds and breed crosses were partitioned to estimate the purebred mean, breed direct, and average direct heterosis. Compared with the purebreds, the crossbred animals had a significantly larger proportion of lung tissues. The fraction of all other body components relative to shrunk slaughter wt for the crossbred was similar to the straightbred animals. These findings of limited heterosis effects upon the proportion of visceral components in cattle have not been previously reported.

For breed transmitted effects, the Brown Swiss had a greater relative effect for proportion of lung, heart, and spleen. Relative to other breeds, Hereford transmitted direct effects for the internal organs tended to be negative and differed from the other two breeds.

Discussion

Typically information regarding body components, especially internal organs, has been discussed in relation to the effect on carcass yield of animals slaughtered. In the following discussion, it is postulated that the proportion of body components may serve as an index for variation in energy requirements among cattle germ plasm resources that differ in production potential. Direct evidence for variation among breeds or breed crosses in energy requirements for maintenance of growing animals is available. Results from research involving mature females of beef breeds is somewhat conflicting, with some researchers citing no differences among breeds or breed crosses for maintenance while others have reported differences in metabolizable energy to maintain body mass or energy balance in mature cows differing in genetic potential for mature size and level of milk production.

Table 1—Means for percentages of specific visceral organs of mature cows[a]

	N	Slaughter wt (lb)	Lung	Heart	Spleen	Kidney	Liver
Breed crosses							
Angus x Hereford	25	1,188	5.3	4.5	1.4	2.2	10.0
Red Poll x A/H	30	1,093	5.7	4.7	1.4	2.5	10.6
Brown Swiss x A/H	31	1,135	5.9	5.0	1.6	2.5	10.7
Gelbvieh x A/H	31	1,166	5.6	4.7	1.5	2.3	10.1
Maine-Anjou x A/H	30	1,278	5.7	4.6	1.4	2.2	9.6
Chianina x A/H	29	1,247	5.5	4.7	1.4	2.2	9.7
Breeds							
Angus	14	1,082	6.3	5.1	1.7	2.5	11.7
Brown Swiss	14	1,153	7.7	5.0	1.3	2.6	11.0
Hereford	13	1,115	5.5	4.6	1.4	2.2	9.7

[a]Relative to fasted slaughter wt.

Table 2—Heterosis and transmitted direct effects for percentage of specific visceral organs of mature cows[a]

	Lung	Heart	Spleen	Kidney	Liver
Transmitted					
Purebred mean	6.4	4.9	1.5	2.4	10.8
Direct effect					
Angus	-.1	-.1	-.1	.1	.4
Brown Swiss	.5	.2	.2	0	.3
Hereford	-.4	-.1	-.1	-.1	-.7

[a]Relative to shrunk slaughter wt.

Data collected from nonlactating, mature dry cows receiving feed *ad libitum* to delineate the relationship of milk yield and size potential upon maintenance as indexed by the liver does not consider the change in the relative amounts of internal organs with varying physiological state (e.g., gestation and lactation). Researchers have reported that the relative wt of the liver is greater in lactating rats than nonlactating rats and that higher maintenance requirements were observed for lactating Hereford cattle when compared to nonlactating Herefords. Evidence suggests that, as level of performance increases, energy expenditure for maintenance increases, as does the relative amount of visceral organs.

Previous discussion by some researchers with regard to the appropriate mating system has indicated that profitability of the livestock enterprise may be defined as a function of reproductivity and productivity, where the former term is a characteristic of the dam and the latter term, the characteristics of the offspring. Other researchers described the commodity of a livestock enterprise as output and indicated that, for a cattle enterprise, output may be increased by developing mating systems that exploit the genetic diversity among cattle germ plasm resources for output characteristics within defined production environments. These approaches recognize that some germ plasm resources are more suitable for use as a maternal population while others are more suitable for use as a paternal population (one to transmit desired growth characteristics to the progeny to be marketed). For maternal populations, both approaches appear to suggest that the decision of the appropriateness of a population for use in the maternal role may be based primarily upon high levels of output (e.g., weaning wt). However, the energy requirements for maintenance of a producing female constitutes a major proportion of the energy expenditure of life-cycle animal production. Therefore, variation among germ plasm resources and the ability to modify energy requirements for maintenance need to be considered when developing mating systems.

The present study suggests that intrinsic differences exist among breeds or breed crosses for some of the empty body components and that these differences are transmitted. It has been previously demonstrated that the energy expenditure by the visceral organs constitutes a major proportion of the total energy expenditure. This energy expenditure (as measured by fasting heat production) was associated with the mass of specific visceral organs. A positive relationship between level of milk production and proportion of lung, kidney, and liver tissue is indicated in the present study. This evidence suggests that, as genetic potential for level of performance (e.g., milk production) increases, energy requirements associated with maintenance would be expected to increase. Furthermore, results indicate significant breed-transmitted effects for the relative amounts of body components, with the largest positive transmitted effects for internal organs associated with the Brown Swiss (the breed with the greater milk production potential in the diallel study).

General consideration. In the above discussion, evidence was provided that metabolically active tissues are affected by breed or breed cross and measures of performance such as daily peak yield and total milk yield for a lactation. This information, in conjunction with the evidence from the literature regarding the proportion of basal energy expenditure associated with metabolically active organs, implies that the production potential of a breed or breed cross under consideration for use as a specialized maternal line should be considered in terms of the nutrient (energy) environment in which the livestock enterprise is to be operated. If the nutrient environment is unrestricted or energy supplementation during period of energy restriction is economically feasible, those maternal germ plasm resources characterized as having greater potential for production may be desirable. However, if females are subjected to extended periods of energy restriction resulting in negative energy balances for extended periods of time, the profitability of an enterprise may be curtailed by a restriction of the reproductive component.

In considering specific breeds or breed crosses for use as specialized maternal lines, information concerning both output and energy requirements needs to be considered. The lack of information from studies designed to evaluate biological interrelationships between output-input characteristics restricts the evaluation of production systems.

Growth and Carcass Traits of Heifers as Affected by Hormonal Treatment

John D. Crouse, Bruce D. Schanbacher, H. Russell Cross, Steven C. Seideman, and Stephen B. Smith[1,2]

Introduction

The beef industry traditionally has discriminated against young heifers in the marketplace when compared with steers. Price discrimination was probably the result of sex effects on fat partitioning and distribution. Also, steers have been observed to be more efficient than heifers in the conversion of feed to carcass weight.

Both testes and ovaries secrete steroids that influence performance traits of cattle. Testosterone appears to stimulate rate of gain and efficiency of feed conversion in the male. Efficiencies of conversion of feed to live-animal weight gains have been less in spayed feedlot heifers than in intact heifers.

It has been suggested that androgens and estrogens are both necessary to realize maximum growth potential. In cattle, the concentration of steroids in blood that results in the fastest growth rates corresponds approximately to a combination of the androgen level in growing bulls and the estrogen level in young heifers. Thus, the optimal treatment should maintain this natural hormone status for as long as possible, preferably several months. If the hypothesis is valid, the greatest benefits would be seen in bulls treated with estrogens, steers treated with an androgen combined with an estrogen, and heifers and cows treated with androgens.

Therefore, the objectives of the investigation were to determine the effects of surgical castration, estradiol immunoneutralization and(or) treatment with an exogenous androgen (trenbolone acetate) on growth, carcass characteristics, and meat palatability of heifers fed in a feedlot.

Procedure

A total of 77 late-maturing, crossbred heifers (Angus or Hereford dams bred to Simmental) or intermediate-maturing crossbred heifers (Hereford x Angus or Angus x Hereford) were randomly assigned within breed type to one of six treatments. Heifers weighed about 440 lb at the initiation of the experiment. Youthful heifers were required to alter hormonal regulation of growth before puberty; therefore, heifers were assigned to treatments before reaching puberty. Animals were fed an 85% total digestible nutrient (NRC, 1982), 10.5% crude protein corn-corn silage diet supplemented with soybean meal and minerals during the finishing phase of the trial. Feed consumption was recorded and animals were weighed, immunized, and(or) implanted at 56-day intervals.

The following treatments were applied to the heifers: group 1—intact heifer controls (C); group 2—ovariectomized heifers; group 3—intact heifers immunized against estradiol conjugated to bovine serum albumin (BSA-E); group 4—intact heifers immunized as in group 3 plus trenbolone acetate (BSA-E + TBA); group 5—intact heifers implanted with trenbolone acetate (TBA); and group 6—ovariectomized heifers implanted with trenbolone acetate (OVX + TBA).

Results

Growth and Performance. Average daily gains (ADG) and quantities of total digestible nutrients (TDN) required per unit of gain for treatments are given in Table 1. Growth and performance treatment means indicate possible results due to treatments, but must be considered tentative because variation among treatment means was not statistically significant. As much as 18 to 22% of variation between treatment means was observed for ADG and TDN/gain, respectively.

The ADG was similar for the C and OVX groups but tended to be less than for other treatments. The BSA-E + TBA treatment seemed to have the greatest rates of gain of liveweight over the feeding trial, as well as the least required amount of TDN per unit of gain of liveweight. The OVX treatment seemed to require the most feed per unit of gain. Results of research are consistent with previous observations. Spayed heifers fed in the feedlot have not performed comparably to intact heifers.

Heifers implanted with TBA tended to have improved rates of gain and efficiency of gain (Table 1). Because trenbolone-treated heifers also possessed less percentage fat of the rib (Table 2), it could be hypothesized that TDN per unit of gain of protein would be significantly greater in the TBA-treated heifers. The experimental design of the present study did not allow this observation to be made, but TDN per unit of gain of protein should be considered in future experimentation.

Immunoneutralization of endogenous estradiol tended to improve ADG of heifers as compared with control or OVX groups. A trend for improved efficiency of gain also was observed.

[1]Crouse is the research leader, Meats Unit, and Schanbacher is a research physiologist, Reproduction Unit, MARC; Cross is a professor of animal science, Texas A&M University (formerly the meats research leader, MARC); Smith is an associate professor of animal science, Texas A&M University (formerly a research chemist, MARC); and Seideman is employed by Bryan Meats, West Point, Mississippi (formerly a research food technologist, MARC).

[2]The full report of this work was published in J. Anim. Sci. 64:1434-1440, 1987.

Table 1—Growth and performance traits of heifers

Trait	Treatment						Residual SD	Probability > F
	Control	OVX	BSA-E	BSA-E + TBA	TBA	OVX-TBA		
No.	14	14	10	9	15	15		
Avg daily gain, lb	2.2	2.2	2.2	2.6	2.2	2.4	.2	.36
TDN/gain[a]	5.69	6.11	5.25	4.99	5.64	5.57	.38	.25

[a]Total digestible nutrients per unit of gain.

Carcass Characteristics. Muscle characteristics evaluated at the 12th rib interface, color, firmness, texture, and maturity were similar among treatment groups. Treatment of heifers with the androgenic hormone TBA did not produce dark-colored meat that has been observed in meat obtained from intact males. Ovariectomy or immunization also had no effect on color or textural characteristics of the lean.

Heifers treated with TBA tended to possess less fat cover, and the OVX-TBA group possessed less fat cover over the 12th rib than the other three groups (Table 2). Trenbolone-treated heifers also possessed less percent fat in the soft tissue of the 9-10-11th rib section than the control group.

Marbling scores did not vary among treatment groups and did not reflect the variation in deposition of rib fat associated with OVX and TBA treatments (Table 2). Observations indicate that TBA may be effective in reducing fat cover of carcasses without decreasing marbling content. Various fat depot sites apparently respond differently to the influences of TBA.

Sensory and Textural Characteristics. Sensory and textural properties of ribeye steaks are given in Table 3. Treatments had no effects on sensory characteristics. Tenderness scores for TBA treatments were very similar to those of the C group. Shear force values also were similar among treatment groups. Therefore, the use of the androgenic hormone, TBA, did not decrease meat tenderness, as commonly observed in meat obtained from intact male cattle. Sensory panel scores for ease of fragmentation and amount of connective tissue support conclusions of overall tenderness values.

Conclusion

Combined BSA-E and TBA tended to be superior to either treatment alone for efficiency of gain and rate of gain. The combined treatment also tended to produce carcasses with greater ribeye areas. Future studies should consider muscle mass or protein deposition per unit of feed as a measure of efficiency. Treatment with androgenic hormone (TBA) was effective in reducing fat deposition and increasing muscle mass. Improvement in growth and carcass characteristics was not associated with a change in meat sensory characteristics.

Table 2—Carcass traits of heifers by treatments adjusted to constant carcass weight

	Treatment						Residual	Probability
Trait	Control	OVX	BSA-E	BSA-E + TBA	TBA	OVX-TBA	SD	> F
Live wt, lb	951	956	954	958	945	958	22	.68
Lean color[a]	5.34	5.31	5.68	5.61	5.37	5.69	.70	.60
Firmness[b]	5.13	4.94	5.34	5.81	5.31	5.18	.76	.32
Texture[c]	4.86	5.07	5.18	5.18	5.02	5.24	.90	.92
Maturity[d]	144	141	138	144	141	141	7	.32
Marbling[e]	464	443	445	473	470	438	116	.96
Adjusted fat thickness, in	.53[g]	.45[g]	.53[g]	.43[g]	.42[gh]	.34[h]	.12	.01
Longissimus muscle area, in^2	11.1[g]	10.8	10.5[g]	11.6[h]	11.7[h]	11.0[g]	.87	.02
K, P, and H fat, %[f]	3.16	3.08	3.33	3.09	3.09	3.09	.32	.47
Moisture of rib, %	41.1[i]	42.4[h]	40.5[i]	44.1[ghi]	45.7[g]	44.5[gh]	2.6	.01
Fat of rib, %	45.7[gh]	43.9[ghi]	46.58[ghi]	41.8[ghij]	39.8[ij]	41.1[ij]	3.5	.01

[a]Scored: 1 = dark red to 8 = light cherry red.
[b]Scored: 1 = very soft to 8 = very firm.
[c]Scored: 1 = very coarse to 8 = very fine.
[d]Scored: 100 to 199 = A.
[e]Scored: 300 to 399 = small; 400 to 499 = modest.
[f]Percent kidney, pelvic, and heart fat.
[ghij]Means in the same line without a common superscript differ (P < .05).

Table 3—Sensory and textural characteristics of steaks for each treatment adjusted to a constant carcass weight

	Treatment						Residual	Probability
Trait	Control	OVX	BSA-E	BSA-E + TBA	TBA	OVX-TBA	SD	> F
Juiciness[a]	5.32	5.25	5.49	5.52	5.39	5.34	.27	.32
Ease of fragmentation[a]	5.33	5.20	5.43	5.40	5.30	5.32	.34	.75
Amount of connective tissue[a]	5.33	5.20	5.42	5.38	5.28	5.31	.35	.79
Overall tenderness[a]	5.35	5.21	5.42	5.40	5.30	5.33	.34	.78
Flavor intensity[a]	5.15	5.21	5.19	5.08	5.13	5.16	.14	.42
Shear force, lb	12.00	12.26	12.00	11.70	11.83	11.39	3.08	.71

[a]Scored: 1 = extremely dry, difficult, abundant, tough, or intense to 8 = extremely juicy, easy, none, tender, or bland, respectively (AMSA, 1978).

Yield Grades and Cutability of Carcass Beef With and Without Kidney and Pelvic Fat

John D. Crouse, Robert M. Koch, and Michael E. Dikeman[1, 2]

Introduction

The Agricultural Marketing Service proposed a revision to the yield grade standards to provide the industry with an option regarding the retention or removal of kidney and pelvic fat (KPF) depending on market requirements. The proposal was subsequently withdrawn. The present yield grades are determined by consideration of external fat thickness, hot carcass wt, ribeye area, and estimated percent KPF. The proposed revision would eliminate consideration of KPF in the determination of yield grades.

The present study used 2,550 observations of retail yield of carcasses obtained from steers with genetically diverse growth rates and fattening characteristics to: 1) examine by yield grade the frequency, mean yield grade, and mean cutability for the present USDA 1980 equation, the present USDA 1980 equation omitting KPF, and the proposed newly developed equation (USDA 1984); and 2) compare precision of the USDA 1980 equation and the proposed equation (USDA 1984) for estimating yield.

Procedure

Carcass sides from F_1 steers from the MARC Germ Plasm Evaluation Program were grouped as British (Angus, Hereford, Red Poll, or South Devon; n = 934), Continental (Charolais, Limousin, Chianina, Brown Swiss, Simmental, Gelbvieh, Maine Anjou, Pinzgauer, or Tarentaise; n = 1,214), Zebu (Brahman or Sahiwal; n = 269), or Jersey (n = 133) sire breeds with Hereford or Angus dams. Steers were fed *ad libitum* on a corn silage and concentrate diet that averaged 2.8 Mcal metabolizable energy/kg dry matter over the finishing period. Each year steers were slaughtered at one of three to five slaughter dates that ranged from 190 to 300 days postweaning.

Yield grade (Y) classifications for carcasses were determined by three equations: 1) the four-variable equation (Y_a) on which the present standards are based (USDA 1980) = 2.5 + 2.50 adjusted fat thickness (AFT), in + .0035 hot carcass wt (HCW), lb - .32 ribeye area (REA), in^2 + .2% kidney, pelvic, and heart fat (KPF); 2) Y_b = present equation with intercept changed to 3.2 and KPF coefficient omitted; and 3) Y_c (proposed; USDA 1984) = 3.0 + 2.50 AFT + .00186 HCW - .202 REA. Frequency distribution of carcasses within yield grades by each prediction equation was determined over all breed crosses and within each breed-cross grouping.

Results

Frequency, mean yield grade, and mean cutability for each estimating equation (a through c) by yield grade are given in Table 1. Average cutability of carcasses was 2 percentage points (44.9 *vs* 46.9) greater when KPF was omitted. Mean cutability within yield grade 1 was .7 of a percentage point greater for equation Y_c than for equation Y_b. Within yield grade 5, however, mean cutability was 1.0 percentage point less for equation Y_c than for equation Y_b. Only .1 of a percentage point difference in cutability was observed between equations Y_c and Y_b within yield grade 2. Therefore, cutability percentages of carcasses classified by equation Y_c tend to be greater in yield grades 1 and 2 and are less in yield grades 3, 4, and 5 as compared with equation Y_b.

Variation in cutability (SD) was similar among yield grade classes within equations, as well as among the three equations.

Frequency distribution of carcasses within yield grade scores differed among the three estimating equations (Table 1). Percentage of carcasses within yield grade 3 remained about the same among the three equations. However, increases in percentage of carcasses with yield grade 2 were observed for equations Y_b and Y_c (30.1 *vs* 37.7 and 43.4%). Equation Y_c produced a greater shift of carcasses into yield grade 2 than did equation Y_b. A shift in percentage carcasses from yield grade 1 to yield grade 2 was observed for equation Y_c. USDA (1984) evaluated the potential shift on a population of 5,846 carcasses. The proposed equation Y_c increased the frequency of carcasses within yield grade 3 by 10.5 percentage points, and there was a concomitant decrease in the number of carcasses in yield grades 1, 2, 4, and 5.

Correlations (not tabulated) between cutability (C) and yield grades indicate that estimative equations Y_a and Y_c were about equal in accounting for variation in percentage cutability, but equation Y_b accounted for slightly less variation. The correlations and standard deviations of cutability from regressions were: .825 and 1.47% for C_a on Y_a; .795 and 1.53% for C_b on Y_b; and .818 and 1.45% for C_c on Y_c. The correlation between cutability without KPF and cutability with KPF (C_a and C_c) was .982. Therefore, after removal of the avg effect of the 2% difference in cutability associated with KPF, the two methods (Y_a and Y_c) of computing cutability had similar accuracy as measures of yield; Therefore, changes in procedures for estimating yield of carcasses should be based on economic considerations.

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[1]Crouse is the research leader, Meats Unit, MARC; Koch is a professor of animal science, University of Nebraska-Lincoln, stationed at MARC; Dikeman is a professor of animal science, Kansas State University, Manhattan.

[2]The full report of this work was published in J. Anim. Sci. 63:1134-1139.

Table 1—Yield grade frequency (F,%), mean yield grade ($\bar{Y}$), and mean actual cutability ($\bar{C}$,%)

Yield grade	Estimating equation[a]											
	Equation a				Equation b				Equation c			
	F	$\bar{Y}$	$\bar{C}$	SD[b]	F	$\bar{Y}$	$\bar{C}$	SD[b]	F	$\bar{Y}$	$\bar{C}$	SD[b]
1	6.3	1.65	48.7	1.6	5.3	1.72	50.4	1.6	2.3	1.81	51.1	1.5
2	30.1	2.55	46.8	1.6	37.7	2.57	48.4	1.6	43.4	2.60	48.5	1.6
3	46.2	3.44	44.3	1.7	45.2	3.42	46.1	1.7	47.5	3.39	45.7	1.7
4	15.9	4.34	41.9	1.6	10.8	4.30	43.4	1.6	6.4	4.28	42.6	1.5
5	1.5	5.32	39.2	1.7	1.0	5.33	40.5	1.6	.4	5.32	39.5	1.2
Avg		3.23	44.9	2.6[c]		3.12	46.9	2.5[c]		3.08	46.9	2.5[c]

[a]Estimating equation Y_a = USDA (1980); Y_b = USDA (1980) with intercept adjusted to 3.2 and coefficient for KPF deleted; Y_c = USDA (1984) proposal.
[b]Standard deviation (SD) represents variation in cutability within a yield grade class.
[c]Standard deviation of individual observations about the overall mean.

Effect of Subcutaneous Fat Removal on Beef Tenderness

Mohammad Koohmaraie, Steven C. Seideman, and John D. Crouse[1]

Introduction

It is now widely recognized that consumers do not accept meat with excessive quantities of fat. To make cuts of meat acceptable to the consumer, packers and retailers are forced to trim much of the subcutaneous fat. If this consumer demand persists, the meat industry will be forced to change its production system to produce leaner cattle.

Subcutaneous fat cover is thought to act as an insulator, retarding rapid temperature decline and consequently preventing cold-induced toughness. Cold-induced toughening is a phenomenon observed when prerigor excised muscles are exposed to cold (< 50°F) temperatures. However, there is no conclusive evidence that cold-induced toughening actually happens under current meat industry practices of slaughtering and carcass handling. The objectives of these experiments were to examine the effect of the removal of subcutaneous fat and high temperature conditioning on beef tenderness. High temperature conditioning (HTC) — storage of carcasses at high temperatures (e.g. 78°F) for 3 to 6 hr after slaughter — was included to attempt prevention of cold-induced toughness in defatted carcasses.

Procedure

Animals. Eight Hereford x Angus and eight Brahman crossbred steers (2 groups each: 4 Hereford x Angus and 4 Brahman-cross) were used to examine the effect of HTC and subcutaneous fat cover on the tenderness in bovine longissimus muscle.

Immediately after slaughter, the first group of carcasses were split. One side was transferred to a 30°F cooler, and the other side was held at 78°F for 6 hr HTC. Carcasses from the second group of steers were split and subcutaneous fat cover over the longissimus muscle completely removed; individual sides were stored as with the first group. After 6 hr, HTC sides from both groups were transferred to the 30°F cooler, and after 24 hr, all sides were transferred to a 34°F cooler, where they remained for the duration of the experiment. Table 1 describes carcasses from the animals used in this study.

Temperature Decline. Temperature and pH were determined at 6, 9, 12, and 24 hr postmortem. Temperature was measured with a fluke (Model 8020A) digital multimeter and temperature probe (Model 80T-150).

Shear force. Shear force of cooked steaks was measured after 1, 3, 8, and 14 days of postmortem aging. Cores (1 in) from cooked steaks were sheared on an Instron Universal Testing machine equipped with a Warner-Bratzler shear device.

Results

Temperature decline data for treatments groups are reported in Table 1. These results clearly indicate that the subcutaneous fat indeed acts as an insulator. At 30°F, the defatted sides had an internal temperature of 51.4°, and the control sides, 60.1°. The data also indicates that the HTC treatment maintained the desired temperature for the 6 hr treatment period. Shear force data are reported in Table 2. These results demonstrate that shear force values were not affected by the treatments and suggest that the presence of subcutaneous fat is not necessary to ensure meat quality. It must be emphasized that data from this study cannot be used to conclude that producing cattle with low backfat would or would not adversely affect beef quality. Therefore, studies of production systems which produce lean animals are necessary to determine their effects on beef quality.

[1]Koohmaraie is a research food technologist; Meats Unit, MARC; Seideman is employed by Bryan Meats, West Point, Mississippi (formerly a research food technologist, MARC); and Crouse is the research leader, Meats Unit, MARC.

Table 1—Effect of subcutaneous fat and high temperature conditioning on temperature decline (least-squares means)

	Hours postmortem (temperature, °F)			
Treatment	6	9	12	24
P > F of interaction	.001	.065	.101	.573
With subcutaneous fat at 30°F	60.1[a]	50.0	42.7	34.7
With subcutaneous fat at 78°F	74.4[b]	59.0	47.21	34.5
Without subcutaneous fat at 30°F	51.4[c]	42.71	38.05	34.2
Without subcutaneous fat at 78°F	70.6[d]	52.63	41.61	34.0
High temperature conditioning:				
30°F	55.8[a]	46.36[a]	40.35[a]	34.4[a]
78°F	72.5[b]	55.81[b]	44.40[b]	34.2[b]
Subcutaneous fat:				
With	67.3[a]	12.50[a]	44.94[a]	34.6
Without	53.0[b]	47.7[b]	39.8[b]	34.1
Residual standard deviation	.65	.37	.44	.15

[abcd]Values within a column within interaction or main effect with different superscripts differ (P < .05).

Table 2—Effect of subcutaneous fat and high temperature conditioning on shear force (least-squares means)

Treatment	Days postmortem (lb force)			
	1	3	8	14
P > F of interaction	.062	.643	.277	.536
With subcutaneous fat at 30°F	18.2	14.9	12.4	12.5
With subcutaneous fat at 78°F	18.74	15.22	13.93	12.4
Without subcutaneous fat at 30°F	22.3	14.6	12.1	9.9
Without subcutaneous fat at 78°F	19.0	14.3	12.1	10.7
High temperature conditioning:				
30°F	20.2	14.7	12.2	10.4[a]
78°F	18.9	14.7	13.0	11.5[b]
Subcutaneous fat:				
With	18.5	15.0	13.1	11.7
Without	20.70	14.4	12.1	10.3
Residual standard deviation	1.17	.93	.86	.61

[ab]Values within a column within interaction or main effect with different superscripts differ ($P < .05$).

Factors Associated with Tenderness of Three Beef Muscles

Mohammad Koohmaraie, Steven C. Seideman, and John D. Crouse[1]

Introduction

Tenderness is the prominent quality determinant and probably the most important sensory characteristic of beef steak and roast meat. Currently postmortem aging (storage of carcass at refrigerated temperatures for 8 to 14 days) appears to be the best method for producing tender meat. Although the improvement in meat tenderness as a result of postmortem aging is measurable both subjectively and objectively, the exact mechanism responsible for this improvement in tenderness is unknown.

It is well known that different muscles within the same carcass react differently to postmortem storage; for example, tenderloin is tender to begin with and does not improve significantly with postmortem storage, while ribeye is the toughest muscle initially and improves greatly with postmortem storage. The purpose of these experiments was to attempt to answer the following questions: 1) Why are some muscles (e.g., tenderloin) tender at 24 hr postmortem and nonresponsive to postmortem aging? and 2) Why do some muscles (e.g., ribeye and tenderloin) respond differently to postmortem aging?

Procedure

Eight heifers with similar backgrounds were slaughtered. At 45 min postmortem, one-half of the Longissimus dorsi (LD; ribeye), Psoas major (PM; tenderloin), and Biceps femoris (BF; bottom round) were removed from one side of each carcass. Each muscle was then cut into samples for extraction of calcium-dependent protease-I (CDP-I), CDP-II, CDP inhibitor, and lysosomal enzymes, and for determination of moisture, fat, and collagen (amount and solubility). Shear force was determined on cooked steaks from each muscle after days 1 and 14 postmortem storage.

Results

On wet or dry basis, the PM had the highest fat content, followed by LD, and then BF (Table 1), while the exact opposite pattern was observed for moisture content. Data regarding the amount and solubility of collagen are reported in Table 3. BF had significantly more collagen than LD and PM. In terms of collagen solubility, PM had the highest percentage of soluble collagen followed by LD and BF (differences between PM and LD were not statistically significant).

Shear force values at different postmortem times are presented in Table 1. At day 1, PM was the most tender muscle (shear force = 8.71), while LD muscle was the toughest (shear force = 18.15), and BF had the shear force value of 13.55. After seven days of postmortem storage, PM was still the most tender muscle but, most importantly, was virtually unaffected by postmortem storage. BF had a shear force of 13.55 at day 1 and 10.30 at day 14 (a 3.25 lb decrease in shear force value as a result of postmortem storage). LD had a shear force value of 18.15 at day 1 and 10.90 at day 14 (a 7.25 lb decrease). Therefore, in terms of aging response (decrease in shear force values as a result of postmortem storage), LD had the highest aging response, followed by BF and PM.

CDP-I, -II and CDP inhibitor activities are reported in Table 2. LD had the highest CDP-I, CDP-II, and inhibitor activities, followed by BF and then PM. LD muscle had approximately twice the CDP-I, -II, and inhibitor activity of PM muscle. Results of this experiment indicate that, for all three muscles, the ratio of CDP-I:CDP-II was approximately 1:1 and the ratio of CDP-I + CDP-II:inhibitor was also 1:1.

Unlike the results of CDP activities, no particular pattern was observed for catheptic enzymes (Table 2). The activities of cathepsins B, H, and B + L are almost identical between muscles.

Results of sarcomere length and fiber type characteristics are presented in Table 3. PM had the longest sarcomeres, followed by BF and LD. These differences were statistically significant.

Fiber type characteristic results (Table 2) indicate that PM had the highest percentage of red fibers and the smallest percentage of intermediate fibers when compared to LD and BF ($P < 0.05$). LD and BF were similar in fiber type characteristics. PM had the smallest average fiber area; BF, intermediate ($P < .05$); and LD, the largest.

Results of this experiment demonstrate that, at 24 hr postmortem, these three muscles differ significantly in shear force. How could one explain these differences? It has been theorized that two muscle components, collagen and the contractile apparatus, determine tenderness. It is now clear that collagen quality is much more significant than quantity. However, we cannot explain these large differences in shear force values (Table 1), neither in terms of collagen amount nor solubility. Collagen solubilities are 7.40% and 6.94% for PM and LD, respectively. This small difference in collagen solubility cannot explain the differences between 8.71 and 18.15 lb of shear force. Of all the parameters examined in this experiment, average fiber size is the only basis on which the differences between these muscles could be explained. We have consistently observed the effect of fiber size on meat tenderness regardless of breed or sex. However, at this point, we cannot offer an explanation for the relationship between fiber size and meat tenderness.

Table 1—Moisture, fat, collagen, and shear force of Longissimus dorsi (LD), Biceps femoris (BF), and Psoas major muscles (PM)

	LD	BF	PM
Moisture, %	72.51[a]	74.23[a]	72.95[a]
Fat, wet basic, %	3.89[a]	2.33[b]	4.56[a]
Fat, dry basic, %	14.00[a]	8.99[b]	16.60[a]
Total collagen, mg/g	3.40[a]	6.16[b]	2.23[c]
Soluble collagen, %	6.94[a]	5.05[b]	7.40[a]
Shear force, lb day 1	18.15[a]	13.55[b]	8.71[c]
Shear force, lb day 7	10.90[a]	10.30[a]	8.40[a]

[abc]Means with different superscripts within a row differ ($P < .05$).

[1]Koohmaraie is a research food technologist and Crouse is the research leader, Meats Unit, MARC; and Seideman is employed by Bryan Meats, West Point, Mississippi (formerly a research food technologist, MARC).

In terms of aging response, LD had the highest aging response, followed by BF, while PM basically did not change from day 1 to day 7. In attempts to understand the differences between LD and PM, we measured the activities of two well-known classes of muscle proteases. It has been postulated that one class of these proteases or their synergistic action is responsible for postmortem tenderization of meat. It is logical to assume that the class of protease responsible for postmortem aging should have high activity in the muscle with a high aging response and vice versa. The results of this experiment indicate that, regardless of the magnitude of aging response, the activities of cathepsins B, H and B + L were basically the same for all three muscles. However, in the case of CDP, its activity followed the same pattern as aging response. Based on the results of this experiment and others, it was concluded that initial levels of CDP-I activity determine the aging response of a given muscle.

If indeed our hypothesis is correct and CDP-I is responsible for postmortem aging, then its inactivation, or postmortem handling of the carcasses to provide unfavorable conditions for its activation should prevent the postmortem aging. We are now addressing this particular point by attempting to deactivate CDP-I in animals and then examining postmortem changes.

Table 2—Ca^{2+}-activated proteases, their inhibitor, and catheptic enzyme activity in Longissimus dorsi (LD), Biceps femoris (BF), and Psoas major (PM) muscles

	LD	BF	PM
CDP-I[d]	91.35[a]	60.63[b]	49.70[c]
CDP-II[e]	108.02[a]	79.87[b]	50.40[c]
Inhibitor[f]	-152.44[a]	-148.57[a]	-90.20[b]
Cathepsin B[g]			
unsedimentable fraction	17.25[a]	22.09[a]	22.08[a]
sedimentable fraction	1.80[a]	1.63[a]	2.23[a]
Cathepsin H[g]			
unsedimentable fraction	48.83[a]	45.73[a]	42.99[a]
sedimentable fraction	10.23[a]	9.04[a]	9.67[a]
Cathepsin L + B[g]			
unsedimentable fraction	41.58[a]	41.78[a]	37.55[a]
sedimentable fraction	3.80[a]	3.98[a]	4.71[a]

[abc]Means with different superscript within a row differ ($P < .05$).
[d]Low calcium-requiring calcium-dependent protease (A_{278}/200 g muscle).
[e]High calcium-requiring calcium-dependent protease (A_{278}/200 g muscle).
[f]Inhibitor of CDP-I and CDP-II (A_{278}/200 g muscle).
[g]Units/min/mg of protein.

Table 3—Sarcomere length and fiber type characteristics of Longissimus dorsi (LD), Biceps femoris (BF), and Psoas major (PM) muscles

	LD	BF	PM
Sarcomere length (μm)	1.68[a]	2.15[b]	3.55[c]
Area of white fiber (μm)	6140.50[a]	5077.37[b]	2230.12[c]
Area of intermediate fiber (μm)	3831.25[a]	3382.12[a]	1524.62[b]
Area of red fiber (μm)	3029.12[a]	2638.00[a]	1460.62[b]
White fiber (%)	40.38[a]	45.18[a]	38.37[a]
Intermediate fiber (%)	28.58[a]	24.37[a]	16.34[b]
Red fiber (%)	31.03[a]	30.43[a]	45.28[b]
Average fiber area (μm)	4333.62[a]	3699.17[b]	1737.45[c]

[abc]Means with different superscripts within a row differ ($P < .05$).

Role of Naturally Occurring Enzymes in Beef Tenderness

Mohammad Koohmaraie, Steven C. Seideman, Judith E. Schollmeyer, and John D. Crouse[1]

Introduction

Over the years, a large number of studies have demonstrated that postmortem storage at 32 to 41°F dramatically improves meat tenderness, and there has been considerable effort directed toward understanding the mechanism(s) responsible for this improvement. However, conclusions are unclear and the mechanism of postmortem tenderization is still a controversial issue.

It is generally accepted that the majority, if not all, of this improvement is the result of proteolytic degradation by proteases in the skeletal muscle cell. Among these proteases, Ca^{2+}-dependent protease(s) seems to be the best candidate(s) as a possible mechanism for proteolytic degradation of myofibrils during postmortem storage. The latest report regarding the effect of low Ca^{2+}-requiring Ca^{2+}-dependent protease from our laboratory (CDP-I) on the myofibrils under actual postmortem conditions appears to strengthen the hypothesis that Ca^{2+}-dependent protease may play a major role during postmortem tenderization of meat.

These studies were conducted to examine the effect of postmortem storage on the activities of the low Ca^{2+}-requiring (CDP-I) and the high Ca^{2+}-requiring (CDP-II) Ca^{2+}-dependent proteases, their inhibitor, myofibril fragmentation index (MFI), and connective tissue.

Procedure

Samples were obtained from longissimus muscle (ribeye) from 15 A-maturity cattle with carcass weights ranging from 478 to 980 lb.

CDP-I and CDP-II Ca^{2+}-dependent proteases and their inhibitor were isolated from 0.78 lb of longissimus muscle immediately after slaughter and after 1, 6, and 14 days of storage at 33.8°F. MFI was determined at 0, 1/2, 1, 3, 6, and 14 days. Collagen content and solubility were determined after 1 and 14 days.

Results

Table 1 indicates the effect of postmortem storage on the parameters studied in these experiments. Postmortem storage seems to have very little effect on the activity of CDP-II; after 14 days of storage, 80.2% of the original activity was present.

Results for shear force values are reported in Table 1. Because of the problems associated with cooking prerigor meat, shear force values were determined after 1, 3, 6, and 14 days. Results indicate that changes in shear values from day 1 to day 6 are the most dramatic, while those from day 6 to day 14 in shear values are reduced.

MFI results are reported in Table 1. These results indicate that almost 50% of the changes in the myofibrils have taken place 24 hr after slaughter, but it takes another 13 days for these changes to be completed. These results clearly demonstrate that postmortem effects begin at the time of bleeding and that quality enhancement is greatest and fastest during the very early post-slaughter period when CDP-I is maximally active.

Immediately after slaughter, the pH and temperature of muscle are 7.0 and 98.6°F, respectively, and the ultimate pH and temperature are achieved gradually over a 24 hr period. CDP-I is, therefore, expected to be more active during this period and capable of inducing maximum changes in the myofibrils as opposed to the period from 1 to 14 days postmortem. It is quite interesting to note the remarkable resemblance between the activity profile of CDP-I and changes in the myofibril fragmentation throughout postmortem storage. Results also indicated that postmortem storage had no effect on the collagen in terms of quantity and solubility.

Because there were no detectable changes in collagen, it was concluded that the improvement in tenderness resulting from postmortem storage at refrigerated temperatures must be derived from changes in the myofibrils. Since CDP-I activities parallel the myofibrillar changes, it is suggested that CDP-I may play a major role in the fragmentation of myofibrils and, consequently, in meat tenderization.

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Table 1—Changes associated with postmortem storage*

	Days postmortem					
	0	½	1	3	6	14
Shear force (lb)	---	---	16.9	13.6	10.1	8.1
Myofibril fragmentation index[a]	28.2	38.3	49.6	55.4	71.2	72.4
CDP-I[b]	64.1	---	29.9	---	28.7	21.5
CDP-II[c]	86.6	---	86.6	---	84.9	76.7
Inhibitor	-123.4	---	25.1	---	13.8	-14.0
Collagen						
Amount, mg/g	---	---	3.67	---	---	3.64
Solubility, %	---	---	11.48	---	---	11.33

[a]Absorbance at 540 nm x 200.
[b]Low Ca^{2+}-requiring Ca^{2+}-dependent protease A_{278}/200 g of muscle (caseinolytic activity).
[c]High Ca^{2+}-requiring Ca^{2+}-dependent protease A_{278}/200 g of muscle (caseinolytic activity).
*n = 15 for all measurements, except for CDP-I, -II, and inhibitor at days 0 and 14 (n = 7).

Use of Mechanical Tenderization to Increase the Tenderness of Bull Beef

Steven C. Seideman, H. Russell Cross, and John D. Crouse[1,2]

Introduction

Numerous studies have shown that meat from bulls is less tender than meat from steers of comparable age and feeding regimen. Collagen crosslinking has been reported to be more extensive in bulls than in steers of similar age and has been implicated as a potential cause of toughness in meat from bulls.

Several studies have shown that blade tenderization improved the tenderness of beef and decreased the amount of sensory panel-detectable connective tissue. Also, it has been reported that blade tenderization of bull muscles resulted in steaks which required less time to cook, had decreased amounts of detectable connective tissue, and had increased tenderness, flavor, and overall palatability ratings. The objectives of this study were to: (1) determine if mechanical tenderization would increase the tenderness of bull beef to a level equal to that of steer beef; and (2) determine the number of passes through a mechanical tenderizer needed to achieve this desired effect.

Procedure

Ten bulls and ten steers of the same breed (Brown Swiss) and age (13 mo) were slaughtered. After a 24-hr chill, carcasses were evaluated for muscle firmness (8 = very firm; 1 = very soft); lean color (8 = light grayish red; 1 = black); lean texture (8 = very fine; 1 = very coarse); lean maturity (100-199 = A; 200-299 = B); skeletal maturity (100-199 = A; 200-299 = B); overall maturity (100-199 = A; 200-299 = B); marbling (000-100 = devoid; 900-1000 = abundant); fat thickness; adjusted fat thickness; percent kidney, pelvic, and heart fat; and ribeye area. The round semimembranosus (SM), biceps femoris (BF), and longissimus dorsi (LD) muscles were removed from both right and left sides (24 hr postmortem), vacuum packaged, and aged for 1 wk. Muscles were then cut into two equal portions perpendicular to fiber direction, and the four half-muscle sections were randomly assigned to one of four treatments to include control (OX), one pass through a Ross TC-700 mechanical tenderizer (1X), two passes (2X), or three passes (3X). Steaks (1.2 in thick) were cut from the LD muscle while all other muscles remained as roasts and were wrapped in polyethylene-coated freezer paper and frozen for 2 wk. Roasts and steaks were thawed and either broiled on Farberware grills (LD) or in convection ovens (SM and BF). Internal temperatures were monitored by iron/constantan thermocouples attached to a recorder. The difference between thawed and cooked wt determined cooking loss.

Sensory panelists were asked to evaluate juiciness (8 = extremely juicy, 1 = extremely dry), ease of fragmentation (8 = extremely easy, 1 = extremely difficult), amount of detectable connective tissue (8 = none, 1 = abundant), overall tenderness (8 = extremely intense, 1 = extremely bland), and off-flavor (4 = none, 1 = intense). In addition, six 1.3 cm diameter cores from each muscle (LD, BF, and SM) were removed parallel to fiber direction and sheared twice each on a Warner-Bratzler shear device attached to an Instron Universal Testing Instrument.

Results

Mean values for carcass characteristics of bulls and steers are presented in Table 1. Bull carcasses had significantly lower mean values for adjusted fat thickness; kidney, pelvic, and heart fat; marbling; and USDA quality grade. The fact that bulls deposit less carcass fat than steers has been reported in numerous studies.

Table 1—Carcass characteristics of bulls and steers

Carcass characteristic	Sex condition[e] Bulls	Steers
Lean firmness[a]	5.6	5.6
Lean color[b]	4.2	4.9
Lean texture[a]	5.5	5.0
Skeletal maturity[c]	A^{24}	A^{20}
Lean maturity	A^{25}	A^{29}
Overall maturity[c]	A^{24}	A^{24}
Hot carcass wt (lb)	600	611
Fat thickness (in)	.12	.18
Adjusted fat thickness (in)	.11	.16
Ribeye area (in^2)	12.4	12.2
Kidney, pelvic, & heart fat (%)	1.80	2.45
Marbling[d]	T^{83}	SL^{70}
Quality grade	ST+	G+

[a]Means according to an 8-point scale (8 = very firm or very fine; 1 = very soft or very coarse).
[b]Means according to an 8-point scale (8 = light grayish red; 1 = black).
[c]Means according to an open scale (A = 100-199; B = 200-299).
[d]Means according to an open scale (000-100 = devoid; 900-1,000 = Abundant).
[e]Means underscored by a common line are different ($P < .05$).

Effects of multiple passes through a mechanical tenderizer on cooking characteristics and textural and sensory properties are shown in Table 2. Cooking loss of all three muscles generally increased with additional passes through the mechanical tenderizer. However, this difference was not always consistent enough for statistical significance. Passing the SM and LD muscles through a mechanical tenderizer one or more times generally decreased peak load.

Effects of multiple passes through a mechanical tenderizer on sensory properties are shown in Table 2. These means represent the average of both sex conditions. Each pass through a mechanical tenderizer generally increased sensory panel ease of fragmentation rating, improved amount of detectable connective tissue (e.g., reduced detection of connective tissue), improved overall tenderness ratings, and improved off-flavor ratings.

Sensory panel attributes of mechanically tenderized LD steaks from bulls and steers are shown in Table 2.

[1]Seideman is employed by Bryan Meats, West Point, Mississippi (formerly a research food technologist, MARC); Cross is a professor of animal science, Texas A&M University (formerly the meats research leader, MARC); and Crouse is the research leader, Meats Unit, MARC.

[2]The full report of this work was published in J. Food Quality 9:49-56, 1986.

Table 2—The effect of multiple passes through a mechanical tenderizer on cooking characteristics and textural and sensory properties

Muscle	Cooking characteristics, textural, or sensory properties	Passes through mechanical tenderizer[e]			
		OX	1X	2X	3X
Textural properties					
Biceps femoris					
	Cooking loss (%)	28.75[c]	30.25[bc]	32.02[ab]	32.86[a]
	Cooking time (min)	2.12[a]	2.09[a]	1.80[b]	1.63[b]
	Peak load (lb)	7.5[ab]	6.7[bc]	8.0[a]	6.3[c]
Semimembranosus					
	Cooking loss (%)	33.94[c]	36.09[ab]	36.35[a]	34.81[bc]
	Cooking time (min)	2.07[a]	2.18[a]	2.09[a]	1.92[a]
	Peak load (lb)	8.8[a]	7.0[b]	7.1[b]	7.3[b]
Longissimus dorsi					
	Cooking loss (%)	28.76[a]	28.88[a]	32.60[a]	31.06[a]
	Cooking time (min)	0.58[ab]	0.48[c]	0.60[a]	0.53[bc]
	Peak load (lb)	10.7[a]	7.8[b]	7.2[b]	6.8[b]
Sensory properties					
Longissimus dorsi					
	Juiciness	5.5[a]	5.3[a]	5.5[a]	5.5[a]
	Ease of fragmentation	5.0[d]	5.3[c]	5.7[b]	6.0[a]
	Amount of connective tissue	4.9[c]	5.3[b]	5.7[a]	5.9[a]
	Overall tenderness	5.0[d]	5.4[c]	5.7[b]	6.0[a]
	Flavor intensity	5.8[a]	5.7[a]	5.8[a]	5.8[a]
	Off-flavor	2.4[c]	2.7[b]	2.6[b]	2.8[a]

[abcd]Means within the same row followed by a different superscript are different ($P < 0.05$).
[e]Means represent the average of both sex conditions.

The original objective of this study was to determine if mechanical tenderization would increase the tenderness of bull beef to the level of steer beef. However, the meat from bulls was only 0.3 sensory tenderness units less tender than meat from steers (4.9 *vs* 5.2). This small tenderness difference may have been attributed to the age of the bulls at slaughter (13 mo) but does tend to reinforce the contention that meat from bulls is less tender than meat from steers. Passing of bull beef once (1X) through a mechanical tenderizer improved the sensory tenderness ratings to those observed in untenderized meat from steers. Increasing the number of passes through the mechanical tenderizer generally increased sensory tenderness ratings by 0.3 units of meat from both bulls and steers.

Based on the results of this study, it can be concluded that the passing of the SM and LD muscles through a mechanical tenderizer one or two times will decrease peak load. Passing of beef through a mechanical tenderizer will improve tenderness rating and will probably increase the tenderness of bull beef to a comparable level to steer beef if the bull beef is initially tough.

The Effects of Rate of Change in Body Weight on Tissue Development and Meat Quality of Youthful Bulls

John D. Crouse, Chris R. Calkins, and Steven C. Seideman[1]

Introduction

Growth and development of meat-producing animals involves a complex integrated system of changes in the structure and mass of body tissues. Researchers have observed and documented that meat animal growth and development may be altered through the diet or alteration of the sex condition. Most significant alterations are in rates of deposition of protein, fat, and connective tissue, as well as the palatability of the cooked meat. Changes in wt of cattle beyond 14 mo of age have been largely associated with the fat deposition in the body. Studies have shown that youthful bulls have advantages in performance of growth and leanness and disadvantages in tenderness when compared with steers. Differences in tenderness have been attributed to variations in fatness and in connective tissue. Connective tissue has been reported to increase markedly at about 12 mo of age and to decrease in solubility with age. These age-related changes in connective tissue also have been reported to be more pronounced in bulls than steers.

It appears that, as steers are fed dietary energy above maintenance, body protein accretion increases. The alteration in protein content is associated with improved product tenderness. Growth rate over a short period may be a more important determinant of tenderness than the length of time that cattle are fed a high-energy diet. Proteolytic enzymes are needed to increase protein turnover, and these enzymes may also influence postmortem changes in meat properties. Animals gaining or losing wt may alter these enzyme profiles. Therefore, a strong possibility exists that protein turnover is increased and a more youthful connective tissue present during wt gain. This experiment was undertaken to determine the effects of change in body wt on body tissue development and meat quality from youthful bulls.

Procedure

Animals. Forty-eight Angus bulls about 13 mo of age were used. Bulls were fed a corn and corn-silage growing diet (74% TDN) for 4 mo and then placed on a finishing diet (84% TDN) composed of corn and corn silage.

After 30 days on the finishing diet, bulls were randomly assigned to one of three groups: 1) *ad libitum*-fed (gained 2.2 lb/day), 2) restriction-fed to maintain wt (lost .35 lb/day), or 3) restriction-fed to lose wt (lost 1.26 lb/day). Bulls were penned by treatment and fed in four replicated pens.

After 30 days on trial, two bulls per pen (24 bulls total) were slaughtered. The remaining bulls were slaughtered after an additional 30 days on trial. Bulls were slaughtered in the MARC abattoir.

Results

Liveweight. Treatment effects due to slaughter group and daily rate of change in wt are given in Table 1. Feeding an additional 30 days had no effect on liveweights or hot carcass wt. Lack of variation in wt associated with slaughter group is primarily due to experimental design. For each unit increase in avg daily gain over the trial, liveweight increased 38 units. Variation in daily rate of change in wt was also reflected in hot carcass wt.

Quality traits. Longissimus muscle at the 12th rib became darker in color, softer, coarser textured, and more physiologically mature when bulls were fed an additional 30 days. Increased daily rate of wt change improved lean texture but had insignificant effects on lean color or maturity scores. These data indicate that age of the animal had more of an effect on lean color and physiological maturity than rate of change of wt.

Composition. No effects due to length of time fed were observed for fat thickness or percentage of rib fat (Table 1). Marbling scores and percentage of kidney and pelvic fat (KPF), however, increased during the final 30-day feeding period. No changes in longissimus muscle area were observed during the final 30-day feeding period; however, percent lean of the rib tended to decrease with additional time fed. Greater effects due to length of time fed were probably not observed due to design of the experiment. The overall effects of length of time fed included losses in wt as well as gains. Increases in fat deposition within the KPF and longissimus muscle depot sites were associated with increases in physiological age as opposed to increases in body wt.

Daily rate of change in wt (regression coefficients, Table 1) affected composition. Increasing the rate of animal wt gains increased fat deposition within all the fat depot sites, except KPF sites, and decreased percentage of lean in the rib. Longissimus muscle area also increased with increases in daily rates of changes in wt. The present study indicates that quantities of body fat can be altered by varying daily wt change through restriction of diet.

Collagen characteristics. Feeding the additional 30 days or daily rate of change in wt had no appreciable effect on collagen characteristics (Table 1). Decreased solubility of collagen has previously been observed in bulls and with increased age of the animal. Collagen turnover has been observed to be accelerated during periods of rapid growth. Variation in the solubility of collagen also has been associated with meat tenderness.

Sensory characteristics. A slight decrease in flavor intensity was observed to be associated with an additional 30 days of feeding (Table 1). However, this was not associated with daily rate of change in wt. No significant variation in tenderness or other observed sensory characteristics was associated with length of time fed or daily rate of change in wt.

It was anticipated that varying daily gain prior to slaughter would affect tenderness. However, tenderness was not significantly affected by treatments in this experiment.

In the present experiment, intact males were studied instead of castrates. Perhaps degree of maturity of the collagen was altered by the intact male condition of the

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[2]The full report of this work was published in J. Anim. Sci. 63:1824-1829, 1986.

animals studied when comparing results with observations reported in the literature of other sex conditions. Total collagen values in the present study are considerably greater than those previously reported. Collagen in the present study also was observed to be considerably less soluble than the collagen in steers of previous studies. Future studies on the growth rate of cattle need to consider interactions of sex conditions. Dietary treatments in the present study failed to affect collagen characteristics in bulls.

Table 1—Slaughter group means and regression coefficients

Trait	Days fed		Regression coefficient[a]
	30	60	
Live wt, lb	870	868	38**
Hot side wt, lb	260	260	10**
Lean color[b]	5.34	4.60**	.13
Lean firmness[b]	5.30	4.54*	.16
Lean texture[b]	5.59	4.71**	.18
Lean maturity[c]	A26	A33**	.09
Skeletal maturity[c]	A24	A32**	.45
Overall maturity[c]	A25	A33**	0
Marbling[d]	SI15	SI72	16*
Fat thickness, in	.17	.15	.03**
Adj. fat thickness, in	.15	.14	.02**
Longissimus muscle area, in^2	11.5	10.7	.28**
KPF,%	.53	1.61**	.05
Rib fat,%	17.9	17.2	1.45**
Rib bone,%	21.5	23.7**	-.91**
Rib lean,%	59.7	58.5	-.54*
Total collagen, mg/g	4.51	4.56	.04
Insoluble collagen,%	84.2	83.8	.04
Cooking loss,%	39.2	38.6	.05
Juiciness[e]	5.12	5.20	.00
Ease of fragmentation[e]	5.17	4.94	.04
Amount of connective tissue[f]	5.12	4.87	.06
Overall tenderness[e]	5.18	4.96	.05
Flavor intensity[e]	5.25	5.12*	.02
Off-flavor[g]	5.9	6.2	.07

[a]Computed from variation in response trait associated with variation in mean avg daily change in wt among bulls. Interaction regression by slaughter group was not an important source of variation. Unit change/lb.
[b]Scored: 1 = black, very soft, or very coarse to 8 = grayish red, very firm, or very fine.
[c]Scored: 100 to 199 = A, 200 to 299 = B.
[d]Scored: 100 to 199 = traces, 200 to 299 = slight, 300 to 399 = small.
[e]Scored: 1 = extremely dry, juicy, difficult, tough, or bland to 8 = extremely juicy, none, tough, or intense.
[f]Scored: 1 = abundant to 8 = none.
[g]Scored: 1 = intense to 4 = none.
*P < .05.
**P < .01.

The Effect of Sex and Age on the Textural Properties and Mineral Content of Beef Steaks

Steven C. Seideman, H. Russell Cross, and John D. Crouse[1,2]

Introduction

Extensive research has been conducted on objectively assessing the palatability characteristics, particularly tenderness, of carcass meat. A patent (#4,009,390) by Satterlee et al. (1977) claimed that the ratio of iron (Fe) to zinc (Zn) in beef was highly correlated to its tenderness and that it is also easy to calculate a Fe/Zn ratio accurately with spectrophotometric methods.

An increase in the crosslinking between strands of collagen decreases the solubility of collagen, and also decreases the tenderness of the meat. High moist heat is required to improve tenderness of meat with extensive crosslinking of collagen. Increases in crosslinking of collagen is generally associated with increases in maturity. Collagen crosslinking has been shown to be impaired in zinc-deficient rats, which tends to suggest that a low concentration of zinc in muscle would prevent collagen crosslinking. Also, zinc concentration was significantly correlated to skeletal maturity, fat thickness, ribeye area, panel-detectable connective tissue, and tenderness. The objective of this study was to relate the zinc and iron content of meat from animals varying in sex and age to the textural properties of meat.

Procedure

Bulls (40) and steers (45) were slaughtered at either 12, 15, or 18 mo of age. Carcasses were chilled for 24 hr, and the ribeye muscle was removed from the left side, vacuum packaged, and frozen. Subsequently, steaks were analyzed for shear force requirements and zinc (Zn) and iron (Fe) analyzed.

Results

Mean values for textural properties and mineral content of meat from bulls and steers stratified by age and sex are shown in Table 1. Shear force values tended to decrease between 12 and 15 mo of age in both bulls and steers, which would suggest an increase in tenderness of meat. Overall, age groups were not significantly different in textural properties of meat from bulls *vs* steers.

The Zn content of meat from animals 12 to 18 mo of age did not differ significantly, but meat from bulls contained 19.3% more Zn than meat from steers. The Fe content steadily increased in meat as the age of the animals increased. In addition, meat from bulls, overall, contained 7.1% more Fe than meat from steers. The Fe/Zn ratio markedly increased between 12 and 15 mo of age by 15.6% and was 14.0% lower in meat from bulls than in meat from steers.

There appears to be an interesting relationship between the textural properties (shear force) of meat and the Zn content and Fe/Zn ratios. As the shear force requirements decreased (more tender), the Zn content decreased and the Fe/Zn ratios increased. A plausible explanation for the increase in tenderness with a decrease in Zn content may lie with relationship of Zn to collagen crosslinking.

Further research is needed to determine if supplemental Zn fed to animals will affect muscle Zn levels and if Zn prevents intramuscular collagen crosslinking.

[1]Seideman is employed by Bryan Meats, West Point, Mississippi (formerly a research food technologist, MARC); Cross is a professor of animal science, Texas A&M University (formerly the meats research leader, MARC); and Crouse is the research leader, Meats Unit, MARC.

[2]The full report of this work was published in J. Food Quality 7:91-96, 1984.

Table 1—Mean values for textural properties and mineral content of meat from bulls and steers stratified by age and sex

Sex	Age (mo)	n	Mineral content: Shear force (lb)	Zn (µg/gm)	Fe (µg/gm)	Fe/Zn
Bull	12	12	11.5	35.21	13.65	0.390
Steer	12	12	11.4	32.42	13.83	0.429
Avg	12	24	11.5	33.81	13.75	0.410
Bull	15	13	6.4	36.31	15.77	0.437
Steer	15	15	8.8	27.67	14.30	0.529
Avg	15	28	8.2	31.68	14.98	0.486
Bull	18	15	10.7	37.00	16.67	0.452
Steer	18	18	8.5	28.44	14.58	0.520
Avg	18	33	9.5	32.33	15.44	0.489
Avg Bull		40	9.5	36.24	15.38	0.429
Avg Steer		45	9.7	29.24	14.29	0.499

Beef Ribeye Muscle Glycogen and Color Response as Affected by Dietary Regimen and Postmortem Electrical Stimulation in Young Bulls

Mark R. Miller, H. Russell Cross, Marietta J. Buyck, and John D. Crouse[1,2]

Introduction

Utilization of the intact male by the beef industry has been the focus of much research in recent years. Advantages of bulls compared to steers in production efficiency, performance, and carcass leanness have been well documented. Disadvantages include aggressive behavior, darker postmortem muscle color, lower USDA quality grades, and, often, less tender meat. The superior production performance of bulls has not been utilized by the meat and livestock industries partly because of these disadvantages.

Postmortem muscle color is associated with energy content of the diet, antemortem muscle glycogen content, postmortem muscle pH decline, and ultimate pH, all of which are affected by the degree and amount of physiological stress induced before slaughter.

Electrical stimulation of prerigor carcasses has resulted in improved tenderness and marbling scores, enhanced lean colors, and increased rate of pH and glycogen decline. Thus, the objectives of this study were to determine the effects of diet and electrical stimulation on postmortem glycogen depletion, muscle color, and sensory properties of bull longissimus dorsi muscle.

Procedure

Eighty young bulls (5 to 6 mo) were randomly assigned to one of two groups and fed either a high-energy or a low-energy diet designed to accelerate or defer growth. The accelerated dietary regimen contained 2.61 Mcal/kg metabolizable energy (ME) fed for the first 100 days, followed by a finishing diet that contained 3.04 Mcal/kg ME fed for the last 110 days. The deferred dietary regimen consisted of good quality pasture for the first 110 days, followed by finishing for 180 days on a high-energy dietary regimen that contained 3.04 Mcal/kg ME. Diets were composed of corn silage (IFN-3-08-153), corn (IFN-4-02-931), and soybean meal (IFN-5-04-604). All animals were implanted with Ralgro at 100-day intervals, and were slaughtered at approximately the same fat thickness. Animals were transported to the MARC abattoir on the morning of slaughter and were all slaughtered within 2 hr after removal from the research feeding facilities.

Carcasses were split; each side was weighed; and the right side was electrically stimulated within 1 hr postmortem. The non-stimulated left sides were used as controls. All sides were evaluated for USDA quality and yield grade traits after chilling for 24 hr. At 7 days postmortem, the ribeye muscle from the short-loin of both sides was removed and sliced into 1 in thick steaks.

Results

Diet and electrical stimulation did not significantly influence liveweight, carcass weight, lean firmness, lean maturity, bone maturity, ribeye area, or kidney, pelvic, and heart fat (Table 1). Meat from animals fed the deferred diet had a brighter, more youthful lean color, lower USDA quality grade, and a lower degree of marbling than carcasses from bulls fed an accelerated diet. Electrical stimulation resulted in a lower incidence of heat ring and brighter, more youthful colored, finer-textured lean and, consequently, a more youthful, overall maturity.

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[2]The full report of this work was published in Meat Science 19:253-263, 1987.

Table 1—Means of carcass traits by diet and electrical stimulation

	Diet		Electrical stimulation	
Trait	Accelerated	Deferred	Stimulated	Non-Stimulated
Hot carcass wt (lb)	836	844	837	843
Heat ring[a]	3.6	3.6	4.4[e]	2.7[f]
Lean color[b]	4.6[f]	5.2[e]	5.6[e]	4.3[f]
Lean texture[c]	5.5	5.6	5.9[e]	5.1[f]
Lean firmness[d]	6.0	6.0	5.9	6.0
Overall maturity	A[70]	A[71]	A[59]	A[73f]
Marbling score	SI[90e]	SI[51f]	SI[76]	SI[64]
USDA yield grade	2.7	2.5	2.8	2.9
Kidney, pelvic, and heart fat (%)	2.1	1.9	2.0	2.0

[a]Scored: 5 = no visible heat ring or two toning; 1 = extreme heat ring or sunken muscle or fat.
[b]Scored: 7 = very light cherry red; 4 = slightly dark red; 1 = black.
[c]Scored: 7 = very fine; 4 = slightly fine; 1 = extremely coarse.
[d]Scored: 7 = very firm; 4 = moderately firm; 1 = extremely soft.
[e,f]Means in the same row within treatment with different superscripts differ ($P < 0.05$).

Cooking and sensory properties. The effect of diet and electrical stimulation on cooking, shear, and sensory properties of steaks from the ribeye muscle are presented in Table 2. Diet did not significantly affect purge loss, juiciness, cooking loss, or flavor intensity. However, steaks from animals fed the accelerated diet were easier to fragment, contained less panel-detectable connective tissue, and were rated more tender. These results indicate a slight advantage in overall palatability of bulls fed a high-energy diet from weaning to slaughter. Therefore, the use of the correct dietary management system will affect the acceptability of the young bull. A high-energy diet fed from postweaning until slaughter may reduce the palatability and carcass trait problems seen in young bulls. Also, the younger the intact male is when slaughtered, the fewer sex- and age-related palatability and carcass problems that will occur.

Electrical stimulation resulted in ribeye steaks that were easier to fragment and more tender than non-stimulated steaks (Table 2). These results were probably due to fracture of the muscle fibers and/or the reduction of cold-shortening in lean bull carcasses. (The non-stimulated lean bull carcasses may have been subjected to a larger amount of cold-induced muscle shortening.)

Table 2—Means of cooking, shear, and palatability segregated by diet and electrical stimulation

	Diet		Electrical stimulation	
Trait	Accelerated	Deferred	Stimulated	Non-Stimulated
Purge loss (%)[a]	2.5	2.7	2.5	2.8
Total cooking loss (%)[b]	34.4	35.4	33.7[e]	36.0[d]
Shear force (lb)	9.5[e]	10.4[d]	8.8[e]	10.8[d]
Sensory panel traits[c]				
Juiciness	5.3	5.3	5.4[d]	5.3[e]
Fragmentation	5.2[d]	5.0[e]	5.2[d]	5.0[e]
Connective tissue	5.1[d]	4.9[e]	5.1[d]	4.9[e]
Tenderness	5.3[d]	5.1[e]	5.3[d]	5.1[e]
Flavor intensity	5.4	5.4	5.5[d]	5.4[e]
Off-flavor	2.6[e]	2.8[d]	2.6	2.7

[a]Purge loss = frozen weight - thawed weight x 100.
[b]Total cooking loss = frozen weight - cooked weight x 100.
[c]Sensory scores: Juiciness: 1 = extremely dry to 8 = extremely juicy. Fragmentation: 1 = extremely difficult to 8 = extremely easy. Connective tissue: 1 = abundant amount to 8 = no detectable connective tissue. Tenderness: 1 = extremely tough to 8 = extremely tender. Flavor: 1 = extremely bland to 8 = extremely intense. Off-flavor: 1 = no off-flavor to 8 = extremely intense off-flavor.
[de]Means in the same row within treatment with different superscripts differ ($P < 0.05$).

Microbial Decontamination and Weight of Carcass Beef as Affected by Automated Washing Pressure and Length of Time of Spray

John D. Crouse, Maynard E. Anderson, and H. Donald Naumann[1]

Introduction

Carcass beef has traditionally been washed by hand to remove foreign material such as hair, soil particles, and microbiological organisms that have contaminated the surfaces. These carcasses are inspected by the Food Safety Inspection Service (FSIS) to detect defects related to carcass cleanliness. Recent research and development of technology have emphasized automated machine washing.

At pressures above that normally used, it is conceivable that water could penetrate tissue surfaces and be absorbed by the carcasses. Also, longer wash periods may enhance water uptake by carcasses. According to the ASHRAE Handbook and Product Directory, the average shrinkage of carcass beef using good current practices was 1.3% at 20 hr postmortem. USDA meat inspection regulations required that carcasses sustain no net increase in weight due to absorption of water during the washing process. There is no available literature on the effects of various automated washing techniques on carcass weights after a 20-hr chill.

The objectives of the study reported presently were to determine the effects of nozzle pressure and length of time washed on the microflora and weights of carcass beef at 20 hr postmortem.

Procedure

Material and design. Carcasses were obtained from 56 heifers that were fed a corn-corn silage diet. Heifers were slaughtered, dressed, and carcasses split by normal commercial procedures. Carcasses were skinned by knife while on the rail without the use of an automated hide puller. Sides were not shrouded after washing. Sides were assigned randomly to a 3 x 2 split-plot experiment. Sides were washed with water at slow (15 ft/min), medium (20 ft/min), or fast (25 ft/min) chain speeds (CS) through an automated carcass washer. Sides within carcasses were assigned to low pressure (350 psi) or high pressure (600 psi) water spray wash (SP). Carcasses were stored in a 32°F cooler during the study.

Washing. Sides passed through a chamber between two spray bars that oscillated on a vertical axis of 45°. The spray bars were opposite each other, and each possessed nine locations for single or double nozzles. Nozzles of opposite bars were 25 inches apart. (Nozzle sizes and locations and a description of the chamber is provided in detail by Anderson et al.) Carcass sides were weighed before washing, 5 min after washing, and 20 hr after washing using on-rail scales.

Microbiology. A random subsample of equal number of right or left sides from 36 carcasses was used to enumerate microorganisms before washing and 20 hr after washing. After treatment (20 hr postmortem), carcasses were sampled from locations adjacent to location of initial sampling. A sterile template (15 in) was used to define the sample area. Two adjacent samples were taken from the round over the Biceps femoris muscle, and two adjacent samples were taken from the forequarter over the Longissimus muscles adjacent to the first through fifth thoracic vertebrae. Sterile forceps and scalpel were used to remove tissue samples .2 in deep.

Tissue from both 15-in sample sites within the forequarter or hindquarter were placed in a stomacher bag containing 100 ml of 0.1% peptone diluent, top sealed by heat, placed in an ice chest, and transported within 8 hr to the laboratory for serial dilution, plating, and incubation.

Violet red bile agar with glucose was used to enumerate *Enterobacteriaceae.* Aerobic microorganisms were enumerated on standard plate count. Samples were plated at appropriate dilutions, and counts were made according to *Standard Methods for the Examination of Dairy Products*, except for incubation temperatures. Standard plates and violet red bile plates were incubated at 95°F for 48 and 24 hr, respectively.

Carcass observations. After holding 24 hr at 32°F, carcasses were evaluated for quality and yield grade factors by USDA procedures (Table 1). Average carcass weight

Automated carcass washer.

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was 643 lb. Marbling (small[10]) and maturity (A[45]) scores indicate that carcasses were typical of those grading low USDA Choice. Carcasses also possessed 0.34 in fat thickness over the longissimus muscle at the 12th rib.

Data analyses. Data were analyzed by least-squares procedures. Variation in weight due to treatments was examined by analyzing differences between weights before washing and weights 5 min after washing or weights 20 hr after washing. Similarly, variation in the microbial contamination due to treatments was examined by analyzing differences in plate counts obtained from samples before treatment with plate counts from samples obtained after treatment. Data on microbiological counts were expressed in logs to the base 10. Main effects and 2-way interactions were fitted to the model. Preliminary analysis indicated that 3-way interactions were not important sources of variation.

Results

Carcass weight. Interactions of SP by CS were not important sources of variation in side wt. Weights of sides were similar at high or low SP at all three CS treatments. Side weights before, 5 min after, and after 20 hr of storage are given in Table 2. Sides gained 1.8 lb (0.57%) in wt during washing. However, the gain in side wt plus an additional 3.3 lb (1.04%) was lost during the 20-hr storage period.

Variation in change (before washing — after washing) of side wt due to SP are given in Table 3. Sides washed with high SP gained more than sides washed with low SP (2.0 *vs* 1.6 lb). After 20 hr of storage, weights of sides were similar in both treatment groups. Therefore, SP does not have long-term effects on water uptake of sides.

Sides washed with the slow CS gained more wt than sides washed with the medium CS 5 min after washing (Table 4). Similarly, sides washed with the medium CS were heavier than sides washed with the fast CS. However, after 20 hr of storage, sides among the three CS treatments were similar in wt.

Bacterial contamination. Washing reduced *Enterobacteriaceae* counts by 1.52 log (Table 2). The reduction in aerobic counts was 0.87 log. The aerobic count reduction is similar to previous observations using a tap water wash, but less than reductions when short-chain organic acids or chlorine are used as sanitizing agents.

Enterobacteriaceae counts were similar for the forequarter and hindquarter and reduction in *Enterobacteriaceae* counts was also similar between the two areas. However, aerobic counts were greater in the forequarter than the hindquarter (5.44 *vs* 5.29 logs). Although this difference was statistically significant, the difference was not likely of practical importance. Washing had a greater impact on the reduction of bacteria in the forequarter than the hindquarter (1.13 *vs* 0.68 logs). The increased reduction in the forequarter cannot be accounted for entirely by the larger initial contamination.

Reduction in *Enterobacteriaceae* counts was not affected by SP (Table 3). However, a trend in greater reductions in aerobic counts was observed for the low-SP compared to the high-SP treatment. *Enterobacteriaceae* counts or aerobic bacteria counts were not affected by CS (Table 4). Means for the slow CS indicated a possibility of greater reduction of *Enterobacteriaceae* than means for the medium or fast CS; however, this increased reduction was not statistically significant.

Research on carcass decontamination presently reported indicates that the pressure of water spray between 350 to 600 psi and speed of chain between 15 to 25 ft/min had no residual effect on water uptake of the carcass after 20 hr. Also, any combination of these pressures and chain speeds will make reductions in bacterial contamination. Forequarters possess greater contamination than hindquarters, but washing the carcass eliminates the differential in number of organisms. Additional research is needed to determine the effects of nozzle size or configuration. Variation in nozzles may affect water droplet size, water uptake by the carcass, and decontamination.

Table 1—Characteristics of carcasses used in carcass washing study

Trait	Mean
Liveweight, lb	1,015
Hot carcass wt, lb	643
Fat thickness, in	.34
Longissimus muscle area, in^2	12.47
Kidney, pelvic, and heart fat, %	3.0
Marbling[a]	410
Maturity[b]	145

[a]Marbling was scored: Slight- (300) to slight + (399), small- (400) to small + (499), etc.

[b]Maturity was scored: A- (100) to A + (199).

Table 2—Variation in change in side wt and reduction in *Enterobacteriaceae* counts and aerobic counts by spray pressures

	Pressure	
Trait	Low	High
Change in wt, lb:		
No.	58	54
5 min	1.60	2.07
20 hr	-3.33	-3.36
Bacterial counts, log:		
No.	36	36
Enterobacteriaceae	1.51	1.54
Aerobic	0.99	0.77

Table 3—Variation in change in side wt and reduction in *Enterobacteriaceae* counts and aerobic counts by chain speeds

	Chain Speed		
Trait	Slow	Medium	Fast
Change in wt, lb:			
No.	38	38	36
5 min	2.10	1.83	1.58
20 hr	-3.38	-3.34	-3.32
Bacterial counts, log:			
No.	21	21	21
Enterobacteriaceae	1.65	1.48	1.46
Aerobic	1.02	0.71	0.90

Table 4—*Enterobacteriaceae* and aerobic counts by locations and reduction

	Location	
Trait	Forequarter	Hindquarter
Enterobacteriaceae, log:		
Before	5.75	5.70
Reduction	3.48	3.26
Aerobic, log:		
Before	5.44	5.29
Reduction	1.13	0.68

Influence of Genotype and Maternal Environment on Growth Hormone and Prolactin Secretion in Cattle

John Klindt and Ralph R. Maurer[1]

Introduction

The phenotype of an individual is the manifestation of that individual's genotype, environment, and the interaction of that genotype and environment. The genotype is attributable to nuclear genetic material equally contributed by the sire and the dam. The *in utero* environment and(or) the genotype of the dam (maternal effects) have long been known to have an influence on fetal and postnatal development. These effects were documented by Walton and Hammond (1938), who described the growth of Shetland pony-Shire horse reciprocal crosses. The physiology of the individual (e.g., enzyme activities, endocrine secretion and function) is the phenotypic expression of that individual's genotype and environment just as much as grossly observed characteristics such as color, height, and weight.

The objective of the present study was to investigate the effects of genotype and prenatal maternal environment on the secretion of two metabolically important hormones [growth hormone (GH) and prolactin (PRL)] and the growth of individual calves of Angus-Red Poll genotype. Through embryo transfer, the confounding of the effects of maternal genetic contributions and prenatal maternal environment was eliminated.

Procedure

Eight full-sib pairs of Angus-Red Poll genotype calves whose gestational development occurred in cows of either the Angus or Red Poll breeds were selected for use in the present study. The eight pairs selected for use in this study represented four pairs with Angus sires and Red Poll dams and four pairs with Red Poll sires and Angus dams (Fig. 1). The male calves were castrated at birth. Three to five days after birth, the calves were removed from their gestational dams and thereafter raised in nursery stalls on milk replacer, thus eliminating the influence of postnatal maternal effects (e.g., lactation) on postnatal performance. The calves were weighed at birth and at an avg age of 150 days, and those weights were adjusted to that age. Average daily gain from birth to 150 days was calculated.

When the calves were 8 to 9 wk of age (60 ± 1 day of age, mean ± SE), they were fitted with indwelling jugular cannalae. The following day, blood samples were collected via the cannulae at 15-min intervals for an 8-hr period.

The temporal concentrations of each hormone within each animal were subjected to an algorithmic procedure which defined the secretory pattern in terms of overall mean concentration, baseline mean concentration, number of secretory peaks, and amplitude above baseline of those peaks.

Results

Calves from Red Poll recipients had significantly greater birth and 150-day weights. The genotype effect was not significant for any growth estimate. However, the effects of sex and the interaction of sex with genotype was significant for 150-day wt and birth to 150-day avg daily gain. The interaction of recipient breed and genotype and the interaction of recipient breed and sex were both significant for 150-day wt and avg daily gain.

Prolactin baseline concentration was influenced by genotype ($P < .05$). Sex of calf had a significant effect on basal concentration of GH, amplitude above basal concentration of the GH peaks ($P < .05$), and, thus, on mean GH concentration ($P < .1$) (higher in the castrate males than in females). The interaction of genotype and recipient breed was significant for mean growth hormone concentration and number of growth hormone peaks. The interaction of recipient breed and sex was significant for mean growth hormone concentration.

Discussion

The influences of uterine or prenatal environment (recipient breed) and the interactions of prenatal environment and genotype (sire breed-dam breed combination) and sex accounted for the majority of the significant effects observed. Genotype differences alone accounted for little of the variation in the phenotypic characteristics studied. Thus, differences in maternal genetic contributions between the Angus and Red Poll breeds had little or no effect on most of the parameters estimated.

It has been demonstrated in previous studies that the influences of the maternal genetic contributions or uterine environment, or both, and postnatal maternal effects (e.g., lactational ability) combined have pronounced and permanent influences on the growth and development of the offspring. In those studies, prenatal and postnatal effects were confounded. Through the use of embryo transfer technology, we have separated prenatal maternal effects caused by breed differences in ovum cytoplasm from those caused by breed differences in uterine environment. By removing calves from dams and rearing with milk replacer diet, we have eliminated the confounding postnatal effects of maternal lactational ability.

[1]Klindt is a research physiologist, Meats Unit, and Maurer is a research physiologist, Reproduction Unit, MARC.

Calf No.	Pair	Genotype (Breed of Sire x Breed of Dam) (GT)	Recipient Breed (RB)	Sex (SX)
1	1	Red Poll x Angus	Red Poll	Female
2			Angus	Female
3	2	Red Poll x Angus	Red Poll	Female
4			Angus	Female
9	3	Red Poll x Angus	Red Poll	Female
10			Angus	Female
11	4	Red Poll x Angus	Red Poll	Male
12			Angus	Male
5	5	Angus x Red Poll	Angus	Male
6			Red Poll	Male
7	6	Angus x Red Poll	Red Poll	Male
8			Angus	Male
13	7	Angus x Red Poll	Red Poll	Male
14			Angus	Male
15	8	Angus x Red Poll	Angus	Female
16			Red Poll	Female

Figure 1—Description of calves used in this study. Calves within a pair were full-sibs. At 8 days post-estrus, the embryos were transferred (→) to recipient cows of each breed.

The effect of recipient breed was significant for birth wt, 150-day wt, and GH peaks. The uterine environment provided by Red Poll cows was more favorable for fetal growth and subsequent postnatal growth than the uterine environment of the Angus cows. However, the uterine environment provided by Angus cows allowed the calves they carried to develop with a greater ability to secrete GH episodically. Thus, GH was negatively associated with prenatal and postnatal growth rate. The calves carried by Angus cows or carried by Red Poll cows and derived from Angus ova had more GH secretory peaks. The uterus and maternal placenta have two major roles, nutrition of the fetus and endocrine synthesis and secretion, both of which may be contributing to the differences observed in the present study. Recipient breed (the environmental influence) represents the nutrient availability to the fetus and the maternally determined endocrine environment to which the fetus is exposed. Genotype effects and sex represent genetic influences which determine nutrient requirements of the fetus.

The data presented provide evidence that the phenotypic characteristics of an individual are the result of both genetic and environmental influences in cattle. These data also imply that the environmental influences impinge upon the development of the individual throughout its life. As reported by Walton and Hammond (1938), maternal effects influence the growth of the individual. Maternal effects, such as maternal genetic contributions and prenatal environment, also influenced GH and PRL secretion, particularly GH.

Relationship of Growth Hormone, Prolactin, and Thyrotropin Secretion to Individual and Progeny Performance of Hereford Bulls

Danny L. Ohlson, Robert M. Koch, John Klindt, and Steven L. Davis[1,2]

Introduction

Evidence from several studies has supported a predictive relationship between measures of somatotropic hormones and genetically determined growth potential in domestic ruminants. In these studies, blood concentrations of hormones associated with growth were generally higher in lines or breeds with greater growth potential. However, no significant positive correlations between measures of hormone secretion and measures of growth in individual animals were observed.

The present study further assesses the association between growth potential, growth rate, and secretion of growth hormone (GH), prolactin (PRL), and thyrotropin (TSH) using bulls of two Hereford lines that differ in growth rate as a result of genetic selection. The objectives of this study were (1) to compare blood levels of GH, PRL, and TSH between the two lines of bulls, and (2) to evaluate the predictive value of sire hormone data for growth rate of their progeny.

Procedure

Animals were representatives of Hereford lines established in 1960 to investigate response to mass selection in traits of economic importance in beef cattle. Briefly, three lines of Herefords were established at the Fort Robinson Beef Cattle Research Station, Crawford, Nebraska, and maintained there through 1971. Selection in one line was practiced for 200-day wt adjusted for age of dam. Adjusted final wt, at 424 days for bulls and 500 days for heifers, was the selection criterion in the second line. Selection based on an index giving equal emphasis to adjusted final wt and muscling score was used for the third line (index line). Muscling score was a measure of thickness of forearm, loin, rump, and round, with degree of fatness discounted. After 1971, a non-selected control line was established using foundation animals.

After the 1982 breeding season, six bulls from the control line and six bulls from the index line were placed in individual stanchions and fed *ad libitum* a diet of corn silage and high moisture corn for 3 wk. The photoperiod was 16 hr light: 8 hr dark, starting at 6 a.m. After this adaptation period, a jugular cannula was inserted into each bull for blood sampling. The next day, 10-ml blood samples were collected into heparinized vacutainers at 15-min intervals for 8 hr, beginning at 8:30 a.m. Samples were chilled on ice during collection, stored overnight at 39°F, and plasma was harvested and stored at -4°F until assayed. The bulls in this study were 2 and 3 yr of age when the blood samples were drawn.

Plasma concentrations of GH, PRL, and TSH were determined by radioimmunoassay. Mean overall concentration (Mn 33 observations), mean baseline concentration (Bl), spike amplitude (Am, magnitude of secretory spike above baseline), and spike frequency (Pk) were calculated for each hormone in each bull.

Results

Bulls representing the index line were heavier at birth ($P < .02$) and gained at a faster rate postweaning ($P < .01$) than bulls representing the control line. Also, the progeny of sires from the index line were heavier at birth and gained more rapidly from birth to weaning and postweaning (all $P < .001$) than progeny from control line sires.

Overall mean concentrations of GH were higher ($P < .03$), and overall and baseline concentrations of PRL tended to be higher ($P < .07$, $P < .08$) in index compared with control bulls. Other measures of hormone secretion did not differ significantly between lines, but were, in each instance, higher in index bulls than in control bulls.

Individual performance of parents was the basis of selection in the experiment. The three types of selection imposed were effective in making slow but significant changes in growth rate. The characteristics of GH, PRL, and TSH (Mn, Bl, Pk, and Am) accounted for significant amounts of variation in birth wt and postweaning daily gain of progeny and, when combined with sire growth rate, increased the accuracy of prediction of progeny performance.

Although meaningful interpretation of the individual partial regression coefficients is not possible in these data, the results indicate that measures of hormone secretion may have value for predicting the expected growth response of progeny. Presumably, useful prediction equations could be obtained from hormone profiles on larger numbers of sires and their progeny. Perhaps more than one "window" of hormone secretory activity should be monitored. Also, monitoring at different stages of the growth cycle should be investigated to determine the optimal time or times for accurate prediction of progeny performance. Results of the present study support those of earlier research comparing Hereford and Simmental bull calves and comparing two lines of Targhee rams. Members of a breed or line with the genetic potential for faster growth or larger mature size exhibit some significantly elevated characteristics of hormone secretion (GH and PRL in Simmentals and GH and TSH in selected rams) when compared with animals with less genetic potential for growth rate and mature size.

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[1]Ohlson was a research associate, Meats Unit, MARC; Koch is a professor of animal science, University of Nebraska-Lincoln, stationed at MARC; Klindt is a research physiologist, Meats Unit, MARC; and Davis is the animal science department head, Oregon State University.

[2]The full report of this work was published in J. Anim. Sci. 65:63-67, 1987.

Follicle and Oocyte Relationships During Superovulation in the Heifer

Thomas H. Wise and Ralph R. Maurer[1]

Introduction

As the female cow matures, the majority of her follicles become atretic and are lost as a store house of the female gamete (oocyte). Emphasis on *in vitro* fertilization to maximize the utilization of superior animals for transplant of frozen embryos is considerably limited by the number of viable mature oocytes that can be collected. Understanding the biochemical environment required to produce maximum numbers of mature, fertilizable oocytes is a prime requirement to utilize this technology in increasing meat animal production and efficiency.

The goal of these studies was to characterize the endocrine and biochemical events associated with follicle and oocyte maturation to establish the best environment for follicle development and maximize numbers.

Procedure

Experiment 1 involved 60 crossbred heifers assigned to control (n = 30) or superovulatory regimen (n = 30) via follicle stimulating hormone (FSH-P). One-third of the animals from each group were ovariectomized 24, 48, and 72 hr after prostaglandin F2α synchronization (PGF2α). Follicular fluid was collected from individual follicles (n = 76, controls; n = 551, FSH = stimulated) and analyzed for progesterone, estradiol, prostaglandin E, prostaglandin F, oxytocin, sodium, and potassium content.

Experiment 2 involved 103 crossbred heifers which were estrous synchronized (PGF2α) and superovulated with FSH. Animals were ovariectomized every 12 hr after PGF2α injection, and follicles were harvested. Twenty-eight animals were implanted with Norgestomet implants 12 hr before the PGF injection, then ovariectomized 72, 84, 96, and 108 hr after PGF2α. Oocytes were evaluated from 2,470 follicles, classified as degenerate or viable, and compared to follicular endocrine parameters (progesterone, prolactin).

Results

Experiment 1. Of the follicular parameters monitored, no differences were noted between follicles developed under normal circumstances or with FSH stimulation to induce multiple follicles. By 72 hr after PGF2α administration, follicular estradiol was decreasing in concentration, and progesterone and oxytocin were increasing, thus signifying a change in the secretory role of the granulosa cells. At 48 hr after the PGF2α injection, sodium decreased and potassium increased, thus signifying a considerable physiological change in the follicle. Prostaglandin E and F increased ten-fold by 72 hr, and increased concentrations were generally found in estrogen-inactive follicles at 72 hr.

Experiment 2. Since 65% of the animals exhibited normal LH surge, the data was divided into three groups (animals exhibiting an LH surge, animals not exhibiting an LH surge, and animals in which the LH surge was suppressed with Norgestomet implants). Follicular fluid prolactin concentrations were similar in all treatment groups in that, from 12 to 48 hr after PGF2α, prolactin increased, then steeply decreased. Follicular progesterone concentrations in large- and medium-sized follicles increased after the LH surge. Animals in which no LH surge was detected or suppressed with Norgestomet implants had follicular progesterone concentrations that remained low in all follicular sizes.

Oocyte recovery was 77% from 2,470 follicles. Oocyte quality increased from 60 to 70% up to the LH surge and remained at 60% for the rest of the time analyzed (60-108 hr). Oocyte quality was considerably better (80%) in large-sized follicles (> 9 mm dia). In Norgestomet-implanted animals, oocyte quality was 36% good at 72 hr after PGF2α and 19% good at 108 hr. Prolactin concentrations in follicular fluid increased up to the period of the LH surge, then sharply declined. For animals in which no LH surge was detected, follicular fluid prolactin changes were similar to those noted in normally ovulating animals. Prolactin concentrations were increased in follicles producing high quality oocytes (before and during the LH surge). After the LH surge, prolactin decreased in all follicles, and, as an index of oocyte quality, is questionable.

Increased concentrations of progesterone and prolactin in human follicular fluid have been reported to be related to oocyte maturity and successful *in vitro* fertilization. Analysis of bovine oocytes and follicular fluid prolactin concentrations support the human data, but no relationships were detected between follicular fluid progesterone concentrations and oocyte quality. The characterization of the endocrine and biochemical events associated with follicle and oocyte maturation will eventually lead to the correct stimulating regimes to maximize oocyte quality and numbers.

[1]Wise and Maurer are research physiologists, Reproduction Unit, MARC.

Fetal Development in Cows With Multiple Fetuses

Sherrill E. Echternkamp[1]

Introduction

About 60% of the nutrient requirements for beef production in the U.S. are for maintenance of the breeding herd. In addition, the bovine female only produces about .7 of her body wt per yr in progeny wt. Thus, increasing the reproductive rate in beef cattle would have a major economic benefit. Although most bovine females are capable of gestating two calves, the natural frequency of twin births is low, ranging from less than .5% to 4% of the calvings, depending upon the breed of cattle. Several studies have indicated that the frequency of multiple births in cattle can be increased by gonadotropin hormonal therapy or by the artificial transfer of two 7- or 8-day-old embryos into the uterus. Unfortunately, the twinning response to these methods has been highly variable both within and among herds of cattle. The present study was conducted to identify causes for the variable twinning response in cattle to low dosages of gonadotropin therapy, to assess fertility in cattle that ovulate multiple oocytes (eggs), and to assess the relationship between number of fetuses and development of the fetus.

Procedure

Nonlactating mature beef cows (96 cows) were given multiple low-dosages of follicle stimulating hormone (FSH) to stimulate multiple follicles on the ovaries to release eggs that would be fertilized and presumably result in twin or multiple fetuses. The FSH (total dosage = 12 mg) was administered intramuscularly twice daily (12 hr apart) for 4 days, starting 8 to 12 days after estrus. The FSH treatment schedule was two injections (a.m. and p.m.) of 2 mg FSH on day 1 of treatment, two injections of 2 mg on day 2, two injections of 1 mg on day 3, and two injections of 1 mg on day 4. Each cow received a 35 mg intramuscular injection of prostaglandin $F_{2\alpha}$ the morning of day 4 to regress the corpus luteum (CL) and synchronize estrus. Cows were bred naturally by fertile bulls at the subsequent estrus; estrus occurred about 60 hr after the prostaglandin injection.

The cows were slaughtered either 6 to 8 days after mating (25 cows) to assess fertilization of the eggs, or 51 to 53 days after mating (71 cows) to assess fetal development. The female reproductive tract was removed, the number of ovulation sites on each ovary was recorded, and the lumen of the uterus and oviducts were flushed with saline to recover embryos, fetuses, and unfertilized eggs (oocytes). Fertilization rate and fetal size and development were measured microscopically or grossly, respectively.

Results

For the cows slaughtered 6 to 8 days after mating, the number of ovulation sites (ovulation rate) ranged from one to five. The relationship between ovulation rate and percentage of normal embryos, dead or degenerate embryos, and unfertilized eggs at 7 ± 1 days after mating is shown in Table 1. Fertilization rate and embryonic development at 6 to 8 days after mating were not affected by number of ovulations.

At 52 ± 1 days after mating, ovulation rate ranged from 1 to 27 and, thus, was more variable to the same FSH treatment in this group of cows than in those cows slaughtered earlier. The relationship between number of ovulations and fetal number and development at 52 ± 1 days of gestation is shown in Table 2. As the number of ovulation sites (CL) exceeded two, the number of dead or abnormal fetuses increased as did the number of unrecovered fetuses. The maximal number of live fetuses recovered from a uterus at 51 to 53 days of gestation was five fetuses, and the maximal number of live fetuses per uterine horn was three fetuses. Weight of the individual corpus luteum (CL) on the ovaries decreased as the number of CL per cow increased from one to two to three or more. Weight, length, and width of individual live fetuses (Table 3) were not affected by the number of live fetuses present in the uterus at 52 ± 1 days of gestation. However, as indicated previously, the number of dead or degenerative fetuses recovered increased as the total number of fetuses (dead + live) increased; the dead fetuses were approximately one-third to one-half the size of live fetuses. In contrast, placental wt per live fetus was decreased proportionally to the number of fetuses present.

[1]Echternkamp is a research physiologist, Reproduction Unit, MARC.

Table 1—Effect of ovulation rate on fertilization rate and embryonic survival at 7 (±1) days postmating[a]

Ovulation rate[b]	No. cows	No. and percentage of embryos or oocytes		
		Normal embryo	Abnormal embryo	Unfertilized oocyte
1 CL	12	7 (58.3)[c]	2 (16.7)[c]	3 (25.0)[c]
2 CL	10	9 (45.0)	3 (15.0)	8 (40.0)
3 CL	1	2 (66.7)	1 (33.3)	
4 CL	1	4 (100.0)		
5 CL	1	3 (60.0)	1 (20.0)	1 (20.0)

[a]Cows received FSH (total dosage = 12 mg) twice daily for 4 days (2 mg x 2, 2 mg x 2, 1 mg x 2, 1 mg x 2) beginning on days 8 to 12 after estrus (estrus = day 0) and 35 mg prostaglandin $F_{2\alpha}$ on fourth day (a.m.) of FSH. Cows bred via natural insemination.

[b]Ovulation rate was the number of corpora lutea (CL) present at 6, 7, or 8 days postmating.

[c]Percentage of embryos or oocytes per number of CL.

In cows with multiple fetuses at 52 ± 1 days of gestation, the placental membranes were generally attached between adjacent fetuses, resulting in a common blood supply among the fetuses. Consequently, death of one bovine fetus in a multiple fetation pregnancy resulted in death and subsequent expulsion of all fetuses contained within the same connected placenta.

Conclusion

The variation in twinning response to hormonal therapy resulted initially from variation among cows in ovarian stimulation and the number of eggs (oocytes) released from the ovaries. The percentage of eggs fertilized by the sperm was not affected by number of eggs present. However, increasing the number of fertilized eggs per cow subsequently increased the total number of fetuses and the number of dead fetuses at 52 ± 1 days of gestation; death of the fetuses generally occurred at about 25 days after mating. Because of the high incidence of placental attachment among bovine fetuses in multiple fetation pregnancies, death of one fetus terminates the pregnancy and, thus, reduces the opportunity for twins or multiple calves. The connecting of placental blood supplies between fetuses is a phenomenon rarely found in other farm animals. The lower birth wt of twin or multiple calves is manifested during the third trimester of pregnancy, whereas fetal wt and development during the first trimester of pregnancy are not affected by number of fetuses present.

Table 2—Effect of ovulation rate on fetal survival at 52 (± 1) days post-mating[a]

Ovulation rate[b]	No. Cows	No. CL	CL wt(g)	Fetal status		
				Normal	Abnormal	Absent
1 CL	16	16	5.28[d]	17 (106.3)[c]		
2 CL	10	20	4.17[e]	20 (100.0)		
3 CL	6	18	2.65[f]	12 (66.7)	3 (16.7)	3 (16.7)
4 CL	6	24	2.28[f]	11 (45.8)	5 (20.8)	8 (33.3)
5 CL	9	45	2.15[f]	15 (33.3)	14 (31.1)	16 (35.6)
6-10 CL	10	81	1.89[f]	11 (13.6)	59 (72.8)	11 (13.6)
10 CL	3	56	2.22[f]	5 (8.9)	32 (57.1)	19 (33.9)

[a]Cows received FSH (total dosage = 12 mg) twice daily for 4 days (2 mg x 2, 2 mg x 2, 1 mg x 2, 1 mg x 2) beginning on days 8 to 12 after estrus (estrus = day 0) and 35 mg prostaglandin $F_{2\alpha}$ on fourth day (a.m.) of FSH. Cows bred via natural insemination.

[b]Ovulation rate was the number of corpora lutea (CL) present at 51, 52, or 53 days postmating.

[c]Percentage of number of fetuses per number of CL present at fetal assessment.

[def]Means without a common superscript differ; [de] $P < .05$, [ef] $P < .01$.

Table 3—Effect of number of fetuses on fetal and placental size at 52 days of gestation

Trait	Number of live fetuses				
	1	2	3	4	5
No. cows	17	18	7	3	1
Fetal wt (g)	6.57	7.01	7.03	7.31	7.13
Fetal length (mm)	43.3	44.4	45.2	45.7	46.2
Fetal width (mm)	14.5	14.7	14.2	14.4	14.9
Placental dry wt (g)	2.19	1.63	1.33	1.21	1.21
Amniotic fluid volume (ml)	28.1	30.1	32.3	30.9	39.3

Current Concepts for Understanding Ovarian Follicular Growth and Function in Cattle

Leon J. Spicer and Sherrill E. Echternkamp[1,2]

Introduction

Ovarian follicular development in cattle during either the estrous cycle or postpartum anestrus is not presently well understood. Although several investigators have suggested that follicular development is continuous, the notion that follicular growth occurs in waves still persists. A better understanding of bovine folliculogenesis is required to solve beef production problems such as prolonged postpartum infertility and variable responses to superovulation and estrous synchronization treatments. Therefore, research was conducted at MARC and results compared with earlier studies to explain follicular growth and function in cattle during postpartum anestrus.

Follicular Growth

Folliculogenesis may be defined as formation of Graafian (mature, preovulatory) follicles from a pool of primordial (non-growing) follicles (Fig. 1). The pool of primordial follicles remains stable from birth until about the fourth yr of life, and then subsequently declines. In comparison, numbers of antral follicles (follicle with a fluid filled cavity) remain constant (30 to 60 per pair of ovaries) in cows up to 10 yr of age and then decline to less than 50% of maximal numbers at 15 to 20 yr of age. Measurements such as numbers of follicles within various size categories and mean sizes (i.e., diameter) of various types of follicles have been the predominant criteria for assessment of follicular growth in cattle. Several researchers have reported significant variation in numbers of various sized antral follicles during both the bovine estrous cycle and postpartum anestrus.

The limited information available on growth of antral ovarian follicles in cattle during postpartum anestrus suggests that follicular growth increases markedly after the first wk postpartum and that large antral follicles (> 10 mm diameter) may be present up to 5 wk prior to the first postpartum estrus. We have shown that large follicles ($\geq$ 8 mm) are present on the ovarian surface as early as 7 days after parturition and that the number of medium-sized follicles (4-7.9 mm in diameter) increases significantly during the first 7 wk postpartum. Thus, large antral follicles are present during postpartum anestrus, but they do not ovulate soon after they appear. Although large doses of gonadotropin-releasing hormone (GnRH) or estradiol can induce normal gonadotropin surges by this time, these large follicles may be incapable of producing sufficient estradiol to increase estradiol in blood (10 to 15 pg/ml of blood) to concentrations required to induce estrual behavior and to stimulate preovulatory gonadotropin surges (and ovulation). We and other researchers have been able to stimulate (in 70-80% of the cows) follicular estradiol production and(or) ovulation by administering multiple low-dose injections of GnRH in suckled beef cattle (Table 1). However, multiple low-dose injections of GnRH have not induced ovulation consistently, which may be due to numerous factors such as dose and injection schedules or nutritional status of dams. Collectively, data from macro- and(or) microscopic evaluation of ovaries of dairy and beef cows suggest that there is growth of small antral follicles into larger follicles during postpartum anestrus. Rate of replacement of large antral follicles within the ovaries during postpartum anestrus in unknown.

Ovarian Follicular Steroidogenesis

The ovaries of cattle are the major source of estrogens, androgens, and progesterone found in peripheral blood. Consequently, concentrations of these steroids in peripheral blood may measure follicular development and ovarian function. In addition to concentrations of steroids in blood, follicular steroidogenic capability may be ascertained by quantifying concentrations of steroids in follicular fluid. There is strong evidence to indicate a high positive correlation between *in vitro* follicular cell steroid production and concentration of steroids in follicular fluid. Thus, the next section will describe changes in concentrations of estradiol, androgens and progesterone in blood and follicular fluid during postpartum anestrus in cattle.

Steroids in Peripheral Blood

Estradiol. In cattle, concentrations of estradiol in peripheral blood decrease sharply at parturition to basal levels of 1-5 pg/ml within 2 to 6 days and then increase just before the first postpartum estrus. This increase in preovulatory estradiol is similar in duration and magnitude to that observed during proestrus and estrus in repetitive estrous cycles. However, first postpartum ovulations that occur without estrual behavior are often followed by a short luteal phase. It is unknown if increases in blood estradiol are "normal" before these short luteal phases. Our studies would suggest that ovarian follicles obtain an increased ability to synthesize estrogens at least 2 wk before the first postpartum ovulation.

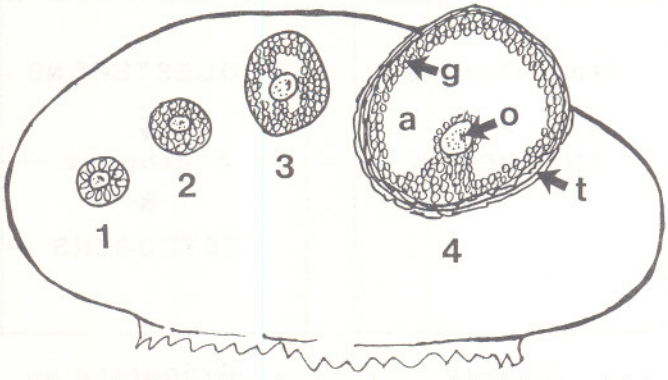

Figure 1—Schematic of various types of follicles present in ovaries of cattle. 1 = primordial follicle; 2 = growing pre-antral follicle; 3 = small antral follicle; 4 = large antral follicle (i.e., Graafian follicle). a = antrum (i.e., cavity filled with follicular fluid); g = granulosa cells; o = oocyte (egg); t = thecal cells.

[1]Spicer is an instructor of medicine, Pennsylvania State University School of Medicine (formally a Michigan State University predoctoral affiliate at MARC); Echternkamp is a research physiologist, Reproduction Unit, MARC.

[2]The full report of this research was published in *Journal of Animal Science* 62:428-451, 1986; 62:734-741, 1986; 62:742-750, 1986; 62:1324-1331, 1986.

Table 1—Comparisons among follicular fluid (FF) steroids and gonadotropin binding sites in granulosa cells (GC) and thecal cells (TC) or large follicles (≥ 8 mm) categorized as either estrogen-active (EA) or estrogen-inactive (EI) after 48 or 96 hr of either LHRH (L) or saline (S) injections in suckled beef cows[a]

Follicle group	n[b]	Average diameter mm	FF estradiol	FF progesterone	GC binding of ^{125}I-hCG	GC binding of ^{125}I-oFSH	TC binding of ^{125}I-hCG
			nf/ml FF		cpm/μg DNA		
48S-EI	6	8.8[c]	11[c]	81[c]	829[c]	1,183[ce]	292
48S-EA	6	10.9[de]	146[d]	51[c]	582[c]	1,928[c]	448
48L-EI	11	9.8[cd]	12[c]	413[d]	1,550[d]	696[de]	298
48L-EA	6	11[de]	157[d]	59[c]	802[c]	1,120[ce]	280
96S-EI[f]	10	9.8[cd]	9[c]	370[d]	594[c]	570[d]	196
96L-EI	6	10.0[cd]	20[c]	319[d]	1,965[d]	583[d]	467
96L-EA	7	12.5[c]	208[d]	73[c]	1,881[d]	1,008[ce]	596

[a]EA = Estradiol concentration > progesterone concentration in FF; EI = progesterone concentrations > estradiol concentration in FF.
[b]Number of follicles.
[cde]Means that do not have a common superscript within a column differ (P < .05).
[f]Only one follicle was EA in 96-hr saline-injected group and was deleted from the table.

Androgens. Studies reporting androgens in peripheral blood during the postpartum anestrous period were not identified.

Progesterone. Concentrations of progesterone in serum are low (< 1.0 ng/ml) at parturition due to the preparturient regression of the corpus luteum of pregnancy and cessation of steroidogenesis by the placenta. Concentrations of progesterone remain low in cows until initiation of estrous cycles. In 40 to 70% of cows examined, a small progesterone peak (< 2 ng/ml) occurs 1 to 6 days before the first postpartum estrus. This increase in concentration of progesterone in peripheral blood, which precedes the first postpartum estrus, may result from formation of a transitory corpus luteum or luteinization of some follicles. However, these structures are unable to maintain normal luteal phase progesterone secretion. The cause of the shortened life span of these corpora lutea (or luteinized follicles) is unknown, but may involve excess prostaglandin production by the uterus or insufficient numbers of follicular receptors for LH.

Follicular Fluid Steroids

Estrogens. Recent studies have reported that concentrations of estradiol in fluid of large follicles (≥ 8 mm diameter) increase significantly between the second and fourth wk postpartum in suckled beef cows. Ovulation did not occur until the sixth wk postpartum in this same study. Thus, it appears that the ability of large follicles to produce estrogens increases about 2 wk before the first postpartum ovulation. These studies also suggest that functional capabilities of ovaries may be limiting reestablishment of estrous cycles during the first 2 to 4 wk postpartum in beef cattle. However, there is no change in the steroidogenic capacity (as measured by concentrations of steroids in follicular fluid) of smaller follicles (1-7.9 mm diameter) during postpartum anestrus. Collectively, studies suggest that circumstances shortly after parturition may allow follicles to develop to a large size but not the development of enzyme systems required for adequate production of estrogen. Recent evidence also indicates that the level of nutrition during the postpartum period may influence follicular estradiol production.

Androgens. In suckled beef cows, concentrations of androstenedione are 2- to 10-fold greater in fluid of medium-sized follicles (4-7.9 mm) than in large-sized follicles (≥ 8 mm) and do not change significantly during the postpartum interval. This suggests that low follicular estradiol secretion may not be due to a lack of aromatizable precursor (androstenedione).

Progestins. Recent studies have reported that concentrations of progesterone in fluid of large follicles (≥ 8 mm in diameter) increase between the first and second wk postpartum in suckled beef cows. This indicates that increased progesterone production preceded estradiol production by large follicles (Fig. 2).

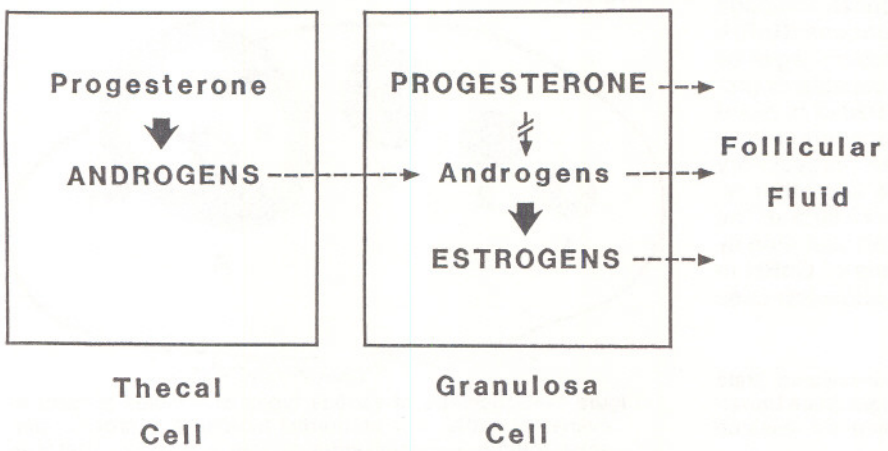

Figure 2—Schematic of the steroidogenic pathway depicting the cellular source of progesterone, androgens, and estrogens found in follicular fluid.

Binding of Gonadotropins to Ovarian Follicles

The concept that the responsiveness of follicles depends not only on changes in concentrations of gonadotropins in serum but also on changes in the concentration of hormone binding sites (or receptors) in cellular membranes of follicles has gained considerable attention during the past few years. Changes in follicular function may be associated with changes in numbers of follicular gonadotropin binding sites.

Numbers of LH receptors in pooled follicular homogenates are significantly higher on day 25 after parturition in nonsuckled *vs* suckled cows. Since nonsuckled cows were approaching first estrus, this may indicate that receptors for LH increase in follicles prior to the first postpartum ovulation. This increase in numbers of LH receptors also is observed near ovulation in cyclic heifers. Number of follicular FSH receptors did not differ between nonsuckled and suckled cows. Similarly, there is no change in number of FSH receptors during the estrous cycle of cattle. Recently, we have found that in anestrous beef cows injected every 2 hr with LHRH (500 ng), the largest follicle per pair of ovaries responds within 96 hr with an increase in number of LH binding sites for both thecal and granulosa cells with no change in number of FSH binding sites (Table 1). This increase in LH binding sites coincided with an increase in concentrations of estradiol in follicular fluid at 96 hr.

Changes in numbers of ovarian LH or FSH receptors were not associated with increased estradiol production in large follicles during the postpartum anovulatory period in suckled beef cattle. This suggests that reduced ovarian function in postpartum cattle is not due to a lack of receptors for gonadotropin hormones.

Conclusions

The mechanism for selection of the follicle(s) destined to ovulate at estrus in cyclic cows or of the follicle(s) destined to ovulate and reinitiate estrous cycles in postpartum anestrous cows is unclear. It is clear, however, that just the presence of a large ($\geq$10mm) follicle on the ovarian surface of postpartum cattle is not a sign of imminent ovulation. Rising titers of estradiol in peripheral blood during the preovulatory periods may be due to increased production of estradiol by large follicles which, in turn, may be due to an increased frequency of pulses of LH in blood and an increased responsiveness to LH within the follicle (i.e., increase in LH receptors). Specific proteins (e.g., inhibin, FSH-binding inhibitor, aromatase inhibitor; insulin-like growth factors) produced by the "selected" preovulatory follicle may aid in its assurance to ovulate.

One cannot rule out potential interactions these intrafollicular peptides have with steroids on ovarian follicles and the anterior pituitary gland. Substances that regulate ovarian blood flow also may be involved in follicular selection, also.

Our current and future research goals are to characterize and define morphological and biochemical markers that could be used to predict ovulatable follicles in cyclic and postpartum cattle. We hope that such markers could be used in such a way as to enhance the success rates of superovulation and ovulation after estrous synchronization treatments.

Mating and Grazing Behavior of Low and High Serving Capacity Beef Bulls During Average and Heavy Mating Loads at Pasture

Garth W. Boyd, Donald D. Lunstra, and Larry R. Corah[1]

Introduction

Although artificial insemination is widely used in dairy cattle, it has found only limited application in beef cattle. Use of bulls in natural mating programs accounts for over 90% of the pregnancies achieved each year in the U.S. beef cattle industry, and a large percentage of the beef bulls used for natural mating are purchased as yearlings. Many of these yearling bulls undergo a breeding soundness examination prior to sale or the breeding season. This involves visual and manual examination of the genital system as well as assessment of semen, which is usually collected by electroejaculation. However, sex drive and mating ability, which are essential for the delivery of viable spermatozoa and impregnation of females, are not commonly measured.

Among beef bulls used for single-sire mating, large ranges in pregnancy rates have been reported, and only low correlations were found between pregnancy rates and semen characteristics. These differences may be potentially explained by differences in the levels of serving capacity (SC) between bulls. Several procedures for testing SC have been used; however, studies investigating the relationship between bulls' SC and herd fertility are inconclusive, with some researchers finding no relationship and other researchers reporting SC test results to be a good predictor of bull fertility. These studies differed in testing procedures used for measuring SC. Thus, differences in the findings may lie in the procedures used for tests or may be due to differences in bull-to-female ratios used when measuring fertility.

At present, there is a lack of research relating the SC of yearling beef bulls in a standardized test with their behavior and fertility under pasture mating conditions. The first objective of this study was to evaluate the sexual and grazing behavior of low and high SC yearling bulls when placed with naturally cycling and estrus synchronized cows under pasture mating conditions during both daylight and dark hours. The second objective was to determine the effect bull SC has on herd fertility, bull body temperature, and distance traveled under these conditions.

Procedure

Eighty crossbred (¼ Angus, ¼ Hereford, ¼ Pinzgauer, ¼ Red Poll) yearling (12-13 mo) beef bulls were subjected to three successive 30 min SC tests. For each test, four estrus-induced ovariectomized heifers were restrained by headgates in a rectangular test pen (25 ft x 50 ft). Bulls were randomly allotted into subgroups of five, and each subgroup was allowed to observe mating activity in the adjacent test pen for 30 min immediately prior to testing. The five prestimulated bulls were then placed in the test pen, and mounts and services were recorded by three independent observers. One week following the last SC test, bulls underwent a standard breeding soundness examination on two successive days. Based on results from these tests and other measurements, 20 bulls were selected that were similar in body wt, scrotal circumference, and seminal traits, but differed in SC. The 10 high SC (HSC) and 10 low SC (LSC) bulls averaged 5.6 and .7 services per test, respectively.

For pasture breeding, the experiment was designed so that each bull's behavior and fertility could be evaluated single-sire. The design was based on a 4-day cycle which was repeated 10 times and evaluated a different pair of HSC and LSC bulls during each cycle (Table 1). Total duration of the experiment was 40 days and began June 16, 1986. To determine mating activity of the bulls, daily observations (Table 1) were made from a centrally located tower (Fig. 1) using telescopes which allowed both daytime and nighttime viewing. In each cycle, bulls were first exposed to 25 naturally cycling cows per bull (average mating load) for three days beginning at 9 a.m. on day 1. These cows were removed at 8 a.m. on day 4 and replaced with 9 estrus synchronized cows for one day (heavy mating load). The heavy mating load was comparable to a bull to cow ratio of 1:175 when 5% of the cows in the herd are in estrus per day.

[1]Boyd is an assistant professor of animal science, Colorado State University (formerly a doctoral candidate at Kansas State University); Lunstra is a research physiologist, Reproduction Unit, MARC; Corah is a professor of animal science, Kansas State University, Manhattan..

Table 1—Design of low *vs* high serving capacity single-sire pasture mating experiment

Day of Cycle[a]	Daily observation schedule[b]	Total time in pasture per bull	No. of cows per pasture[c]	Mating load and status of cows
Days 1-3	6 a.m.-8 a.m. and 7 p.m.-9 p.m.	72 hr	25[d]	Average; Naturally cyclic cows (random estrus)
Day 4	9 a.m.-9 p.m.	24 hr	8.8[e]	Heavy; Synchronized cows (all in estrus)

[a]The design was based on a 4-day cycle which was repeated 10 times (cycle A-J). Total duration of experiment was 40 days and began on June 16, 1986.
[b]During cycles D, F, H, and J, animals were observed for 24 hr continuously on days 2 and 4. On day 1, when new block began, animals were observed from 9 a.m. to 11 a.m. rather than 6 a.m. to 8 a.m.
[c]For each cycle, two identical patterns (one with a LSC bull and one with a HSC bull) were used.
[d]The same 50 naturally cycling cows (25 per pasture) were used for cycles A-E (20 days), after which time they were replaced with 50 new cows for the remaining five cycles.
[e]Represents an average across all cycles.

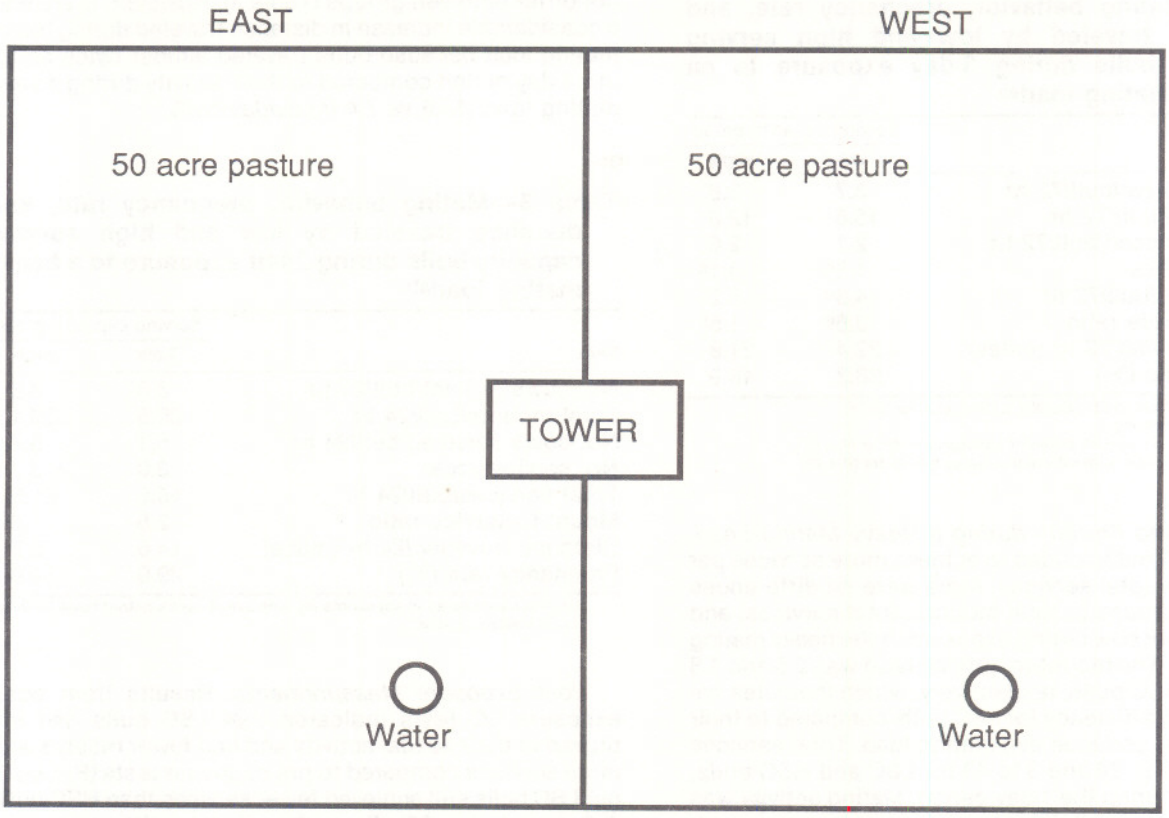

Figure 1—Diagram of identical 50-acre brome pastures where low *vs* high serving capacity single-sire mating experiment was conducted.

On the morning of the first day of each cycle, the pair of bulls to be evaluated were fitted with vibracorders, body temperature recording modules, and pedometers to monitor grazing time, body temperature, and distance traveled, respectively. After a short acclimation period (30 min to 1 hr), this equipment did not appear to affect the bulls' normal behavior. In early August, 10 days after completion of the last cycle, all 20 bulls underwent three post-exposure SC tests, followed 2 days later by breeding soundness examinations conducted in the same manner as those done pre-exposure.

Results

Behavior and Fertility During an Average Mating Load. During each 4-day period, each LSC and HSC bull was exposed to a similar number of cows in standing heat per bull (Table 2). HSC bulls had significantly more total services than LSC bulls, but number of total mounts tended to be higher for LSC bulls (Table 2). Mount-to-service ratio for LSC *vs* HSC bulls was 3.6 and 1.5, respectively ($P < .05$), which indicates that HSC bulls were more efficient when mating, although neither group bred all cows in standing heat. The range in services per cow was 0-4 for LSC and 0-8 for HSC bulls, and the number of services per cow was significantly higher for HSC bulls. During dark hours, there was surprisingly little sexual activity by either group of bulls. Except for a 1- to 2-hr grazing period that occurred around midnight, most of the herd spent the majority of the dark hours lying or standing. During the daylight hours, most cow-cow and bull-cow mounting activity occurred between 6 a.m. to 11 a.m. and 6 p.m. to 9 p.m.

Pregnancy rate did not differ significantly between SC groups during exposure to average mating load for 3 days (Table 2). Distance traveled was not different between SC groups (Table 2) and averaged 7.4 miles/24 hr/bull, which is considerable given the small size of the pasture (50 acres). During each 24-hr period under an avg mating load, LSC and HSC bulls grazed 7.8 (32.6%) and 9.0 hr (37.5%), respectively, which tended ($P = .12$) to indicate that LSC bulls spent less time grazing, and this may be related to the lower mating efficiency of LSC bulls. LSC bulls appeared to spend more time in courtship behavior with cows in heat than did HSC bulls. Body temperature did not differ between SC groups and averaged 102.7°F over each 24-hr period.

Table 2—Mating behavior, pregnancy rate, and distance traveled by low and high serving capacity bulls during 3-day exposure to an average mating load[ab]

Item	Serving capacity group	
	Low	High
No. cows in heat/bull/72 hr	3.7	3.8
Total mounts/bull/72 hr	15.6	12.0
No. cows serviced/bull/72 hr	2.1	2.6
No. services/cow	1.5[c]	3.1[d]
Total services/bull/72 hr	4.3[e]	8.2[f]
Mount-to-service ratio	3.6[e]	1.5[f]
Distance traveled/72 hr (miles)	22.4	21.8
Pregnancy rate (%)	58.3	48.9

[a]Each bull exposed to 25 naturally cyclic cows for 72 hr.
[b]Least-squares means.
[cd]Means within a row with different superscripts differ (P = .07).
[ef]Means within a row with different superscripts differ (P < .05).

Behavior and Fertility during a Heavy Mating Load. Although HSC bulls tended to achieve more services per cow and more total services, there were no differences between SC groups in total mounts, total services, and avg services per cow during exposure to the heavy mating load (Table 3). The mount-to-service ratio was 2.5 and 1.8 for LSC and HSC bulls, respectively, which indicates improved mating efficiency for LSC bulls compared to their efficiency (3.6) under an avg mating load. Total services ranged from 5 to 29 and 3 to 43 for LSC and HSC bulls, respectively, during the 1-day period. Mating activity was continual throughout the day despite occasional air temperatures as high as 100°F. Again, sexual activity during hours of darkness was practically nonexistent. Overall, pregnancy rates were low and did not differ between SC groups (Table 3). A possible explanation for low pregnancy rates is that synchronized cows were sorted prior to and immediately after bull exposure, and stress associated with this may have impaired conception or increased embryonic mortality.

There was no difference between bull SC groups for grazing time or body temperature, and the combined avg was 8.3 hr (36%) and 102.9°F, respectively. The increased sexual activity by bulls during exposure to synchronized cows did not result in a decrease in grazing time per 24-hr period (8.4 hr during avg mating load *vs* 8.3 hr during heavy mating load). Distance traveled did not differ between groups (Table 3). However, there was a considerable increase in distance traveled during heavy mating load because bulls traveled almost twice as far in a 1-day period compared to their activity during an avg mating load (13.6 *vs* 7.4 miles/day/bull).

Table 3—Mating behavior, pregnancy rate, and distance traveled by low and high serving capacity bulls during 24-hr exposure to a heavy mating load[ab]

Item	Serving capacity group	
	Low	High
No. cows in heat/bull/24 hr	8.8	8.8
Total mounts/bull/24 hr	39.5	39.1
No. cows serviced/bull/24 hr	5.1	5.7
No. services/cow	3.0	3.7
Total services/bull/24 hr	15.6	21.5
Mount-to-service ratio	2.5	1.8
Distance travelled/24 hr (miles)	14.6	12.6
Pregnancy rate (%)	29.0	34.8

[a]Each bull exposured to approximately nine estrus synchronized cows for 24 hr.
[b]Least-squares means.

Post Exposure Measurements. Results from post-exposure SC tests indicated that LSC bulls had improved in their sexual activity and had fewer mounts and more services compared to pre-exposure tests (P < .001), but LSC bulls still achieved fewer services than HSC bulls (3.2 *vs* 4.4, P = .06). Even though this difference was significant, LSC bulls' behavior indicated that they were not as low in SC as previously thought based on pre-exposure tests. This increase in the SC of LSC bulls was probably due to the sexual experience provided by the 4-day exposure to cows. Consistent with our findings, more recent research has found that some LSC yearling bulls showed a dramatic increase in their SC after exposure to short-duration sexual experience. Our observations indicated that LSC bulls appeared to be learning while exposed to an average mating load and had become more proficient when exposed to a heavy mating load as evidenced by a lower mount-to-service ratio. Results from this study suggest that LSC yearling bulls should be offered sexual experience and then retested before their inherent SC is determined.

Serum Concentrations of Luteinizing Hormone, Testosterone, and Thyroid Hormones in Low and High Serving Capacity Beef Bulls

Garth W. Boyd, Donald D. Lunstra, Bruce D. Schanbacher, and Larry R. Corah[1]

Introduction

Adequate sex drive in bulls is essential for natural mating to be successful. Expression of male sexual behavior and mating ability during sexual maturation is dependent upon attaining adequate testicular development and blood levels of luteinizing hormone (LH) and testosterone (T). Several researchers have investigated the relationship between levels of sexual behavior in postpubertal bulls and blood concentrations of LH and T. Some of these researchers reported a positive relationship between T and serving capacity (SC), and others found that individual differences in sexual performance could not be predicted based on circulating levels of T or LH. In those studies, comparisons between sexual behavior of bulls and hormone levels were based on a single blood sample or on infrequent blood sampling. Because no previous studies have utilized a frequent enough sampling regime to determine the episodic release of LH and T, there is a lack of research characterizing the hormonal patterns such as peak frequency, height, and area under the peaks of these hormones in bulls of differing serving capacity. Hormones other than LH and T may influence SC, but little research is available relating these to sexual behavior in bulls. However, thyroid hormones may have some relationship to sexual behavior because earlier research found that removal of the thyroid gland in the bull resulted in disappearance of sex drive and that the feeding of thyroid substance promptly restored sex drive in the hypothyroid bull. Whether this is an effect of a lowered metabolism or a specific endocrine effect has not been established.

The objective of the present study was to provide more definitive information on the relationship between the serving capacity of yearling beef bulls and their profiles of LH and T during sexual rest and their blood levels of thyroid hormones. In addition, the interrelationships between these hormones and parameters of testicular function, such as scrotal circumference, paired testicular volume, and seminal traits, were studied.

Procedure

Ten high SC (HSC) and 10 low SC (LSC) bulls (see preceding article in this Progress Report) were moved into individual stalls and acclimated for 4 days to stall housing. Each bull's jugular vein was cannulated; sampling began approximately 2 hr after cannulation; and samples were collected at 15 min intervals for 4 hr. Serum was harvested and frozen until assays were conducted for LH and T. Because of the long half-life of triiodothyronine (T_3) and thyroxine (T_4), serum was pooled for each bull using all samples, and concentrations of T_3 and T_4 and percentage T_3 uptake (a measure of the capacity of thyroxine binding globulin to bind T_3) were determined using assay kits.

Results

Figures 1 and 2 show the average changes in LH and T by 15 min intervals throughout the 4-hr collection period for 10 LSC and 10 HSC bulls. There were no differences between SC groups for avg concentration, number of peaks, avg peak height, or total area under the peaks for either LH or T (Table 1). However, there was considerable variation between individual bull hormone profiles regardless of SC, as depicted by representative bulls in Figure 3. During the 4-hr period, 14 (7 LSC, 7 HSC) bulls showed small fluctuations (peaks of small height) in their hormone profiles, while three bulls (2 LSC, 1 HSC) were

[1]Boyd is an assistant professor of animal science, Colorado State University (formerly a doctoral candidate at Kansas State University); Lunstra is a research physiologist, Reproduction Unit, MARC; Schanbacher is a research physiologist, Reproduction Unit, MARC; and Corah is a professor of animal science, Kansas State University, Manhattan.

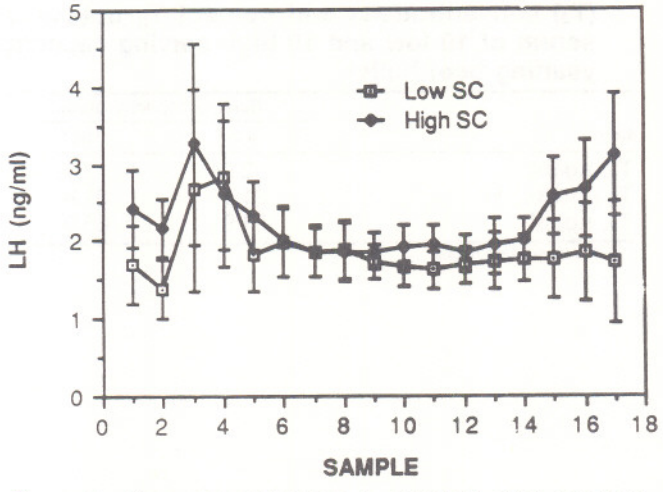

Figure 1—Mean concentrations ± standard error mean of luteinizing hormone (LH) in serum for 10 low and 10 high serving capacity (SC) crossbred yearling beef bulls sampled every 15 min during a 4-hr period in May 1986.

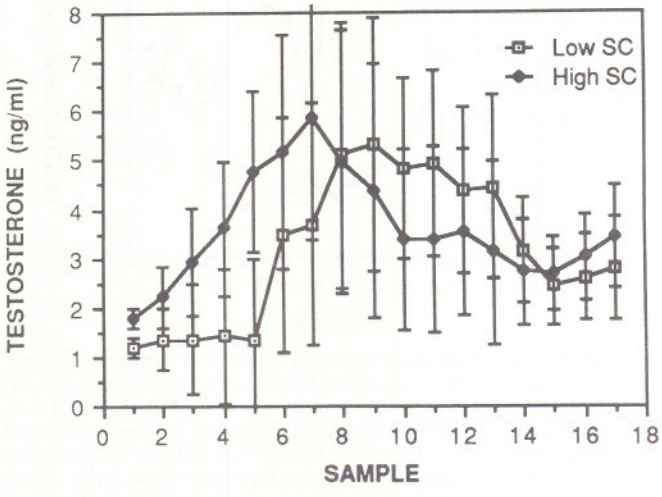

Figure 2—Mean concentration ± standard error mean of testosterone in serum for 10 low and 10 high serving capacity (SC) crossbred yearling beef bulls sampled every 15 min during a 4-hr period in May 1986.

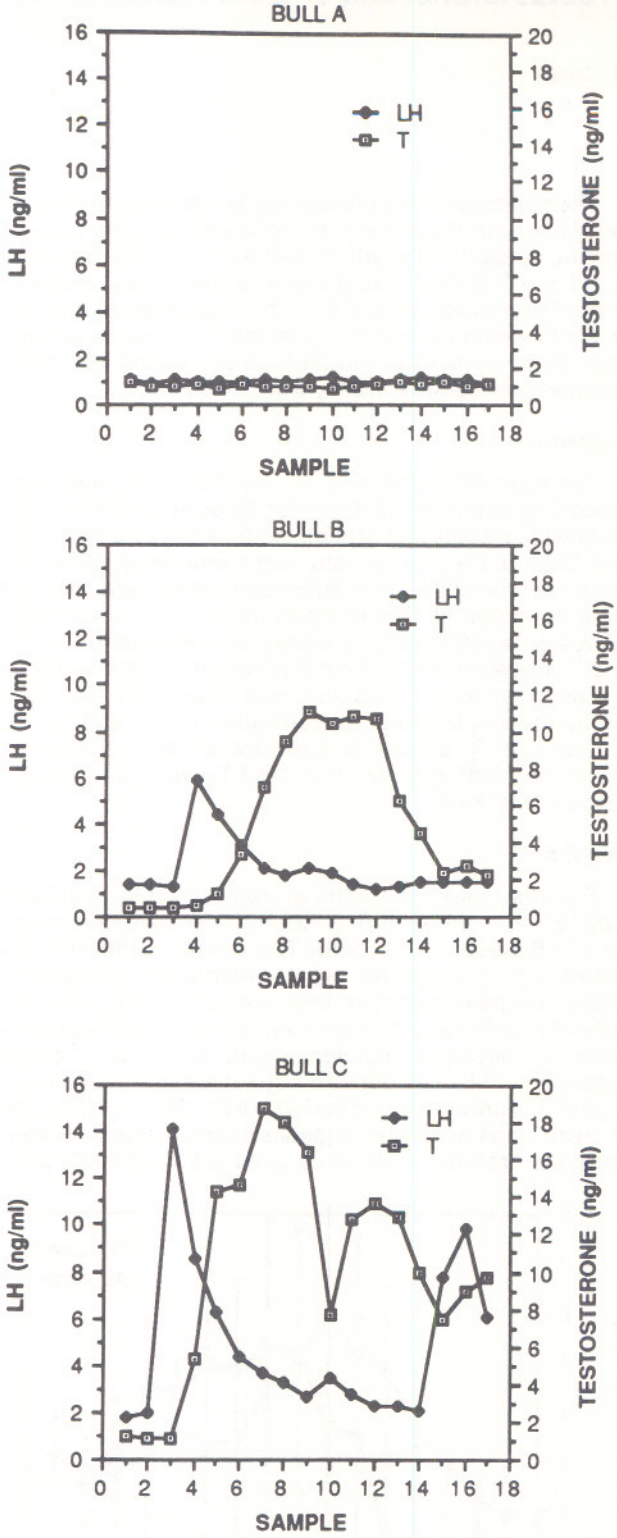

Figure 3—Serum concentrations of luteinizing hormone (LH) and testosterone (T) in representative crossbred yearling beef bulls bled every 15 min for a 4-hr period. Bull A (HSC) was typical for 14 bulls showing small fluctuations (peaks of small height) in LH or T. Bull B (LSC) and Bull C (HSC) were typical for three bulls showing intermediate and three bulls showing extreme height, respectively, for LH and T peaks.

intermediate and three bulls (1 LSC, 2 HSC) showed extreme peak height. Peaks for both LH and T were distributed randomly throughout the 4-hr sampling period. The coincidence of a T peak being preceded by an LH peak for all bulls was 65%, and the lag time was 1 hr.

Correlations between profile characteristics of LH or T and body wt, scrotal circumference, semen quality measures, and sexual behavior were low and nonsignificant for both LSC and HSC bulls. This suggests that circulating levels of LH and T were unrelated to known predictors of bull fertility.

Mean concentrations of T_3 and T_4 and percent T_3 uptake (Table 2) did not differ between SC groups and were similar to levels reported for dairy cows. Most combined correlations between T_3 or T_4 and previously mentioned measures were low and nonsignificant.

In summary, the present study confirms the lack of a relationship between sexual behavior and circulating levels of LH, T, and thyroid hormones, as well as other measures of bull fertility.

Table 1—Mean profile characteristics for luteinizing hormone (LH) and testosterone (T) in serum of 10 low and 10 high serving capacity yearling beef bulls[a]

	Serving capacity group	
Item	Low	High
LH:		
Mean, ng/ml	1.8	2.3
No. peaks/4 hr	1.3	1.0
Avg peak height, ng/ml	2.3	3.7
Total area under peaks, ng/ml x min	315.4	379.1
T:		
Mean, ng/ml	3.0	3.5
No. of peaks/4 hr	1.4	1.21
Avg peak height, ng/ml	4.4	6.4
Total area under peaks, ng/ml x min	530.5	595.8

[a]Least-squares means.

Table 2—Mean triiodothyronine (T_3) and thyroxine (T_4) concentrations and percent T_3 uptake in serum of 10 low and 10 high serving capacity yearling beef bulls[a]

	Serving capacity group	
Item	Low	High
T_3, ng/ml	2.01	2.10
T_3 uptake, %	31.6	31.8
T_4, ng/ml	84.9	86.9

[a]Least-squares means.

Effect of Season and Relocation on Reproductive Competence in Brahman and Hereford Bulls

Robert W. Godfrey, Ronald D. Randel, Charles R. Long, Donald D. Lunstra, Thomas G. Jenkins, and James

Introduction

Careful selection of a breed or breeds and emphasis upon selection pressure within a breed can increase productivity of a beef cattle herd. Furthermore, productivity within a herd may be effectively increased by utilizing crossbreeding programs. Crossing genetically diverse breeds permits combination of important traits and taking advantage of hybrid vigor. Many crossbreeding programs currently in use involve crosses between *Bos indicus* and *Bos taurus* cattle. One of the more commonly used *Bos indicus* breeds is the American Brahman. Use of the American Brahman in crossbreeding programs throughout the U.S. would increase demand for bulls of this breed.

Brahman cattle and their crosses have been shown to be adapted to the southern regions of the U.S. along the Gulf Coast, while many *Bos taurus* breeds do not perform well in these areas. A growing interest in Brahman cattle will increase demand for Brahman crossbred cattle in areas of the country that do not have environmental conditions to which the Brahman is adapted. It is desirable to know if Brahman cattle can function in areas with colder temperatures and shorter daylengths during the winter. Learning whether Brahman cattle can function in northern areas will be the first step in establishing crossbreeding programs involving Brahman cattle in these areas.

Procedure

Brahman bulls (n = 18, 17.6 mo of age) from Texas and Louisiana and Hereford bulls (n = 15, 14.1 mo of age) from Nebraska and Montana (n = 15, 15.6 mo of age) were randomly assigned to one of three experimental locations: Texas A&M University Agricultural Research and Extension Center, Overton (TX); MARC, Clay Center, Nebraska (NE), and Montana State University, Bozeman (MT). Each location received six Brahman bulls and five Hereford bulls each from NE and MT. The bulls were relocated during a 4-day period in late May 1984 (5/27-5/30). All bulls were puberal (50 x 10^6 cells/ejaculate with 10% motility obtained by electroejaculation) at the time of relocation. Bulls were subjected to management practices which were common for each location.

At 28-day intervals after relocation, the following measurements were taken on each bull: body wt, hip height, scrotal circumference (SC), avg testis length (ATL), and paired testes volume (PTV). Paired testes volume was determined by using the formula PTV = ATL x SC^2 x .0396. Data were collected for approximately 21 mo after relocation.

Within 1 wk of relocation and at 90-day intervals beginning in November 1984, semen was collected from each bull by electroejaculation. Two ejaculates were collected on consecutive days. Within 5 min of collection, the following evaluations were made on each sample: volume, color, gross motility rating, progressive motility rating, and % motility. Other traits measured included % live cells, concentration (x 10^6 cell/ml), % normal acrosomal ridges, % normal heads, % normal tails, and % proximal droplets. All the motility ratings were done at each location, while the histological evaluations were done at Nebraska by one technician.

For this discussion, semen quality will refer to a combination of sperm motility, viability, morphology, and concentration. Sperm motility was evaluated and given a score on a scale of 1 through 5, with 1 indicating little or no movement and 5 indicating the presence of many rapid swirls with many sperm moving in a forward direction. Sperm viability was determined using a live-dead stain and a score (1, 2, 3, 4, or 5) was given according to the percentage of live cells (0-20, 21-40, 41-60, 61-80, or 81-100%, respectively). Morphology was also scored 1 through 5 with the same scale as viability, except that the percentages refer to morphologically normal cells. Sperm concentration was given a score of 1 through 5 according to the actual concentration of sperm cells in an ejaculate (0-200, 201-400, 401-600, 601-800, and > 800 x 10^6 cells/ml, respectively). Overall semen quality was determined as the avg of the scores of the four individual traits.

Within 2 wk prior to relocation, 1 wk after relocation, and at 90-day intervals, all bulls were given 200 μg of gonadotropin releasing hormone (GnRH) i.m. Blood samples were taken via indwelling jugular catheter (NE, MT) or tail vessel puncture (TX) at 0, 30, 60, 150, and 300 min post-injection. Serum was analyzed for testosterone (T) and luteinizing hormone (LH) by radioimmunoassay. The magnitude of the LH and T peaks, area under the curve, and time to peak were calculated for each bull at each bleeding period. Basal hormone levels were determined from the one sample collected prior to GnRH injection. Mean hormone concentrations were determined on five samples per bull for each bleeding period.

At 6 mo intervals beginning in November 1984, all bulls were subjected to an 8 hr intensive blood sampling. An indwelling jugular catheter was placed in each bull the evening prior to the day of the blood sampling. The following morning, the bulls were either placed in stanchions (MT and NE) or haltered and tied to dividing panels in a holding pen (TX). Blood samples (20 ml) were drawn at 20-min intervals for 8 hr. Serum was analyzed for testosterone (T) and luteinizing hormone (LH) by radioimmunoassay. The number of LH and T peaks, magnitude of the peaks, area under the peaks, duration of the peaks, mean hormone concentration, and basal hormone concentration were calculated for individuals at each bleeding period.

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[2]Full report of this work by Robert W. Godfrey. 1987. The effect of season and relocation upon reproductive competence in Brahman and Hereford bulls. Ph.D. Thesis, Texas A&M University Library, 196 pp.

Results

Body and testicular growth. Brahman bulls in Texas gained wt more rapidly during the first 16 mo after relocation than those in Nebraska or Montana; however, Brahman bulls exhibited similar wt at all locations at the end of the study (Fig. 1). The lag time may be due to adaptation to the new environment, although it was not evident in the Hereford bulls which were moved to TX. There was some evidence of heat stress in Herefords in TX, so sunshades were constructed. All bulls at the northern locations were provided with shelter during the cold seasons of the year. At the end of the study, there were only two Brahman bulls remaining in MT; four bulls died due to metabolic acidosis and some disease problems, not the cold environment. Montana Herefords and Nebraska Herefords gained wt at a slower rate in NE than in MT or TX during the first 16 mo of the study, which may be due to the different management practices at the three locations. By the end of the study, however, Hereford bulls at all locations weighed the same (approximately 1,600 lb). Brahman bulls were taller in TX than in NE or MT during the first winter, but not by the second. This indicates that there was normal long bone growth, although it was suppressed during the first winter. On the average, Brahman bulls were taller than Montana and Nebraska Herefords at all locations (56.7 in *vs* 51.9 in, respectively).

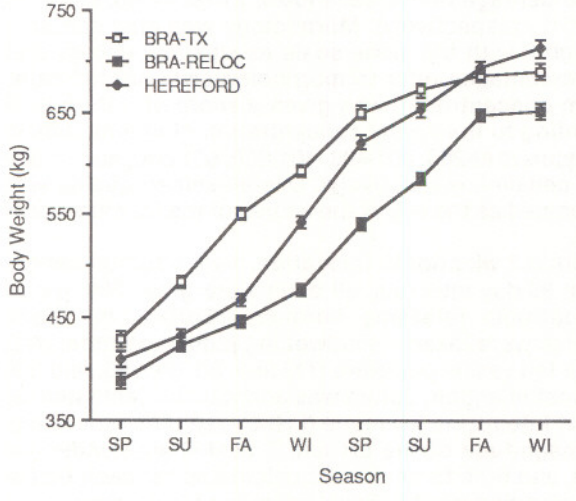


Figure 1—Mean body wt of relocated Brahman bulls (BRA-RELOC), control Brahman bulls (BRA-TX), and Hereford bulls (HEREFORD) after relocation.

Brahman bulls in TX exhibited a more rapid increase in scrotal circumference (SC) than in NE or MT (Fig. 2). Relocated Brahman bulls had little increase in SC through the first winter but increased rapidly after that. They still had smaller SC than control Brahman bulls at the end of the study. Testes volume exhibited a similar pattern (Fig. 3). Relocated Brahman bulls had lower testes volume during much of the study period, with decreases during the winter. Testes volume of Hereford bulls was not affected by season or location.

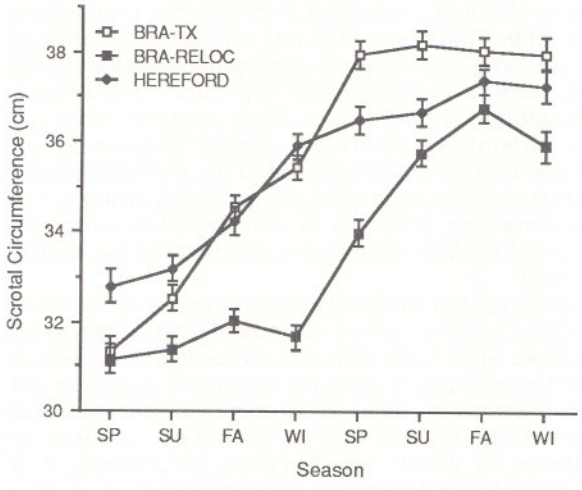


Figure 2—Mean scrotal circumference of relocated Brahman bulls, control Brahman bulls, and Hereford bulls after relocation.

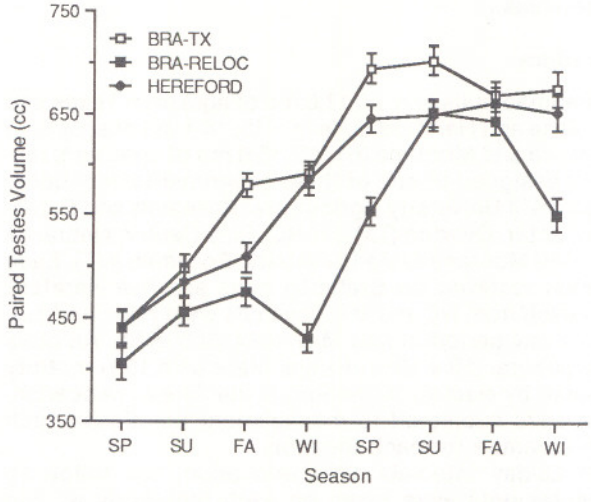


Figure 3—Mean paired testes volume of relocated Brahman bulls, control Brahman bulls, and Hereford bulls after relocation.

Semen quality. Semen quality score is represented in Figure 4. Hereford bulls had higher average semen quality scores than Brahman bulls throughout much of the study period. Both control and relocated Brahman bulls had decreased semen quality during the first winter, but only relocated bulls decreased during the second winter. All bulls had adequate semen quality during the summer. Hereford bulls did not exhibit any seasonal variation in semen quality.

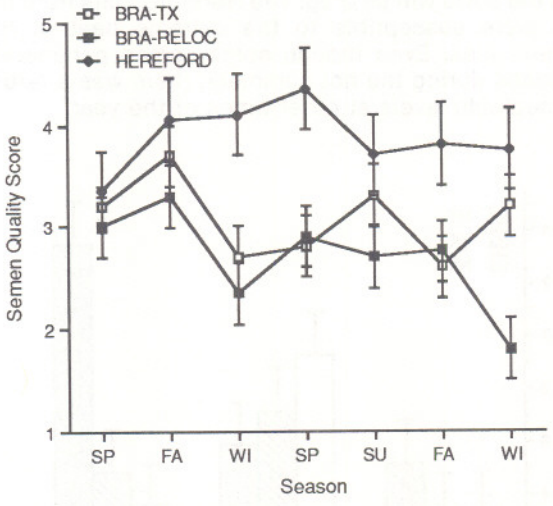


Figure 4—Mean semen quality scores of relocated Brahman bulls, control Brahman bulls, and Hereford bulls after relocation.

LH and testosterone secretion. There was no difference in basal serum LH concentrations between the breed types. Time to LH peak was greater for Nebraska Hereford bulls than for Montana Hereford and Brahman bulls. The height of the LH peak was also different between breed types. Brahman bulls had the smallest LH peak height and Nebraska Hereford bulls had the largest. Brahman bulls had the smallest area under the LH curve and Nebraska Hereford bulls had the largest.

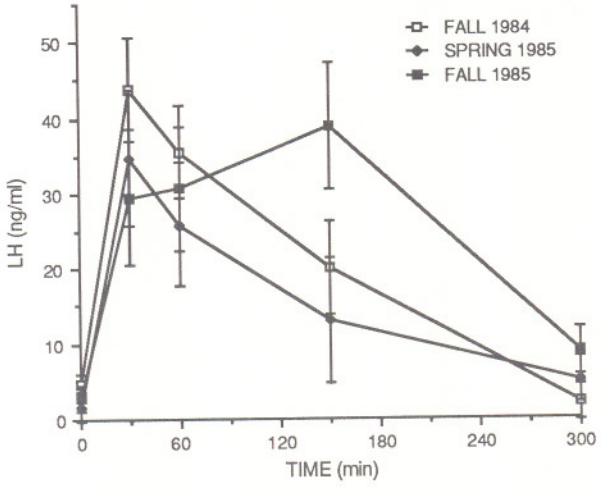


Figure 5—Mean GnRH-induced LH secretion of relocated Brahman bulls during three seasons.

Montana Hereford bulls had higher basal serum testosterone (T) concentrations than Brahman bulls. Nebraska Hereford bulls had the longest time to T peak. There was no difference between breed type in area under the T curve.

The GnRH-induced LH surge was greater in relocated Brahman bulls in the winter than in the spring (Fig. 5). This may be due to the fact that during the winter the LH is not being released from the pituitary and greater quantities are stored. When challenged with GnRH, the pituitary of the Brahman bulls released this stored LH into the peripheral circulation. During the spring, there was less response to GnRH, indicating that the pituitary may not have as much LH stored at this point. There was very little difference in the endogenous LH secretion in relocated Brahman bulls between the seasons (Table 1).

Table 1—Mean circulating LH parameters in relocated Brahman bulls[a]

Trait	Fall 1984	Spring 1985	Fall 1985
Mean LH (ng/ml)	2.1	1.9	2.6
Basal LH (ng/ml)	1.1	0.8	1.6
No. peaks	4.5	5.1	4.7
Peak Amplitude (ng/ml)	3.2	2.6	2.7
Duration of Peaks (min)	72.0	73.2	65.8

[a]No effect of season was detected.

The testosterone response of relocated Brahman bulls to the GnRH-induced LH is shown in Figure 6. The response was lower during the winter than the spring. The testosterone concentration prior to GnRH was also influenced by season, with a decrease in winter. There was an increase in endogenous serum T concentration over time, which is most likely due to maturation of the bulls (Table 2).

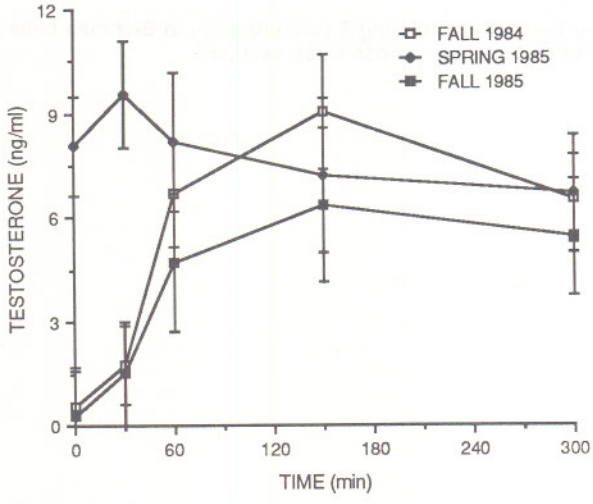


Figure 6—Mean GnRH-induced T secretion of relocated Brahman bulls during three seasons.

Table 2—Mean circulating testosterone (T) parameters in relocated Brahman bulls

Trait	Fall 1984	Spring 1985	Fall 1985
Mean T (ng/ml)	1.3^{a}	2.7^{b}	3.6^{c}
Basal T (ng/ml)	0.8^{a}	1.2^{ab}	1.5^{b}
No. peaks	1.6^{a}	2.3^{b}	1.6^{a}
Peak Amplitude (ng/ml)	2.4^{a}	5.8^{b}	6.9^{b}
Duration of Peaks (min)	61.2^{a}	93.8^{b}	135.6^{c}

[abc]Means within a row with different superscripts are different ($P < .001$).

T concentration seemed to be more seasonally influenced than LH concentration in relocated Brahman bulls (Fig. 7 and 8). Both mean T concentration and amplitude of T peaks were greater in the late spring than in the autumn in Brahman bulls in MT. This trend was not apparent for Brahman bulls in TX or NE.

The data from this study indicate that Brahman bulls have different growth patterns and endocrine profiles than Hereford bulls. Relocation of Brahman bulls to northern environments affected growth and semen quality of Brahman bulls. There was not quite as much influence on the hormonal status of the bulls. There was some influence on serum testosterone, which may have been due to a direct influence on testicular steroidogenic capability, or it may have been due to suppression of testicular growth in the relocated bulls. Relocated Brahman bulls exhibited a lag time of 6 mo in growth traits compared to control Brahman bulls. To efficiently utilize Brahman bulls in breeding programs in the north, this lag time must be taken into consideration when moving young bulls. The semen traits of relocated Brahman bulls were suppressed during the winter months in the north. The semen quality returned to levels similar to control Brahman bulls during the summer. Since most cattle operations utilize spring calving in the north, the semen quality of Brahman bulls will be at an acceptable level at the time of the year when the cows will be bred. The Hereford bulls from the north were susceptible to the extreme heat of the southern area. Even though some semen parameters decreased during the hot summers, there was a return to acceptable levels at other times of the year.

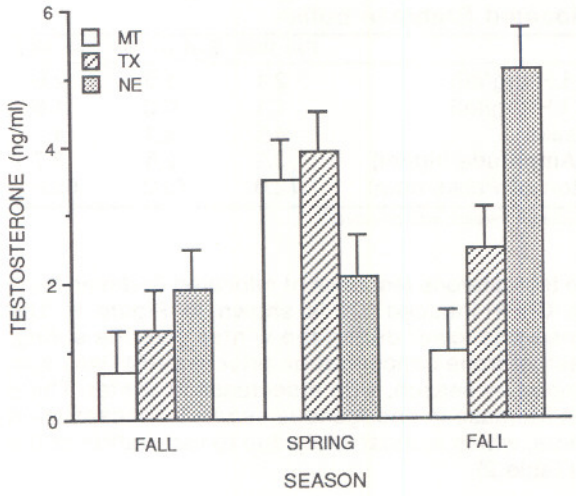


Figure 7—Mean circulating T concentration in Brahman bulls at three locations across three seasons.

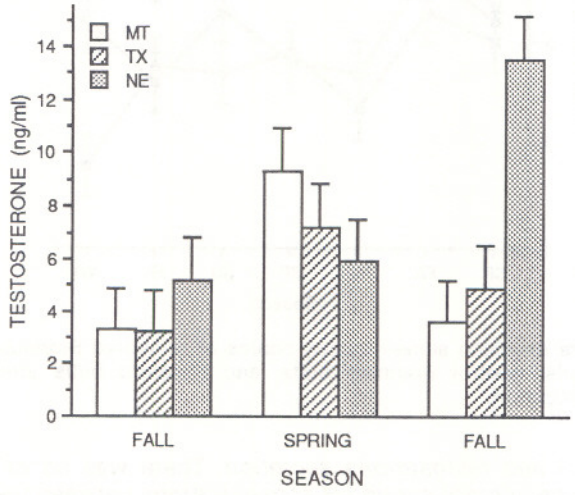


Figure 8—Mean amplitude of endogenous T peaks in Brahman bulls at three locations across three seasons.

Demasculinization of Beef Bulls by LH Immunization

Bruce D. Schanbacher[1]

Introduction

Intact bull calves grow more rapidly in the feedlot than do their castrate counterparts but are generally less acceptable to the packer because of excess masculinity and insufficient intramuscular and external fat for postmortem handling and storage. Steers, on the other hand, are less efficient and yield less lean meat than bulls. Therefore, it was envisaged that reducing the masculinity of bulls by a noninvasive, nonsurgical procedure might yield a more suitable market animal.

A nonsurgical approach to castration of bulls would possibly provide advantages to the producer and find favor with animal welfare groups. Immunocastration by active immunization against the hypothalamic hormone, luteinizing hormone releasing hormone (LHRH), has proven successful in a number of species, including sheep and swine. This vaccination procedure is so effective at inducing a castration effect, however, that we have attempted to produce only partial castration by immunizing bull calves against the pituitary hormone, luteinizing hormone (LH). It was hypothesized that immunization against this hormone would decrease testosterone secretion and cause moderate demasculinization of bull calves.

Twenty spring-born bull calves were weaned in September and randomly assigned to one of three treatment groups. These included ten immunized controls, five immunized against purified sheep LH, and five immunized against an LH-human serum globulin conjugate (LH-hSG). Preliminary studies showed the conjugate to be more antigenic than LH alone.

Bull calves weighed approximately 350 lb at the time of primary immunization and gained 750 lb (controls), 586 lbs (LH), and 646 lbs (LH-hSG) during the 293-day trial. These gains manifested themselves in differences for avg daily gain, final wt, carcass wt (Table 1), and ribeye area (Table 2). Scores for the secondary sex characteristics (Table 2), weights of the accessory sex glands, and serum testosterone levels (Table 3) suggest that immunization against LH, and especially LH-hSG, produces a condition of androgen deficiency. From this standpoint, the response to the LH-hSG vaccine was comparable to the castration effect achieved by LHRH immunization in sheep and pigs. Although the LH-hSG calves were sterile and were usually similar to steers, kidney and backfat estimates and USDA quality and yield grades were not different from intact controls. Additional studies are required to evaluate the efficacy of this vaccine to demasculinize beef bulls fattened in the feedlot.

Like LHRH immunocastration, LH immunocastration is a simple, effective way to neuter calves. As an attractive alternative to conventional castration, it avoids the primary shock and secondary consequences of hemorrhage and infection that are associated with surgery in the feedlot. The immunocastrate is also interesting in that it may be possible to reactivate the dormant testes with exogenous gonadotropin.

[1]Schanbacher is a research physiologist, Reproduction Unit, MARC.

Table 1—Growth rates and carcass weights of intact bull calves (controls) and calves immunized against either LH or LH conjugated to human serum globulin (LH-hSG)

Treatment	Initial wt (lb)	Final wt (lb)	Avg daily gain (lb/day)	Carcass wt (lb)
Control	350	1,100	2.49	690
LH	366[a]	952[a]	2.03[a]	600[a]
LH-hSG	357[a]	1,003[a]	2.18[a]	608[a]

[a]$P < 0.05$. Significantly different from intact control group.

Table 2—Carcass characteristics of intact bull calves (controls) and calves immunized against either ovine LH (LH) or LH conjugated to human serum globulin (LH-hSG)

Treatment	Secondary sex characteristics[a]	Backfat thickness (in)	Kidney fat (%)	Ribeye area (in^2)	Quality grade[b]	Yield grade[c]
Control	3.8	.17	2.3	12.7	9.6	2.5
LH	2.8[d]	.14[d]	2.3	11.7	7.8	2.4
LH-hSG	1.6[d]	.16	2.2	11.7[d]	10.4	2.5

[a]Sex characteristics, 1 = steer-like (no masculinity); 9 = very masculine.
[b]Quality grade, 8 = average good; 9 = high good; 10 = low choice.
[c]Yield grade, 1 = high cutability; 5 = low cutability.
[d]$P < 0.05$. Significantly different from intact control group.

Table 3—Reproductive parameters of intact bull calves (controls) and calves immunized against either LH or LH conjugated to human serum globulin (LH-hSG)

Treatment	Serum testosterone (ng/ml)	Testes diameter (cm)	Testes wt (gm)	Seminal vesicle wt (gm)
Control	6.1	7.1	582	69.4
LH	3.5[a]	6.2[a]	471	44.0[a]
LH-hSG	.2[a]	5.2[a]	313[a]	11.4[a]

[a]$P < 0.05$. Significantly different from intact control group.

Anabolic Steroids and Implants in Feedlot Steers

Bruce D. Schanbacher and John Brethour[1]

Introduction

Profit from livestock production is affected by daily liveweight gain, cost of gain, and feed conversion efficiency. Young beef calves are recognized as suitable converters of forages and grains into wholesome red meat, but constraints to maximum production efficiency are recognized. While their growth and development are often discussed in light of genetic potential, nutritional requirements, and environmental constraints, administration of anabolic agents to maximize their gains is a common practice. Several implants are available to the cattle industry as growth promotants; some of these contain steroids of gonadal origin while others are nonsteroidal.

Steroids secreted by the testes are thought to be responsible for differences in growth rates and feedlot performance of bulls and steers. Testosterone is the most likely steroid conferring a growth advantage to the intact calf; however other steroids, including estradiol, possess growth-promoting activity. Estrogen and progesterone are effective ingredients in some implants but are often used in feedlot heifers to prevent cyclic ovarian activity; e.g., melengestrol acetate (MGA). Ovariectomy or spaying of heifers is popular in some feedlots, but initial weight loss and occasional death have kept this practice from being widespread in the U.S.

[1]Schanbacher is a research physiologist, Reproduction Unit, MARC; and Brethour is a beef research scientist, Fort Hays Experiment Station, Kansas State University, Hays.

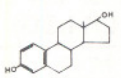
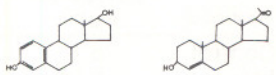
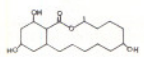
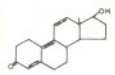
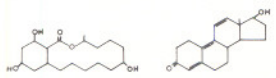
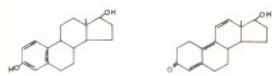
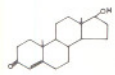
	Trademark	Chemical name(s)	
I.	Compudose	estradiol	
II.	Synovex-S	estradiol + progesterone	
III.	Ralgro	zeranol	
IV.	Finaplix	trenbolone	
V.	Forplix	zeranol + trenbolone	
VI.	Revalor	estradiol + trenbolone	
VII.	Testosterone	testosterone	

Figure 1—Chemical name and structure of commercially available implants for growth promotion in cattle.

In view of the numerous implants available as growth promotants for cattle and the extensive application of these implants to growing-finishing steers, we have compared the efficacy of several implants singularly or in combination. For simple reference, the trade name, chemical ingredient, and structure of these anabolic agents are presented in Figure 1.

Procedure

In our first study, we investigated the effects of Ralgro, Synovex-S, and Compudose on the performance of 151 yearling, 600-lb Hereford and Angus-Hereford crossbred steers. Performance was assessed during a 77-day grazing period and during a further 128 days in the feedlot on a high-grain *ad libitum* ration. Gain response and carcass traits of these steers are shown in Table 1. There were no significant treatment differences in gains during the grazing phase of this study because of individual variability. Seven Compudose implants were lost during this part of the trial; with these calves omitted from the analysis, avg gain for the Compudose implant group was 145 lb. These steers were reimplanted at the beginning of the feedlot phase. During the finishing phase, Ralgro and Synovex-S implanted calves grew faster than those given Compudose, and yet all implant groups outperformed nonimplanted calves. Over the complete trial, Ralgro-implanted calves gained the most, averaging 67 lb more gain than the nonimplanted calves. Feed efficiency did not differ significantly among implant treatments but tended to be better among Ralgro and Synovex-S groups than for those given Compudose. Implanting significantly reduced marbling score and percent USDA choice quality grade only for those implanted with Synovex-S. Other carcass traits were similar. This study confirms the extra gain and improved feed efficiency claim of the estrogen-based implants in feedlot steers.

Our next study was conducted to test the anabolic efficacy of trenbolone acetate either administered alone (Finaplix) or in combination with zeranol (Forplix) or estradiol (Revalor). One hundred twenty-four crossbred steers averaging 850 lb were grain-finished. A nonimplanted control group and six implanted groups were superimposed on a 109-day feeding trial (Table 2). During the first 68 days, when the implants were believed to be most effective, gains of steers implanted with Forplix and Revalor were significantly greater than steers receiving other implants, their gains averaging 22% and 26% more than nonimplanted controls. These findings suggest that implants combining androgenic and estrogenic activity increase gains more than implants with single effects. Steers were finished in mixed treatment groups, thus precluding data necessary for comparing feed efficiency. Carcass traits were similar with the exception of depressed marbling score and carcass grade in Revalor implanted calves.

This trial shows the benefit of combination implants and suggests that the greater gains observed with Finaplix, Forplix, and Revalor implants are associated with leaner carcasses. The benefits of trenbolone acetate in this trial and reported elsewhere for heifers suggest a need for androgenic steroids in implants for bovine use.

Table 1—Comparison of Ralgro, Synovex-S, and Compudose implants for grazing-finishing steers

Treatment	Control	Ralgro[a]	Synovex-S[a]	Compudose
No. head	36	38	39	38
Avg initial wt, lb	600.3	602.3	599.9	604.4
Avg final wt, lb	1,083.2	1,152.3	1,122.7	1,125.5
Avg total gain, lb[b]	482.9	550.0	522.8	521.1
Percent response		+ 13.9	+ 8.3	+ 7.9
Avg gain, grazing phase	133.4	140.8	129.7	139.1
Avg gain, feedlot phase	349.5	409.2	393.1	382.0
Feedlot phase, 7/20 to 11/24, 128 days				
Avg dry matter intake, lb	21.16	22.96	22.38	22.31
Lb DM/100 lb gain	787	718	725	743
Percent response		+ 9.5	+ 8.5	+ 5.9
Carcass data				
Dressing %	64.69	64.23	64.76	64.22
Backfat, in	.48	.50	.50	.49
Caloric density, C/g	4.17	4.13	4.09	4.14
Marbling score	5.05	4.90	4.62	5.07
Percent choice	86	82	69	82

[a]Ralgro and Synovex-S reimplanted at the start of feedlot phase and on day 55 of feedlot phase.
[b]Gain data corrected to 64% carcass yield.

Table 2—Response of finishing yearling steers to six different implants

Treatment	Control	Ralgro	Synovex-S	Compudose	Finaplix	Forplix	Revalor
No. head	17	17	18	18	18	18	18
Avg initial wt, lb	875.3	865.2	831.7	826.6	867.8	862.8	865.3
Avg final wt, lb	1,171.1	1,169.1	1,147.6	1,143.6	1,168.8	1,185.5	1,193.9
Avg gain, 109 days, lb	295.0	303.9	315.9	317.0	301.0	322.7	328.6
Avg daily gain, lb	2.66	2.74	2.85	2.86	2.71	2.91	2.96
Percent response		2.7	6.8	7.2	1.8	9.1	11.1
First 68 days:							
Avg gain, lb	143.2	161.4	167.2	169.6	158.7	174.3	180.1
Percent response		12.7	16.8	18.4	10.8	21.7	25.8
Carcass data							
Marbling score	4.94	4.78	4.79	4.83	4.87	5.02	4.49
Percent choice	82	53	72	83	83	83	44
Backfat, in	.56	.55	.57	.55	.52	.60	.51

A Simple Method for Freezing Bovine Embryos

Sherrill E. Echternkamp and Donald Elliott[1]

Deep freezing (cryopreservation) of bovine embryos provides an efficient economical method for storing embryos until suitable recipient cows (surrogate mothers) are available, or for transporting embryos to recipient cows at a distant location (e.g., exportation or importation of embryos between continents or geographic areas). Pregnancy rates achieved with frozen bovine embryos have increased steadily during the past five years and are approaching those obtained with fresh bovine embryos. However, acceptable pregnancy rates are only achieved when Grades 1 and 2 quality (excellent and good quality) embryos are frozen; survivability of Grade 3 (fair quality) embryos is considerably higher if the embryos are transferred fresh rather than frozen. A simplified method for freezing and thawing bovine embryos is described, and pregnancy rates obtained are compared with those for fresh embryos.

Procedure

Bovine embryos at the morulae and early to expanded blastocyst stages of development were obtained nonsurgically from superovulated donor cows 7.5 days after artificial insemination. After the embryos were located in the flush medium of 2% bovine serum albumin (BSA) in Dulbecco's phosphate buffered saline (PBS), they were transferred with a micropipette into a holding medium of .4% BSA in modified PBS (PBS-BSA), held at 75°F for 1-2 hr until all embryos were located and evaluated for quality. Subsequently, the Grades 1 and 2 embryos were transferred to the cryoprotective freezing medium of 1.5 M glycerol (11% v/v) in PBS-BSA, allowed to equilibrate for 5 min at room temperature (~ 75°F), and then each embryo was aspirated individually into a .25 cc plastic French semen straw in a small volume of freezing medium. Embryos were loaded one per straw with an air bubble at each end to restrict movement of the embryo within the straw as shown in Figure 1. The open end of the plastic straw was sealed with a heat sealer and the opposite end (plug end) was labelled with the identity of the embryo; heat sealing of the plugged end of the straw is optimal. The sealed straws were positioned vertically in a holding rack and submerged in an alcohol bath of a mechanically refrigerated freezer (Bio Cool II Freezer, FTS Systems, Inc., Stone Ridge, NY) except for the labelled area. A thermal conductor was inserted into a sham .25 cc plastic French semen straw with freezing medium to monitor temperature of the freezing medium at embryonic site and to determine or monitor the ice crystallization temperature of the cryoprotective freezing medium.

The embryos were cooled from 75°F to 20°F at a rate of 1.8°F/min; 21°F was previously determined to be the ice crystallization temperature. Ice crystallization ("seeding") of the freezing medium within each straw was induced by touching the exterior surface of each straw near the top level of the medium with a cold steel rod; the steel rod was cooled in liquid nitrogen. The straws

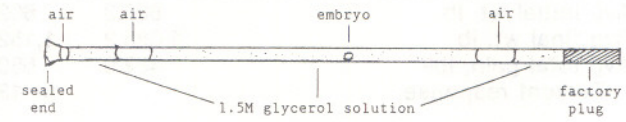


Figure 1—Schematic representation of an embryo loaded into a plastic French semen straw containing the cryoprotective medium of 1.5M glycerol in PBS-BSA.

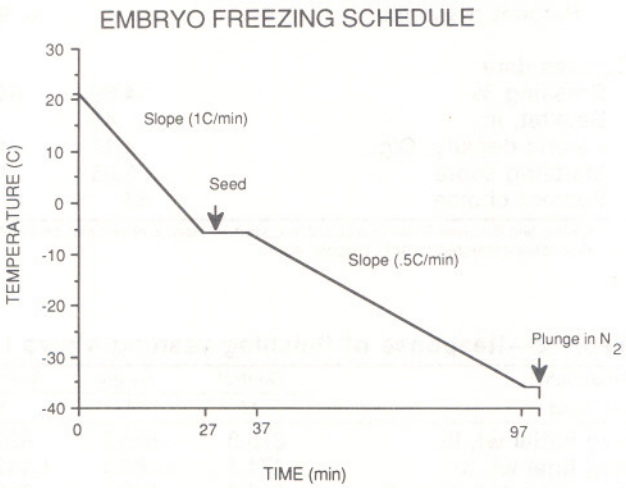


Figure 2—Schematic representation of the freezing schedule for bovine embryos.

were maintained at 20°F for 5 to 8 min after seeding or until the medium was completely crystallized . The second cooling schedule or ramp was from 20°F to -33°F at .8°F/min. At -33°F, the straws were plunged into liquid nitrogen and transferred to a liquid nitrogen storage tank. The embryo freezing schedule is illustrated in Figure 2.

Thawing of the embryos was achieved by holding the straw in air for 15 sec at room temperature (70° to 75°F), followed by 30 sec in 98°F water. Both ends of the plastic straw were clipped off and the contents emptied into a small petri dish. Removal of the cryoprotectant (glycerol) was accomplished by step-wise dilution in sucrose. Upon recovery from the straw, the embryo was placed immediately in a thawing medium of .13 M glycerol and .69 M sucrose in PBS-BSA for 5-10 min at room temperature, transferred to a second thawing medium of .4 M sucrose in PBS-BSA for 5-10 min, and then rinsed twice in PBS-BSA medium. The embryo was subsequently loaded into a .25 cc plastic French semen straw and transferred nonsurgically into the uterine horn ipsilateral to the corpus luteum of a recipient cow at 7 to 8 days postestrus.

Results

Pregnancy rates for embryos transferred nonsurgically into recipient cows either fresh or after cryopreservation are presented in Table 1. Pregnancy rate was about 10% lower in recipient cows receiving deep-frozen embryos

[1]Echternkamp is a research physiologist, Reproduction Unit, MARC; and Elliott is a professional embryo transfer specialist, Mitchell, Nebraska.

Table 1—Pregnancy rates for fresh and deep-frozen bovine embryos

Status of Embryo	No. of Recipients[a]	Pregnant (%)
Fresh	87	49 (56.3)
Deep-frozen[b]	50	23 (46.0)

[a]One embryo was transferred nonsurgically per recipient cow.
[b]Embryos were suspended in a cryoprotectant, cooled to -33°F, and frozen and stored in liquid nitrogen.

(46.0%) than in recipient cows receiving fresh embryos (56.3%). Although, slightly lower pregnancy rates were obtained with deep-frozen bovine embryos than with fresh embryos, deep freezing of embryos increases managerial, transportational, and/or marketing opportunities. Fresh bovine embryos can be stored for 6 to 8 hr at about 70°F or up to 24 hr at 102°F in a special culture medium, whereas deep-frozen embryos can be stored for several months with no reduction in embryonic survivability, and for several years with a small reduction in survivability. For maximal fertility with embryo transfer, the recipient female should be in standing estrus within ± 12 hr of the donor female in order to synchronize the stage of embryonic development with the status of the reproductive system of the recipient female. Synchrony between the stage of embryonic development of the deep-frozen embryo and day of the estrous cycle of the recipient female can be easily achieved by thawing and transferring the embryos on the designated day of the estrous cycle. In contrast, transfer of fresh embryos requires estrous cycle regulation in the recipient female to synchronize the estrous cycles between the donor cow and the recipient cow, or the treatment of 10 recipient cows if the donor cow is superovulated. Thus, the number of recipient cows required and the cost of maintaining the recipient herd is less when deep-frozen rather than fresh embryos are utilized.

Because of the previously noted differences in storage life between deep-frozen and fresh embryos, it is more economical and practical to transport deep-frozen embryos long distances. Likewise, the exportation or importation of genetic material or germ plasm among countries can be accomplished more economically by transporting deep-frozen embryos than live animals, provided proper embryo-washing and sanitation procedures are employed.

Conclusion

Pregnancy rates obtained with deep-frozen (cryopreserved) embryos are about 10% lower than those obtained with fresh embryos. However, the lower fertility with deep-frozen embryos is compensated for with increased managerial, transportational, and marketing benefits or opportunities. The freezing and thawing procedures described in this report are simple, practical, and economical to perform and provide results comparable to those obtained with elaborate, complicated procedures.

Zinc and Protein Levels in Finishing Diets of Medium- and Large-Frame Steers

Wilson G. Pond and Robert R. Oltjen[1]

Introduction

The National Research Council lists the daily protein requirements of medium-frame and large-frame steers weighing 770 lb and gaining 2.2 lb daily as 1.7 and 1.8 lb, respectively; comparable values at 1,100 lb are 1.9 and 2.1 lb. These amounts of protein are expected to be provided for medium-frame steers weighing 880 lb and gaining weight at 2.2 lb daily by a diet containing 10.3% protein; the corresponding value for large-frame steers is 10.2% protein. Medium- and large-frame steers weighing 1,100 lb and gaining weight at 2.2 lb daily require 9.5% protein in the diet.

The zinc requirement of steers is not well defined; an estimated requirement of 30 ppm has been derived from experiments with calves and sheep. Corn grown at MARC contains 20 to 30 ppm zinc, a level that may be marginal for finishing beef cattle.

The known involvement of zinc in protein metabolism and the greater growth rate of large-frame than of medium-frame growing-finishing beef cattle suggests the possibility of an interaction of dietary zinc and protein levels and cattle frame size with respect to weight gain and feed utilization. The purpose of this experiment was to test this possibility.

Procedure

Three hundred twenty crossbred steers representing two frame sizes (large-frame, Gelbvieh x Simmental x Angus x Hereford and medium-frame, Pinzgauer x Red Poll x Angus x Hereford) were used to determine the effect of dietary protein (10 *vs* 13%) and zinc (24 *vs* 60 ppm) on wt gain, feed consumption, and efficiency of feed utilization. Diet composition is described in Table 1. The experiment was conducted in two replicates (January-June and July-December) of 160 steers each, composed of 80 large-frame and 80 medium-frame steers kept in partially slotted-floor pens in groups of five. Steers were weighed on day 0 and at 28-day intervals throughout a 140-day period in each replicate. Feed was added to each feed bunk daily and wt of refused feed was recorded each 28 days. Total feed intake of each pen of five steers was recorded, and daily wt gain and gain to feed ratio were calculated for each pen.

Results

Initial body wt, final wt, adjusted final wt, daily gain, daily feed intake, and gain to feed ratio are summarized by diet and frame size in Table 2.

Large-frame steers had higher adjusted final wt, daily gain, and gain to feed ratio than medium-frame steers. Steers in replicate 1 (January to June) had higher adjusted final wt, daily gain, and daily feed intake than steers in replicate 2 (July to December), possibly a reflection of lower environmental temperatures prevalent during the feeding period of steers in replicate 1. Dietary zinc level had no effect on final wt, daily gain, daily feed intake, or gain to feed ratio. Steers fed the high protein diet (13%) had a higher final wt and daily gain than steers fed low protein (10%). There were no interactions between or among any of the traits measured.

[1]Pond is the research leader, Nutrition Unit, and Oltjen is the director, MARC.

Table 1—Ingredient composition of diets (as fed)[a]

	Low protein Low zinc	Low protein High zinc	High protein Low zinc	High protein High zinc
Corn silage	50.0	50.0	50.0	50.0
Corn, cracked	47.0	47.0	43.0	43.0
Soybean meal, 44% C.P.			4.0	4.0
Mineral-vitamin supplement w/o Zn[b]	3.0		3.0	
Mineral-vitamin supplement with Zn[c]		3.0		3.0

[a]Dry basis (calculated): Dry matter (DM) 59.50%; crude protein 10.9%; Calcium (Ca) .52%; Phosphorus (P) .34%.

[b]Soybean meal 74.7%; limestone 21.7%; dicalcium phosphate 2.0%; vitamin A premix percent (4.0 million units vitamin A/lb) 0.60%; trace mineral mixture 1%, containing the following elements to provide the indicated amounts in the final mixed diet: Iron (Fe)(as $FeSO_4 \cdot 7H_2O$), 10.0 ppm; Manganese (Mn)(as $MnSO_4 \cdot H_2O$), 80 ppm; Copper (Cu)(as $CuSO_4 \cdot 5H_2O$), 15 ppm; Cobalt (Co)(as $CoCO_3$), 1 ppm; I (as EDDI), 2 ppm; $CaCO_3$ as carrier to make up the 1% total.

[c]Same as for footnote b, except that ZnO is included. The ZnO provides a total of 36 ppm zinc (Zn) in mixed diet as fed (60.5 ppm Zn in DM).

The greater daily gain (2.6 *vs* 2.5 lb) of steers fed 13% protein than of those fed 10% protein suggests the possibility that a corn silage-corn finishing diet containing 10% protein should be supplemented with protein to maximize wt gain of large- and medium-frame steers. The small magnitude of response, however, is of minimum biological significance. The absence of a dietary protein level x frame-size interaction provides evidence that the greater wt gain and daily gain of large- compared with medium-frame steers is not affected by supplementary protein. The amounts of protein consumed by steers fed the 10% protein diet, based on computations of dry matter and protein analyses of the diets were calculated to be about 1.7 lb daily over the entire feeding period (range of 1.62 lb for large-frame steers fed high zinc-low protein to 1.75 lb for medium-frame steers fed low zinc-low protein). The steers in the present experiment had an overall daily gain of 2.53 lb (2.48 and 2.57 lb for 10 and 13% protein, respectively) which would suggest that the lower daily gain of steers fed the low protein diet was associated with a marginal protein intake. A possible factor limiting growth in steers fed the low protein diet was their inability to consume sufficient dry matter from a corn silage-based diet to satisfy daily protein requirement. The 13% protein diet clearly provided more protein than needed; steers fed the high protein diets failed to respond with improved gain to feed ratios.

The absence of a beneficial effect of supplementary zinc on any of the traits measured provides evidence that a level of 20 to 28 ppm zinc in a corn silage-corn diet for finishing steers is adequate and that large-frame steers, despite their faster wt gain and presumably greater protein accretion rate, do not respond to supplemental zinc with increased wt gain or feed intake. The failure of supplemental zinc to improve performance agrees with previous work in which 100 ppm added to an all-concentrate corn-based diet did not affect wt gain of feedlot cattle.

Table 2—Feedlot performance of large- and medium-frame size steers fed finishing diets containing two levels of protein and two levels of zinc

	Low zinc		High zinc		Low zinc		High zinc	
Frame size	med	lg	med	lg	med	lg	med	lg
No. of replicates	2	2	2	2	2	2	2	2
No. of steers	40	40	40	40	40	40	40	40
Initial body wt, lb	726	774	733	763	719	766	730	770
Final body wt, lb	1,069	1,142	1,071	1,118	1,074	1,155	1,078	1,144
Adj. final body wt, lb[a]	1,088	1,121	1,084	1,106	1,098	1,140	1,092	1,124
Adj. daily gain, lb[a]	2.42	2.64	2.38	2.53	2.49	2.77	2.44	2.66
Adj. daily feed intake, lb[a] (as fed)	28.1	27.8	27.6	27.3	28.6	28.0	28.8	25.9
Adj. gain to feed ratio[a]	.087	.095	.088	.094	.087	.100	.085	.105

[a]Adjusted to constant initial wt by covariance.

More Lean, Less Fat With Clenbuterol

Joan H. Eisemann, Gerald B. Huntington, and Calvin L. Ferrell[1,2]

Introduction

There is too much fat on beef carcasses today. Research in beef cattle production is directed towards solving this problem by maximizing partitioning of dietary nutrients to lean muscle growth and minimizing deposition of carcass fat. Partitioning agents called β -adrenergic agonists are able to cause this type of nutrient partitioning. Earlier work showed two of these compounds, clenbuterol and cimaterol, can be fed and are effective in many species including pigs, sheep, and cattle. At levels that did not depress gain, clenbuterol feeding increased protein content of the 9th to 11th rib section by 13% and decreased fat content by 20% in cattle. Even more dramatic carcass changes were observed in cattle in response to cimaterol.

Of interest are the underlying metabolic changes and controls that must be altered to bring about the carcass changes previously cited. To date, the mechanisms responsible for altering nutrient partitioning in response to β -adrenergic agonists are not well defined. The objectives of our study were to compare the initial and adapted effects of clenbuterol on blood flow, heart rate, and metabolism in the hindquarters of growing steers.

Procedure

Animals and diets. Four Hereford steers, 11 mo of age, were gentled and adapted to a diet formulated to meet protein requirements for 2.2 lb daily wt gain at restricted intake beginning 1 mo before surgery. Catheters were surgically implanted with tips in the aorta and caudal vena cava in order to sample blood supplying and draining the hindquarters. Also, an ultrasonic flow probe was placed around the abdominal aorta for measurement of blood flow to the hindquarters.

Following surgery, the steers were moved to individual stalls in a completely enclosed room having a light:dark cycle (hr) of 16L:8D. The diet was fed to steers in 4 equal aliquots at 6 hr intervals beginning at 7 a.m. Steers consumed all their feed prior to and on each sampling day. The experiment began 2 wk after surgery. Average body wt was 531 lb.

Design. The experimental design was a balanced, single reversal including a 9-day control period and a 9-day period of clenbuterol feeding (8 mg/day divided equally across feedings) with a 5-day interim period. Meals with clenbuterol were prepared daily for each steer to assure daily allotment of 8 mg per steer. Meals fed during sampling were prepared separately to assure each meal contained 2 mg clenbuterol.

Blood samples were collected on days 1 and 9 of each period. Blood was withdrawn simultaneously from the abdominal aorta (A) and caudal vena cava (V) at 30-min intervals beginning at 7 a.m. for one feeding cycle (6 hr, 13 samples per steer). Blood samples were collected in heparinized syringes and immediately placed on ice. Aliquots of whole blood were removed for later analyses; packed cell volume (PCV) was determined; and the samples were centrifuged at 1500 x g for 20 min at 39°F to obtain plasma. Plasma was aliquoted and stored at 4°F until analysis. A transit time ultrasonic blood flow meter was used to measure blood flow and heart rate at the time of each blood sample.

Calculations. Plasma flow was calculated using the following equation:

$$\text{Plasma flow (L/min)} = (1 - (\text{PCV}/100)) * \text{Blood flow (L/min)}$$

Net uptake or release of nutrients was calculated as the product of arteriovenous (AV) concentration difference and whole blood (or plasma) flow.

Results

Initial consumption of clenbuterol caused a rapid doubling of heart rate (Fig. 1a). Heart rate decreased slightly from this peak but remained elevated and relatively constant throughout the duration of sampling on day 1. There was some fluctuation in heart rate after control feeding but no dramatic changes. Blood flow showed a

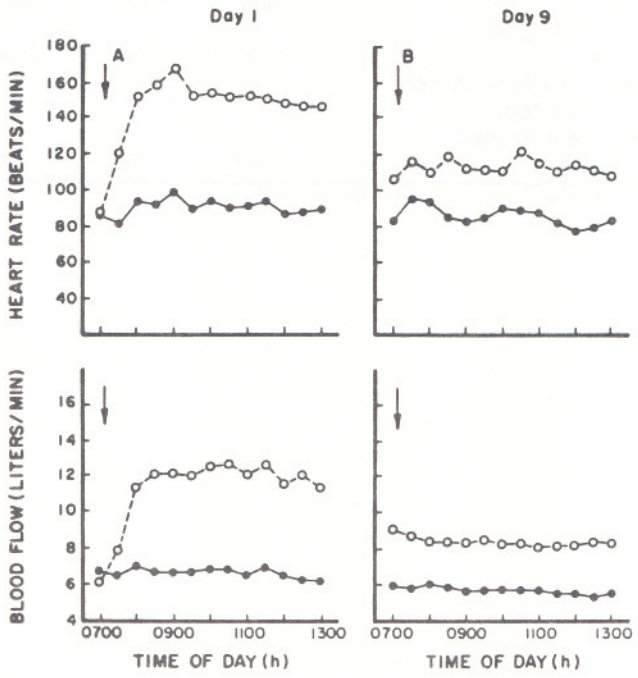


Figure 1—Heart rate and blood flow to the hindquarters in steers at each sampling time. Sampling began at 7 a.m. and continued for 6 hr at 30 min intervals. The arrow indicates time of feeding. A: Samples taken on day 1 of control (●—●) or clenbuterol (o--o) treatment. Average SEM for control and clenbuterol treatments, respectively, was: heart rate (beats per min), 3.2 and 4.4; blood flow (liters per min), 1.00 and 1.12. B: Samples taken on day 9 of control (●—●) or clenbuterol (o--o) treatment. Average SEM of control and clenbuterol treatment, respectively, was: heart rate (beats per min), 5 and 4; blood flow (liters per min), .82 and 1.02.

[1]Eisemann is a research physiologist, Nutrition Unit, MARC; Huntington is a research animal scientist, Beltsville Agricultural Research Center, Maryland; and Ferrell is a research animal scientist, Nutrition Unit, MARC.

[2]The full report of this work was published in J. Anim. Sci. 66:342-353, 1988.

response similar to that of heart rate. By day 9, heart rate and blood flow did not increase following consumption of clenbuterol at the beginning of the sampling period; however, on average, both heart rate and blood flow were elevated ($P < .01$) after 9 days of clenbuterol compared to control feeding (Fig. 1b).

The rapidity of the cardiovascular responses to initial clenbuterol feeding (Fig. 1a) probably indicates the drug is absorbed in the proximal sections of the gastrointestinal tract. Other researchers reported increased heart rate in young bull calves fed clenbuterol; however, adaptation, indicated by a heart rate returned to pretreatment values, occurred by day 3 of treatment. Immediate increased heart rate in response to clenbuterol or cimaterol was observed in sheep. An initial increase in blood flow to the hindquarters in response to cimaterol was observed also in sheep by other scientists.

On day 1, net uptake of oxygen increased and net uptake of α-amino nitrogen (AAN) decreased; whereas, net release of both L-lactate and free fatty acids (FFA) increased with clenbuterol compared to control feeding. Oxygen is an indicator of total tissue metabolic activity; AAN is a precursor of protein; L-lactate is an end product of muscle metabolism; and FFA are a precursor of tissue fat and a source of energy. By day 9, clenbuterol feeding caused a sustained increase in uptake of oxygen, increased uptake of AAN and increased net release of L-lactate compared to control feeding. Net uptake of other metabolites was not altered ($P > .10$) by initial (day 1) or sustained (day 9) feeding of clenbuterol (Table 1).

By day 9 of treatment, hindquarters uptake of AAN was increased, suggesting an increase in protein deposition in response to chronic clenbuterol treatment. Previous workers showed that sustained administration of clenbuterol to rats resulted in either an increase or no change in fractional synthesis rate of muscle protein. Also, other studies reported the fractional synthesis rate of muscle protein was not altered in sheep with sustained clenbuterol administration. Therefore, the mechanism responsible for increased protein deposition is still not clear.

Comparing the immediate and sustained metabolic responses to clenbuterol feeding exemplifies two types of metabolic control, homeostasis (short-term regulation to maintain similar conditions) and homeorhesis (long-term coordination of metabolism to support a dominant physiological process, such as growth). Initially, the steers showed a general catabolic response to a β-adrenergic agonist by releasing stored nutrients and decreasing peripheral anabolic processes (Table 2). The rapid change in heart rate and blood flow after initial feeding demonstrates the extent to which steady state was altered and the need for rapid interplay of homeostatic compensatory mechanisms. Adaptation is indicated by lack of immediate response in blood flow and heart rate to clenbuterol ingestion by day 9, and indicates the steers had reached a new steady state or were moving along a more tightly regulated continuum. Decreased AAN uptake by the hindquarters on day 1 and increased AAN uptake on day 9 illustrate changing metabolic control and the importance of chronic, homeorhetic regulation.

Our data detail metabolic changes that contribute to altered nutrient partitioning (increased muscle and decreased fat accretion) previously observed in response to clenbuterol feeding. Initial and sustained changes illustrate homeostatic and homeorhetic regulatory mechanisms, respectively, for metabolic control. Perhaps the data on AAN metabolism best illustrate the critical need for longer-term evaluation of regulatory agents in order to understand regulatory mechanisms coordinating nutrient partitioning during growth.

Table 1—Hindquarters uptake or release of nutrients in steers fed control and clenbuterol treatments

	Day 1 (initial)			Day 9 (sustained)		
	Control	Clenbuterol	P < [a]	Control	Clenbuterol	P < [a]
Uptake or release, mmoles/min[b]						
Whole blood						
Oxygen	12.10	15.71	.06	13.41	16.47	.06
Acetate	2.01	1.67	NS	2.03	1.41	NS
Propionate	.103	.109	NS	.140	.107	NS
D-β-hydroxybutyrate	.57	.65	NS	.59	.80	NS
Plasma						
Glucose	.77	2.88	NS	.89	1.03	NS
L-lactate	-.02	-1.59	.01	.20	-.46	.07
FFA (μeq/min)	-111	-834	.07	12	-240	NS
AAN	.32	.10	.02	.34	.49	.02

[a]Type I error probability: NS = $P > .10$.
[b]Uptake or release = Blood or plasma flow x AV concentration difference.

Influence of Biological Types on Energy Requirements

Calvin L. Ferrell and Thomas G. Jenkins[1]

Introduction

Since the introduction of new germ plasm resources into the U.S. beginning in the early 1960's, the influence of biological types on various aspects of beef production have been evaluated extensively. Traits studied include preweaning calf performance, postweaning growth and feed efficiency, carcass characteristics, puberty and other reproductive characteristics, and milk production, to name a few. In general, however, most of the research efforts have concentrated on the areas involving the growing animal and/or its carcass characteristics. That is, output characteristics of the various biological types of cattle have been of primary interest to researchers. Much less effort has been expended to quantify the impact various biological types of cattle may have on input components of beef production. There has been, in particular, a dearth of information regarding the influence of biological type on the feed requirements of mature cows, even though various researchers have noted that the feed required to replenish and maintain the cow herd constitutes a major portion (65 to 75%) of the feed resources required for beef production. Differences among biological types in the feed required to maintain the cow herd may have a substantial impact on the efficiency of beef production. Thus, in this report, we will attempt to summarize our data relative to the effect of biological type on feed energy requirements of mature cows.

Procedure and Results

A series of studies was initiated to develop greater understanding of energy utilization and requirements of mature cows of various biological types during the production cycle. A study was designed to quantify the metabolizable energy (ME) required to maintain wt of mature cows of four biological types during a production cycle when fed forage diets of differing qualities. Diets consisted of 70% brome haylage: 30% alfalfa haylage; 35% brome haylage: 65% alfalfa haylage; and 100% alfalfa haylage. Dry matter contents of the diets were determined and ME contents calculated. Four biological types of cows were represented by Angus or Hereford (AHX), Charolais (CX), Jersey (JX), or Simmental (SX) sired cows produced from Angus or Hereford dams. These cows were chosen as representatives of cows having genetic potential for moderate size, moderate milk production (AHX); large size, moderate milk production (CX); moderate size, high milk production (JX); and large size, high milk production (SX). All cows were mated to Brown Swiss bulls. Cows were individually fed each of the three diets indicated above by use of Calan-Broadbent electronic headgates. The diets were fed from about 100 days prepartum until weaning at 196 days postpartum. Weights of the cows were recorded at the beginning, end, and at approximately 28-day intervals during the study. Daily feed intakes were summed over each wt interval. Milk production of each cow was determined on days 14 and 28 postpartum and at 28-day intervals during the remainder of the study. Calves were creep fed throughout the study.

A quadratic regression was fit to the wt of each cow; initial and final wt were calculated from the regression as the wt at day 0 and 297, respectively. Empty body wt (EBW) at each of those times was calculated as:

$$EBW = 0.88 \times \text{liveweight} - 16.34.$$

Total ME intake was calculated as the sum of the feed intake during the 297-day study times the appropriate dry matter and ME contents of the diet. To estimate the ME required for zero wt change during the 297-day period, actual ME intakes were adjusted for empty body wt changes. Daily milk yield at the times specified above were used to estimate parameters of a lactation curve for each cow with the empirical equation:

$$Y(n) = n/ae^{kn}$$

where Y(n) is the daily milk yield during the nth week postpartum and a and k define the shape of the lactation curve. Total milk yield was calculated by integrating the equation over the interval from 0 to 25 wk postpartum. Effects of sire breed and dam breed of the cow, diet, and the two-way interactions on the response variables were evaluated by analysis of variance. The two-way interactions were not significant for any variable, and were thus deleted from the final statistical model.

Lactation curves of the four biological types of cows are depicted in Figure 1. These curves indicate milk yield at peak lactation was greatest for SX cows and least for AHX cows. Rates of decline in milk yield after peak yield was greatest for CX cows and least for AHX and JX cows. Initial empty body wt, daily wt change, total milk yield, and ME intakes were significantly ($P < .10$) influenced only by sire breed. Means for sire breed groups are presented in Table 1. The CX and SX cows were heavier than JX and AHX cows, and the SX and JX cows produced greater quantities of milk than AHX or CX cows, as anticipated. Although not significantly different, rates

[1]Ferrell is a research animal scientist, Nutrition Unit, and Jenkins is a research animal scientist, Production Systems Unit, MARC.

Table 1—The influence of biological type of cow (sire breed) on initial empty body weight (IEBW), average daily gain (ADG), milk yield, and metabolizable energy (ME) intakes during a production cycle[a]

Sire breed	N	IEBW (lb)	ADG (lb)	Milk yield (lb per 25 wk)	ME intake	
					Actual	Adjusted[b]
Angus, Hereford	14	1,087^{cd}	-.084	2,685^{c}	6,694^{c}	6,885^{c}
Charolais	15	1,175^{e}	-.075	2,862^{cd}	7,293^{cd}	7,467^{c}
Jersey	14	1,056^{c}	-.123	3,314^{cd}	7,115^{a}	7,422^{c}
Simmental	17	1,133^{de}	-.205	3,448^{d}	8,274^{d}	8,691^{d}

[a]The production cycle began about 100 days prepartum and ended about 196 days postpartum.
[b]Actual ME intake adjusted to zero empty body wt change.
[cde]Means with different superscripts are significantly different.

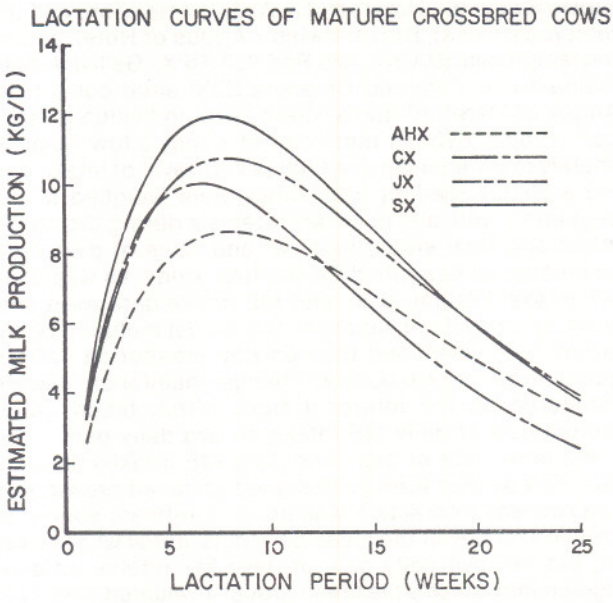


Figure 1—Lactation curves of mature crossbred cows of different types.

of gain tended to be greater for breed crosses having the lower milk yields. The small (5% or less) adjustments of actual ME intakes for wt changes tended to favor AHX and CX cows over the higher milk-producing types. Inspection of ME intakes adjusted to zero wt change during the 297-day interval indicate CX, JX, and SX cows required about 108, 108, and 126% of that required by AHX cows.

Differences relative to the AHX cows appear to be due to size (CX), and size and level of milk production (JX and SX).

In a subsequent study, mature, non-pregnant, nonlactating AHX, CX, JX, and SX cows were used. In each of 2 yr, cows of each type were fed a corn silage-soybean meal diet at either a low, medium, or high level of intake. Cows were fed individually each day for 140 days and feed intakes and wt changes were recorded. Body composition was estimated by deuterium oxide dilution procedures at the beginning and end of the study. Empty body energy change during the 140-day study was calculated as the difference between final and initial empty body energy contents. Maintenance (zero empty body energy change) requirements of each type of cow were estimated by regression analysis.

Results from these analyses (Table 2) indicate maintenance requirements of mature, non-pregnant, nonlactating cows differed among biological types. When expressed as kcal ME/kg$^{0.75}$/day, SX cows had the highest maintenance requirements followed by JX cows, and the CX and AHX cows had the lowest maintenance requirements. When the results were expressed on a daily basis, however, AHX and JX cows had similar requirements; CX cows were intermediate; and SX cows had the highest requirements. In these results, like those in the first study, maintenance requirements appeared to reflect both size and milk production potentials of the cows, even though they were neither pregnant nor lactating during the study.

Annual ME requirements for maintenance (Table 3) were calculated by multiplying estimates of daily requirements by 365. Data on birth wt of calves produced by mating mature (4 to 8 yr) cows of these types to Brown Swiss bulls were obtained from results of the Germ Plasm Evaluation program. The ME requirements for gestation were estimated and scaled by calf birth wt. Estimates of the milk yield of cows of the same breed crosses during a 25-wk lactation period (Table 1) were used to estimate ME requirements for milk production, assuming 1.06 Mcal ME was required to produce each lb milk. Annual ME requirements were calculated as the sum of the requirements for maintenance, gestation, and lactation.

It should be noted that estimates of annual ME requirements reported in Table 3 should not be directly compared to the values reported in Table 1 because of the different time intervals (297 *vs* 365 days) and the differing qualities of the diets fed (alfalfa: brome *vs* corn silage:soybean meal). However, the ranking of the cows of the four sire breeds was remarkably similar between the two studies. Results shown in Table 3 indicate CX, JX, and SX cows had annual requirements 109, 106, and 128% of those of AHX cows, whereas comparable values from the first study were 108, 108, and 126%, respectively. Within each of the cow types, maintenance requirements accounted for 71 to 75% of the total annual

Table 2—Mean initial empty body weight (IEBW), metabolizable energy intake (MEI), daily body energy gain (EG), and maintenance requirements of cows of four sire breeds

Cow sire breed	N	IEBW (lb)	MEI (kcal/kg$^{.75}$/day)	EG (kcal/kg$^{.75}$/day)	Maintenance requirements (kcal/kg$^{.75}$/day)	Maintenance requirements (Mcal day)
Angus/Hereford	22	1,038	180	21.3	130	14.0
Charolais	18	1,267	166	12.0	129	15.0
Jersey	17	923	197	15.9	145	14.2
Simmental	21	1,151	175	4.3	160	17.9

Table 3—Annual metabolizable energy (ME) requirements of cows of four sire breeds

Cow sire breed	Maintenance (Mcal/yr)	Calf birth[a] wt (lb)	ME for[b] gestation (Mcal)	ME for[c] lactation (Mcal)	Total ME required (Mcal/yr)
Angus/Hereford	5,010	91	529	1,300	6,839
Charolais	5,475	98	573	1,380	7,428
Jersey	5,183	83	484	1,600	7,267
Simmental	6,533	93	562	1,660	8,755

[a]Based on data from the MARC Germ Plasm Evaluation Program; calves were all sired by Brown Swiss bulls; N = 431 to 624.
[b]Calculated by scaling the energy requirements for pregnancy by calf birth wt.
[c]Calculated from the milk yield estimates of cows of these types (Table 1) assuming 1.06 Mcal ME/kg milk.

requirements for energy, whereas gestation and lactation accounted for 6.4 to 7.7% and 18.6 to 22.0%, respectively. This demonstrates the relative contribution of maintenance requirements to annual cow energy requirements.

In a third study, cows sired by Red Poll (RX), Brown Swiss (BX), Gelbvieh (GX), Maine-Anjou (MX), or Chianina (CiX) bulls and out of Angus or Hereford dams were fed to maintain their initial body wt during a 138- or 139-day lactation period commencing at about 45 days postpartum. Cows raising Simmental sired calves were assigned to replicated pens (2 pens/yr) of 12 cow-calf pairs/pen/breed group. Cows were fed a corn silage-based diet and were weighed at 14-day intervals. Feed allowances were adjusted at those times in an attempt to achieve zero wt changes. Milk production was estimated by weigh-suckle-weigh procedures. Calves were creep fed each yr, and pen creep feed consumption was recorded. Calves were weighed at the beginning and end of the study each yr, as well as at the time of milk yield determinations. Metabolizable energy consumption of the dams was adjusted to zero biweekly wt change by regression procedures.

Results of this study (Table 4) indicated significant cow breed effects on initial and final calf wt, but not on calf ME consumption. Initial and final cow wt differed among the cow breed groups, as did avg daily milk production. The ME required for zero wt change differed among the cow types during the 138 days of lactation evaluated. The observed differences reflected differences in cow size and milk production, as observed in previous studies.

An additional study was conducted using mature, nonpregnant, non-lactating cows from cycle II of the GPE program plus cows from a three-breed diallel. The breeds and breed crosses used in the study included Angus (A), Brown Swiss (B), Hereford (H), Angus x Hereford and the reciprocal (AHX), Brown Swiss x Angus or Hereford and the reciprocals (BAHX), and Red Poll (RPX), Gelbvieh (GX), Maine-Anjou (MX) and Chianina (CiX) sired cows from Angus or Hereford dams. Cows were individually fed a corn silage-soybean meal diet at either a low (approximately maintenance) or a high (*ad lib*) level of intake during a 96-day feeding trial. Cows were weighed at the beginning, end, and at 14-day intervals during the study. Initial and final empty body wt and rates of gain were calculated as described for the first study, as was daily ME intake. Weight, gain, and ME intake data were analyzed by analysis of variance. The model included breed group, feed level, and the two-way interaction. ME requirements for zero body wt change (maintenance) were estimated as the intercept from within breed group regressions of daily ME intake on avg daily gain.

Final wt, rate of gain, and daily ME intakes were influenced by feed level as designed (data not presented). The two-way interaction was not a significant source or variation for any of the measured traits. Initial wt and final wt, but not avg daily gain or daily ME intake, differed significantly among the breed groups evaluated. The daily ME required for zero body wt change (maintenance) differed among the breed groups. Ranking on the basis of daily feed required to maintain body wt of non-pregnant, non-lactating crossbred cows was similar to ranking of the same breed crosses during lactation. In general, differences in maintenance requirements reflected differences in cow size and milk production potential. In addition, although not rigorously analyzed, maintenance of crossbred cows tended to be slightly lower than the avg of straightbred cows. This observation warrants further study.

Table 4—Weights and metabolizable energy intake of cows of different biological types and their progeny from 45 to 183 days postpartum

Cow sire breed[a]	Calf wt (lb)		Calf ME intake from feed	Milk yield	Cow wt (lb)		Cow ME intake[b]
	Initial	Final	(Mcal/day)	(lb/day)	Initial	Final	(Mcal/day)
Angus/Hereford	175	509	5.7	15.1	1,111	1,157	24.9
Red Poll	197	542	5.5	17.9	1,032	1,056	26.2
Brown Swiss	200	556	5.3	21.0	1,100	1,124	28.6
Gelbvieh	202	549	5.1	19.8	1,144	1,164	28.6
Maine-Anjou	206	560	5.3	18.5	1,221	1,254	27.4
Chianina	200	540	5.3	14.6	1,221	1,239	28.3

[a]Cows were produced from Angus or Hereford dams; all calves were sired by Simmental bulls.
[b]Cow ME intakes were adjusted to zero wt change by regression analysis.

Table 5—Least-squares means empty body wt, rate of gain, metabolizable energy (ME) intake, and ME required to maintain body wt on non-pregnant, non-lactating cows of several breeds or breed crosses

Breed or breed cross	N	Empty body wt (lb)		Gain	ME intake	Maintenance[a]	
		Initial	Final	(lb/day)	(Mcal/day)	Mcal/day	kcal/kg$^{.75}$/day
Angus (A)	12	875	972	1.01	21.8	12.7	138
Brown Swiss (B)	12	941	1,030	.90	22.6	17.9	184
Hereford (H)	11	919	981	.66	20.9	13.0	137
AH X	20	983	1,078	.99	21.0	12.0	119
BAH X	35	944	1,043	1.01	22.9	15.3	156
Red Poll X[b]	22	891	979	.95	21.4	13.0	149
Gelbvieh X	23	967	1,041	.75	21.6	17.2	174
Maine-Anjou X	24	1,045	1,140	.99	23.7	14.9	142
Chianina X	23	1,030	1,116	.90	22.4	16.4	158

[a]Daily maintenance (ME required for zero body wt change) was estimated as the intercept of the linear or quadratic regression, within breed or breed cross, of daily ME intake on avg daily empty body wt gain. Estimates of daily maintenance requirements were scaled by average empty body wt $^{.75}$ to adjust for cow size.
[b]Red Poll, Gelbvieh, Maine-Anjou, and Chianina crossbred cows were produced from Angus and Hereford dams.

The estimates of ME required for maintenance were scaled by avg empty body wt raised to the .75 power (MBS) to adjust for cow size differences. No estimates of variation are available due to the procedures used, thus the values presented in Table 5 should be viewed with some caution. Within the straightbred cows, Brown Swiss had higher maintenance requirements than Angus or Hereford cows. Within the crossbred populations evaluated, AHX cows had the lowest and GX, CiX, and BAHX cows tended to have the highest maintenance requirements per kg MBS. These results were consistent with those observed in previous studies.

Discussion

As noted previously, feed required for cow maintenance is a major component of the feed resources required for beef production. Observations reported here suggest that maintenance accounts for 71 to 75% of the ME required by the cow during the production cycle. Maintenance has also been shown to account for 30 to 50% of the ME required by growing-finishing cattle and for about 50 to 60% of the ME required by replacement heifers. Thus, it is evident that maintenance requirements are a major component of the feed energy required for beef production. Results from the four studies presented suggest that biological type of the cow may have a substantial impact on the ME required for maintenance (wt or energy stasis). Estimates of the ME required for maintenance differed among types evaluated within a study by as much as 50%. Obviously, differences of that magnitude may have a substantial impact on the efficiency of beef production. As a result, it is appropriate that attempts be made to quantify sources of variation in energy expenditures for maintenance.

Data reviewed previously indicated generally positive relationships between estimates of maintenance requirements and measures of genetic potential for production such as rate of growth or milk production. A plot of estimates of maintenance requirements for non-pregnant, non-lactating cows *vs* mean milk yield at peak lactation of cows of the same breeds or breed crosses (Fig. 2) supports that observation. Those results suggested that maintenance requirements increased about 6.16 kcal/kg$^{.75}$/day for each kg increase in milk yield at peak lactation (2.8 kcal/kg$^{.75}$/day/lb increase in peak milk yield). They further suggested that about 50% of the observed variation in maintenance requirements in the populations evaluated was attributable to variation in milk production potential as measured by weigh-suckle-weigh procedures.

Taylor and coworkers, working in Scotland, have also noted substantial differences in maintenance requirements of cows of different types. Their data indicated maintenance requirements of Angus, Hereford, Dexter, British Friesian, and Jersey to be 123, 126, 136, 150, and 150 kcal/kg$^{.75}$/day, respectively. They observed a significant positive relationship between maintenance requirements and total or peak milk yield. About 70% of the variation in maintenance requirements was associated with variation in milk production. After an extensive review of the literature, they concluded that "most of the variation in published estimates (of maintenance requirements) for mature fed cows is, therefore, explained by breed differences linked to lactability."

Further expansion of this concept may be appropriate. Maintenance appears to increase with increased potential for growth rate, as well as with increased potential for milk production. For example, the data of Frisch and

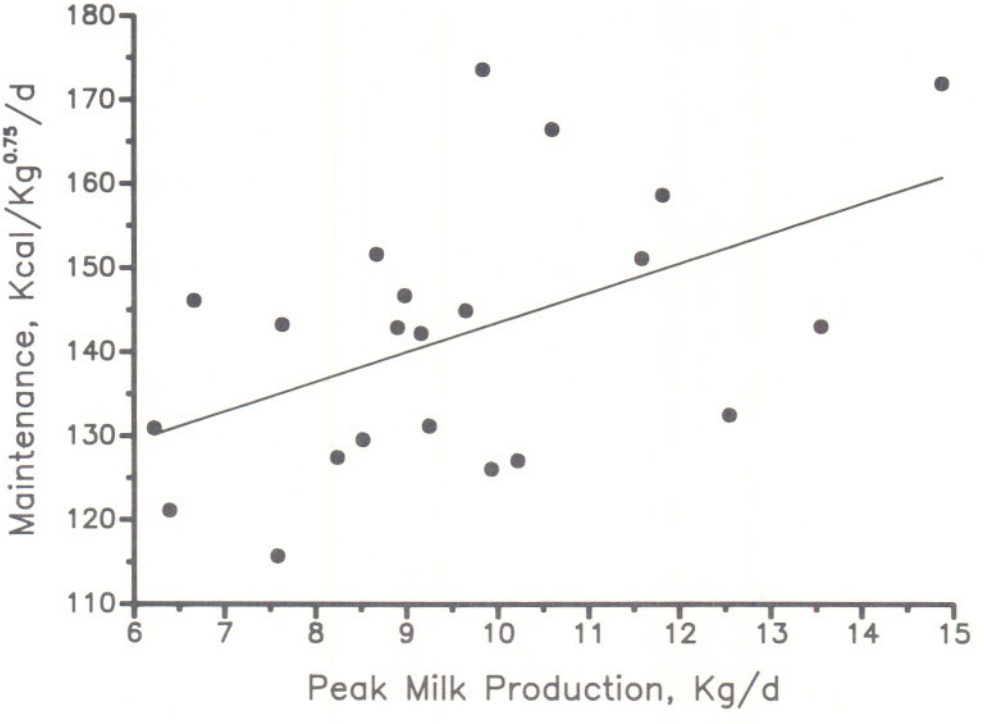


Figure 2—Regression of maintenance requirements (kcal/kg$^{.75}$/day) of non-pregnant, non-lactating cows on milk production at peak lactation (kg/day); maintenance = 70.5 (± 16.2) + 6.16 (± 1.38) * milk, R^2 = .50, N = 22.

Vercoe indicated Brahman and Africander differed from Hereford x Shorthorn by having a lower metabolic rate, lower growth rate, and lower feed intake. Rogerson similarly noted lower fasting heat production and lower growth rate of Boran as compared to Hereford steers. We noted lower maintenance requirements of heifers as compared to bulls and of Hereford as compared to Simmental growing cattle. Similarly, several reported studies indicate that dairy breeds are more productive than beef-dairy crosses and beef-dairy crosses to be more productive than beef breeds with the higher productivity associated with higher fasting energy expenditures or maintenance requirements in each case. Analysis of data reported from several studies indicated a positive, linear increase in maintenance requirements with productivity of genotype.

Variation in maintenance requirements may reflect responses to the environmental conditions in which breeds of cattle evolved or were selected. For example, in tropical grazing conditions, *Bos indicus* cattle generally have more wt gain than *Bos taurus* cattle. Conversely, under *ad lib* pen feeding, *Bos indicus* cattle generally consume less feed and gain wt less rapidly than *Bos taurus* cattle. It has been shown experimentally that selection for increased growth rate in an environment with high levels of heat, humidity, and parasites results in decreased fasting production. Selection for increased growth rate in a more ideal environment, on the other hand, is expected to result in increased mature size and fasting or maintenance energy expenditure. Thus, selection may result in a population of animals becoming highly adapted to a specific environment, but may render it less adapted to a different environment. Correlated responses to selection may also result in decreased adaptability to fluctuating environments. As a result, care should be taken to ensure synchronization of cattle type and the production environment.

Conclusions

Data have been presented to indicate that maintenance requirements account for a large portion of the feed resources required for beef production, and that maintenance requirements appear to differ among various biological types of cattle. In general, there appears to be a positive association between genetic potential for productivity and maintenance requirements. Thus, in terms of improvement in beef production efficiency, there is an antagonistic relationship between productivity and feed requirements. Numerous other antagonistic genetic relationships between traits important to beef production, such as growth rate *vs* birth wt and dystocia, retail product *vs* marbling, retail product growth rate *vs* age at puberty or mature size, have limited improvement in beef production efficiency. As noted by Cundiff, it is clear that no one breed or type excels in all characteristics of economic importance to the beef industry, nor is it reasonable to expect simultaneous improvement in all desired characteristics by selection. Use of various crossbreeding systems that exploit complementarily, heterosis, and the opportunity to match genetic resources to the production environment provide the most effective available means to manage trade-offs from genetic antagonisms.

A Voice-Input and Knowledge-Based Expert System for Grading Carcass Beef

Yud-Ren Chen[1, 2]

Introduction

Assessing meat yield and quality in carcasses is important for exporting meat and for the domestic consumer. The U.S. livestock and meat industries depend heavily on USDA to provide the rating of their meat for marketing. There is also a trend in the U.S. meat industry to process meat closer to the site of slaughter because of increasing transportation and energy costs. Only the edible portion of the carcass will leave the slaughter plant. These trends will increase the volume and demand for more consistent, equitable, and timely methods for grading meat.

Since the USDA meat grading system was first put into use in 1927, meat has been graded by human graders. Because grading is subjective in nature, it is very difficult (if not impossible) to achieve consistency and equity. The development of instruments to assist the human grader in evaluating grade factors has been strongly recommended.

Current developments in the expert systems and natural languages make it possible to devise systems to assist meat graders. At MARC we have initiated a project with an immediate objective of developing systems to assist graders in grading meat, and an ultimate objective of automating the meat grading process through applications of image processing, natural languages, pattern recognition, and expert systems technologies.

This paper describes a knowledge-based expert system which has been developed to assist meat graders in deciding beef carcass yield and quality grades.

System Configuration

Figure 1 is a block diagram of the voice-input, knowledge-based expert system for grading carcass beef. This consists of voice recognition and knowledge-based subsystems. When the meat grading system is first started, the knowledge-based subsystem is invoked and it is ready for the inputs of the characteristics of the first carcass. The meat grader inputs the characteristics by talking into a microphone headset while examining the carcass. Upon the reception of the characteristics of the first carcass, the computer program reasons through the production rules of the expert system to reach the quality and yield grades and prints out the results. After the results are printed out, the computer is ready for the inputs of the characteristics of the next carcass from the meat grader. This is continued until all the carcasses are graded. Both subsystems reside in a COMPAQ DESKPRO 386 computer (two megabytes of memory).

Voice Recognition Subsystem

The VoiceScribe-1000 Speech Recognition System developed by Dragon System, Inc. of Newton, MA, which is a discrete utterance, speaker dependent, recognition system (up to a 1,000 word vocabulary), was used. Table 1 lists the vocabulary of the voice input subsystem. This vocabulary matches the parameters used in production rules of the knowledge-based subsystem and consists of descriptive words and phrases taken from the Official U.S. Standards For Grades of Carcass Beef.

Since the voice recognition system is speaker dependent, a grader must "train" the system to his or her voice for each word or phrase in the vocabulary. The voice patterns of these training words are saved on computer hard disk for routine usage.

After all the patterns are formed, recognition can then be activated. Once in the recognition mode, a pattern is formed for the incoming utterance and is compared to all the reference patterns in the active vocabulary. The word or phrase that matches the incoming pattern with the highest correlation score is considered the "winning" word or phrase. If the score exceeds the reject threshold, the speech driver outputs the results to the computer as if they were typed in through the keyboard.

[1]Chen is the research leader, Biological Engineering Unit, MARC.

[2]I would like to acknowledge Steven A. Robinson, systems analyst, for his assistance with this project.

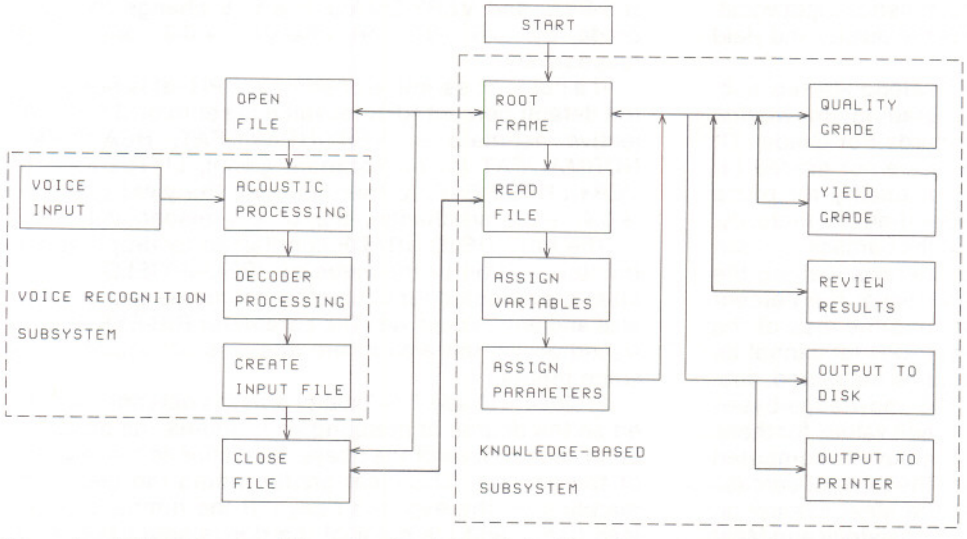


Figure 1—A block diagram of the voice-input, knowledge-based expert system for grading carcass beef.

Table 1—Vocabulary of the beef carcass characteristics used in the voice-input and knowledge-based system

Carcass I.D. Number	Marbling is	Color is
Back Fat	Abundant	Bleached Red
Carcass Wt	Slightly Abundant	Light Red
Ribeye Area	Moderate	Moderately Light Red
KPH Fat	Modest	Cherry Red
	Small	Slightly Dark Red
	Slight	Moderately Dark Red
	Traces	Dark Red
	Practically Devoid	Very Dark Red
	Devoid	
Firmness is	Maturity is	Ribeye Size is
Firm	Alpha	Very Small
Moderately Firm	Bravo	Small Ribeye
Slightly Firm	Charlie	Normal Size
Slightly Soft	Delta	Avg Size
Moderately Soft	Echo	Large
Soft		Very Large
Very Soft		
Chine Bone is	Thoracic is	Texture is
Red and Porous	Not Ossified	Fine
Slightly Red and Soft	Slightly Ossified	Moderately Fine
Tinged with Red	Partially Ossified	Slightly Coarse
Moderately Hard White	Considerably Ossified	Coarse
Hard White		
Flinty		
Cartilage Outline is	Lumbar is	Carcass Fat is
Plainly Visible	Somewhat Ossified	Very Light
Barely Visible	Nearly Ossified	Light
	Completely Ossified	Normal Fat
Sacrum is		Avg Fat
Not Fused	Rib Bones Are	Heavy
Fused	Slightly Rounded	Very Heavy
	Slightly Wide and Flat	
	Moderately Wide & Flat	
	Wide and Flat	
	Very Wide and Flat	

Knowledge-based subsystem

Personal Consultant Plus Expert System Shell from Texas Instruments (PC+) was used to develop the knowledge-based subsystem. The knowledge-based subsystem reads the files of beef characteristics input vocally by the meat grader and determines the quality and yield grades of beef carcasses.

The production rules of the knowledge-based subsystem are based on the meat grading knowledge described in the Official U.S. Standards For Grades Of Carcass Beef. Bulls and veal calves are not graded for their carcass quality. Cows will not qualify for prime quality, and bullocks cannot be older than "A' maturity.

(1) *Yield grade.* The yield grade of the carcass is determined based on the values of the carcass weight; the backfat thickness on the exposed ribeye; the percent kidney, pelvic, and heart (KPH) fat; and the area of the ribeye. If an accurate estimate of the KPH fat cannot be made or the area of the ribeye cannot be measured, subjective estimates can be entered. The knowledge-based system is capable of determining default values for these parameters. This default area of the ribeye is computed by a linear equation developed from the table of carcass weights and ribeye areas given in the Meat Evaluation Handbook, published by the National Livestock and Meat Board.

The default value is further adjusted according to the subjective estimates entered by the grader. The subjective estimates of VERY-LARGE-RIB-EYE, LARGE-RIB-EYE, NORMAL-RIB-EYE, (or no estimate given), SMALL-RIB-EYE, and VERY-SMALL-RIB-EYE change the yield grade by -0.6, -0.3, no change, +0.3, and +0.6, respectively.

If a numeric estimate of percent KPH fat is not given, the default percent KPH fat value is set to be 3.5. A subjective estimate of VERY-HEAVY-FAT, HEAVY-FAT, NORMAL-FAT (or no estimate given), LITTLE-FAT, or VERY-LITTLE-FAT, further changes the yield grade by +0.4, +0.2, no change, -0.2, or -0.4, respectively.

The final YIELD-GRADE is obtained by dropping the fraction portion of the value of PRELIM-YIELD-GRADE after it is adjusted for subjective estimates of the ribeye size and any excess fat. The parameter RIB-EYE-SIZE is traced only if the area of the ribeye is not found in the voice inputs.

2) *Quality Grade.* The quality grade is determined, based on the degree of marbling and firmness as observed on the cut surface of the ribeye, in relation to the maturity of the carcass. The meat grader inputs the degree of marbling on the exposed ribeye. If the firmness of the lean tissue and the color of the ribeye area have an effect on the quality grade, they should also be given.

Otherwise, the knowledge-based subsystem assumes that the firmness of the lean tissue is comparably developed with the degree of marbling, and the quality will be determined on maturity and marbling alone.

Maturity can be entered three different ways. First, the stage of maturity can be entered with a letter stage such as A, B, C, D, or E. However, the grader has the second option to input skeletal characteristics, such as condition of the vertebrae, rib bones, chine bones, and color and texture of the meat. This is particularly necessary when the grader cannot decide on a letter stage of maturity for the carcass because the stage of maturity is on the borderline between two stages. The third option is that using the default value of 'A' for the stage of maturity if no letter maturity or skeletal characteristics are given. If the skeletal characteristics are given, they have a higher priority than the letter indication and will be used to determine the stage of maturity. Based on the skeletal characteristics, the knowledge-based system will determine the stage of maturity of that carcass.

For all beef carcasses having 'A' maturity, degree of maturity within 'A' is not used to determine the quality grade. However, for other maturity groups, an increase in the degree of marbling is required to compensate for the progressive increase in maturity in each grade. To accommodate this feature, the grader should include a numeric value for the degree of marbling and stage of maturity inputs to the knowledge-based system. Rule040 is an example of a very young carcass:

```
IF: CHINE-BONE = RED-POROUS AND
    THORACIC-VERT = NO-EVIDENCE-OSS
    OR THORACIC-VERT = SOME-EVIDENCE-OSS
    AND RIB-BONES = SLIGHTLY-ROUNDED
    OR RIB-BONES = NOT-FOUND
    AND LUMBAR-VERT = LUMBAR-SOME-OSS
    OR LUMBAR-VERT = NOT-FOUND
THEN: STAGE-MATURITY = A
      AND PERCENT-MATURITY = 20
```

In this rule, if the conditions of RIB-BONES and LUMBAR-VERT are not given (NOT-FOUND) because they are not in disagreement with the overall carcass maturity while other parameter values meet the conditions, the rule still will conclude that STAGE-MATURITY = 'A' with a percent maturity of 20. However, if RIB-BONES or LUMBAR-VERT is given, this rule will be concluded only if they also match the conditions of RIB-BONES or LUMBAR-VERT as required by the rule.

The rules to determine the maturity of the carcasses with a PERCENT-MATURITY of 100 (carcasses at the juncture between two maturity groups) are coded directly according to the Standards. For carcasses which are not at the juncture between two stages of maturity, other rules having comparable percent of maturity are searched and matched. When skeletal characteristics are used, emphasis is placed on the conditions of the CHINE-BONE, followed by the THORACIC-VERT, and less on the RIB-BONES, LUMBAR-VERT, SACRAL-VERT, MEAT-COLOR, and MEAT-TEXTURE. The latter parameters are used mostly to decide different percentages of the same stage of maturity.

Once the stage of maturity has been determined and the degree of marbling has been entered, the quality grade is determined according to Figure 1, page 11 of the Standards. If maturity is greater than 'A', then the rules try to determine the percentage of that stage. If no percentage is in the file, the system assumes it is 100. Rule002 demonstrates an 'A' maturity carcass:

```
IF: STAGE-MATURITY = A
    AND DEGREE-MARBLE = ABUNDANT
    OR DEGREE-MARBLE = SLIGHTLY-ABUNDANT
    AND FIRMNESS = MOD-FIRM
    OR FIRMNESS = FIRM
    OR FIRMNESS = NOT-FOUND
    AND SUB-CLASS != COW
THEN: QUALITY-GRADE = PRIME
```

Rule002 also indicates that the cow cannot qualify for PRIME grade. The following Rule009 demonstrates the effect of PERCENT-MATURITY and PERCENT-MARBLE on the QUALITY-GRADE of a 'B' maturity carcass:

```
IF: STAGE-MATURITY = B
    AND DEGREE-MARBLE = SMALL
    AND FIRMNESS = SLIGHTLY-FIRM
    OR FIRMNESS = MOD-FIRM
    OR FIRMNESS = FIRM
    OR FIRMNESS = NOT-FOUND
    AND VALUE PERCENT-MATURITY
        VALUE PERCENT-MARBLE
THEN: QUALITY-GRADE = SELECT
```

In Rule009, the QUALITY-GRADE = SELECT is true because the PERCENT-MATURITY increased greater than the PERCENT-MARBLE.

(3) *Decision-making Process.* QUALITY-GRADE and YIELD-GRADE are the two goals which this knowledge-based system tries to find. For example, to find QUALITY-GRADE, the program looks at all the rules that have QUALITY-GRADE in the THEN portion of the rule. The inference engine then tries these rules to find one that is TRUE. If a parameter such as 'CHINE-BONE' is used in the rule being tried and has no present value, the program stops processing the original search for the value of QUALITY-GRADE and searches for the value of CHINE-BONE. If CHINE-BONE is NOTKNOWN, a function call is made to find the value of CHINE-BONE in the input characteristics.

Once the program has determined the value of CHINE-BONE, it goes back to the rule it was trying and continues where it left off. If the reasoning process requires the value of THORACIC-VERT, and no value was assigned to it, the program will then use a function call to search for the characteristics of the thoracic vertebrae. Once all the parameter values in the IF portion are KNOWN and if the rule is TRUE, the THEN portion of the rule is processed. If the rule is FALSE, then the search continues with the rules that have the current goal in the THEN portion. This continues until a rule which has current goal in the THEN portion and the IF portion is TRUE. In this way, the inference engine processes only those rules that may supply the goal value, and searches only for the unknown parameter values that are necessary to conclude those rules. This is called backward-chaining process.

The program will stop processing when the goals of the program have been concluded.

Program Output

When the data have been processed, the results and the accompanying characteristics will be stored in a permanent file with the identification number of that carcass as the file name and the same data will be sent to the printer. Following is an example of the resulting printout for Carcass no. 1001:

(CARCASS-DATA-FILE-FOR CARCASS-NO 1001)
(QUALITY-GRADE-IS MED-CHOICE)
(YIELD-GRADE-IS 2)
(MODERATE 60 TINGED-RED PARTIALLY-OSS SLIGHTLY-WIDE-FLAT MOD-FINE MOD-LIGHT-RED CARCASS-WEIGHT 605 BACK-FAT 0.4 RIB-EYE-AREA 12.3 KID-PELVIC-HEART-FAT 3 ( ) ( ) ( ))

After the output is given, the grader has the option of saying CONTINUE to continue for the next carcass or, if the grader is interested in knowing how the system reasoned to reach the result, the grader may select the option 'HOW' and the specific parameters he or she is interested in.

Discussion

This system has been tested extensively with a wide variety of carcass characteristics, and the results are consistent with the Standards. It requires about 20 sec for a meat grader, with one-half day's experience with the system, to vocally input the characteristics of a carcass. With the development system, the computer requires about 8 sec to reach the conclusions and print out the grades of each carcass. The time required to grade a carcass will be greatly reduced as the grader acquires experience and becomes more familiar with the system.

With this system, the grader needs to be only a trained carcass characteristic inspector and the computer will do the grading. This will relieve the grader from the intensive mental work of assigning grades to the carcasses. Since the computer is doing the reasoning, the process would not deteriorate after long hours of continuous work.

Also, since the rules are based on specifications of the official meat grading rules, the resulting grades should always be equally or more consistent than those assigned by the human meat grader. However, the consistency of the final yield and quality grade is dependent on the consistency of the meat characteristics observed by the meat graders. The rules are easily changed or upgraded to implement new standards. Also, the meat characteristics and yield and quality grades are permanently recorded, and the processes of decision-making can be easily reviewed. This system can be used not only on the industrial kill floor, but is also very useful as a training tool for future meat graders and a good research tool when meat quality and yield are important parameters.

Summary

This paper describes a knowledge-based, voice-input system being developed to assist meat graders in deciding carcass yield and quality grades. By talking into a microphone headset while examining the beef carcass, the meat grader inputs the meat characteristics into the computer via a voice recognition system, and the computer, based on the meat characteristics, reasons through the production rules to reach the quality and yield grades of the carcass. This system also records the characteristics of each carcass and allows the meat grader to review how the final yield and quality grades have been determined by the program.

Nutritional Value of Anaerobically Fermented Beef Cattle Wastes as a Feed Ingredient for Livestock

Ronald L. Prior, Andrew G. Hashimoto, John D. Crouse[1]

Introduction

Waste is produced in large quantities in cattle feedlots, and this is a potential environmental pollutant. Recycling of feedlot waste as livestock feed has been investigated extensively as one means of lowering the disposable waste load. Refeeding fresh manure will only partially alleviate waste disposal problems. In one study, only about one-half of the manure collected daily could be refed, and the remainder was discarded.

Currently, there is increased interest in the development of a microbial process for recycling and utilizing feedlot wastes. Commercial digestors are in operation. In some of these systems, the potential exists for capturing methane as a product of fermentation and recovering a biomass product which has potential feed value. Because of high capital costs associated with the equipment, labor, etc., necessary for the fermentation process, preliminary economic analyses indicate that, for the fermentation system to be profitable at moderate feedlot sizes, the operation must show a reasonable return for the feeding value of the fermentor effluent biomass. Based on its nutrient content (particularly total nitrogen, amino acids, and some essential minerals), fermentor effluent should be a good dietary supplement for ruminant livestock.

Thermophilic (high temperature) anaerobic fermentation of livestock manures has several advantages that make it attractive for more detailed investigation. Thermophilic fermentation has the potential for higher methane production rates, and minimizes the potential for disease transmission compared with mesophilic (ambient temperature) systems. In addition, fermentation systems have the potential of improving the nutritive value of the nitrogen present in the waste.

Data in this paper describe the chemical composition of the cattle wastes and different fractions of effluent obtained from the anaerobic fermentor and the *in vitro* digestibility of these fractions. *In vivo* experiments in cattle were also used to evaluate the potential feed value of the fermentor biomass using short-term (21 to 35 day) digestion and metabolism studies.

Procedure

The MARC pilot scale thermophilic, anaerobic fermentation system was used to produce the product used in these experiments. Material used in our nutritional studies was obtained as follows: fresh manure was gathered daily from steers housed in a partially roofed structure with concrete-floored pens and fed a standard diet composed of approximately 88.5% corn, 2.5% soybean meal, and 9% corn silage on a dry matter basis. Antibiotics and other feed additives were not fed to these steers. The manure was transported to the pilot plant by a small front-end loader and dumped into the slurry tank. Water was added and the slurry mixed for about 2 hr. Samples were taken for dry matter (DM) and organic matter (OM) determinations. Based on DM and OM concentrations, a given amount of slurry was pumped into a weigh tank, and water was added to dilute the slurry to a specified DM concentration. Slurry in the weigh tank (referred to as fermentor influent, FI) was mixed, while slurry was pumped through a heat exchanger loop and into the fermentor with a working volume of 180.1 cu ft. Before adding fresh slurry into the fermentor, a specified volume of fermented effluent (FE), corresponding to the desired retention time, was removed. The FE was either mixed directly with other feed ingredients for livestock feeding trials or centrifuged. The solids [referred to as dried centrifuged biomass (DCB)] were recovered and dried in a forced-air oven at 158°F.

Experiment 1. A total of 30 crossbred steers (640 lb avg liveweight) were grouped by wt and assigned at random to one of three dietary treatment groups (10/group; control, negative control, and FE; Table 1). All steers were adjusted to the control (C) diet over a 3-wk period. During this time, steers were trained to use individual feeding stalls with electronic headgates. Water was added to the positive and the negative control diets to provide a diet DM content that was approximately similar for the three treatments. On the first three days, only 25% of the designated amount of water or FE was added to the dry diet. The amount of FE or water was increased by 25% every three days so that, by day 10, steers were receiving the designated amount of FE or water. After 21 days on the respective diets, steers were weighed on two consecutive days; thereafter, weights were taken every 21 days for a total of eight periods (168 days).

At the conclusion of the experiment, a final wt was obtained on two consecutive days, and steers were transported to a commercial plant for slaughter the next day. Hot carcass weights were obtained, and other carcass data were obtained after a 24-hr chill. Carcasses were evaluated for marbling, grade, and percentage of kidney, pelvic, and heart fat. Longissimus area was traced and external fat thickness measured at the 12th rib.

Experiment 2. Eighty yearling crossbred heifer calves were assigned by wt and breed to one of the four dietary treatments outlined in Table 1. Eight heifers/treatment were fed using individual feeding stalls with electronic headgates. An additional 12 animals per treatment were housed and fed in groups of 4 animals per pen. Cattle waste, obtained daily from steers fed and housed on concrete, was diluted with water to provide a slurry containing approximately 7% DM (FI). Part of this slurry was mixed with the appropriate diet ingredients for feeding, while the remainder of the slurry was used to provide substrate for the anaerobic fermentor. The amount of FE or FI added to the appropriate diet was adjusted to provide the same amount of DM from either source. The diets containing FI and FE were mixed fresh daily. A diet with no supplemental soybean meal was used as a negative control, while the positive control diet contained supplemental soybean meal (Table 1). A 21-day period was allowed for adaptation to the diets and individual electronic headgates. After adaptation, liveweights were

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Table 1—Percentage composition[a] of diets fed to beef cattle (Experiments 1 and 2)

Item	Positive control	Negative control	Negative control + effluent	Negative control + influent
Experiment 1 (Steers)				
Ingredient composition				
Brome, smooth, hay	20.00	20.00	20.00	
Corn, yellow, grain, ground	72.00	79.00	72.55	
Soybean, seed, solvent-extracted ground	7.20	0	0	
Limestone, ground, mn 33% calcium	0.90	1.00	1.00	
Fermentor effluent (solids)	0	0	6.45	
Vitamins A, D, and E[b]	+	+	+	
Total	100.00	100.00	100.00	
Nutrient composition[c]				
Dry matter, %	44.0	44.0	38.1	
Crude protein, %	12.1	10.0	12.2	
Ash, %	5.7	5.4	7.1	
Neutral detergent fiber, %	31.4	35.0	32.3	
Cellulose	11.4	10.4	10.6	
Acid detergent fiber, %	16.2	13.9	15.5	
Lignin, %	2.9	2.6	3.1	
Gross energy, Mcal/lb	2.0	2.0	2.0	
Experiment 2 (Heifers)				
Ingredient composition				
Brome, smooth, hay	20.00	20.05	20.00	20.00
Corn, yellow, grain, ground	71.47	78.40	72.08	72.08
Soybean, seeds, solvent-extracted ground	7.10	0	0	0
Limestone, ground, mn 33% Ca	1.42	1.44	1.32	1.32
Calcium phosphate, dibasic, commercial	0	0.15	0.14	0.14
Solids from effluent	0	0	6.45	0
Solids from influent	0	0	0	6.45
Trace minerals	0.01	0.01	0.01	0.01
Total	100.00	100.00	100.00	100.00
Nutrient composition				
Dry matter	85.4	85.2	37.4	50.9
Crude protein[a]	11.4	10.0	12.2	11.3
Ash[a]	4.3	3.9	5.9	5.3
Ca[a]	0.28	0.28	0.60	0.50
P[a]	0.30	0.27	0.34	0.33

[a]Expressed on dry matter basis.
[b]Added to provide 2,200 IU vitamin A, 219 IU vitamin D_3 and .1 IU vitamin E/lb of dry ration.
[c]Values based on laboratory determinations. Expressed on dry matter basis except for dry matter.

taken on two consecutive days and then at 21-day intervals. Daily samples of each diet were obtained and composited over each 21-day weigh period. Feed not consumed was weighed and sampled for nutrient analysis every week. The experiment ran for a total of 126 days.

Results

Chemical Analyses. DM, ash, nitrogen (N), and total volatile acids (TVA) composition of the FI and FE are presented in Table 2. Because water is added to the raw waste before pumping into the fermentor, DM content of the FI is a reflection of the amount of water added. The 48.6% decrease in DM due to the fermentation process is similar to that observed previously. Total N and ash contents (g liter^{-1}) of the FI and FE were not different. However, if expressed on a DM basis, N and ash content increased due to reduction in DM during fermentation. Assuming that all nonammonia-N is in the form of protein, the protein content, expressed as a percentage of DM, is enriched from approximately 20% to 26% during the fermentation process. Ammonia-N concentration as a percentage of the total N increased from 24.9% to 46.3%. TVA concentration in FE decreased when expressed on both a DM basis and g liter^{-1} basis compared with FI.

Gross energy content of DM is not different between FI and FE (Table 2). However, energy that is available to the animal is undoubtedly less in FE compared with material in FI. FE contained a higher percentage of acid detergent fiber (ADF; lignocellulose) and lignin than FI (Table 4). Thus, material remaining in FE represents a more highly lignified, less digestible material than in FI. The material isolated following centrifugation (DCB) represents one of the least digestible FE fractions. The lignin and ADF content was more than double, and gross energy content lower, in DCB than in FE (Table 2). Thus, centrifugation yields a product that is chemically less desirable as a nutritional supplement than the complete FE.

Data in Table 2 indicate that loss of some N occurs during centrifugation and drying of FE. In wet centrifuged biomass, about 50% of the total N is recovered. During the drying process, more N is lost, primarily as NH_3-N (ammonia nitrogen), so that total N recovery after centrifugation and drying is about 40%. The conditions

Table 2—Composition of fermentor influent and effluent and dried centrifuged biomass

Component	Fermentor influent (FI)	Fermentor effluent (FE)	Dried centrifuged biomass
Dry matter[a], %	9.83[c]	5.05[b]	23.1
Ash, %[e]	0.26	.23	26.8
Cell contents[e]	58.6[c]	60.0[c]	21.2[b]
Cell walls (NDF)[e]	41.5[b]	40.1[b]	78.8[c]
Cellulose[e]	10.5[b]	10.6[b]	22.6[c]
Acid detergent fiber[e]	15.3[b]	20.0[c]	46.2[d]
Lignin[e]	3.1[b]	6.4[c]	13.4[d]
Gross energy (kcal/lb)	2.12	2.12[c]	1.81[b]
Total N			
lb N/cu ft[a]	0.26	0.24	---
lb N/lb dry matter (wet) x 1000	---	76.6	39.2
(after drying) x 1000	---	---	29.6
Ammonia-N			
lb/cu ft[a]	0.06[b]	0.11[c]	---
% of total N[a]	24.9	46.3	15.6
lb/lb dry matter x 1000	---	35.4	6.1
Total volatile acids (TVA)			
lb/cu ft	0.47[c]	0.15[b]	---
lb/lb dry matter x 1000	76.8[c]	46.4[b]	---

[a]Determinations made three times weekly during the 32-week experimental period except for centrifuged biomass. Fermentor retention time was 12 days. Effluent was used in a cattle feeding experiment during this period.
[bcd]Means without a common superscript differ ($p < .05$).
[e]Expressed as % of dry matter.

used in obtaining these data were controlled more than would be the case under practical conditions. Under some conditions, total N recoveries obtained were as low as 12 to 20%. This low recovery of N is of major concern because one objective of this research is to recover a high-protein livestock feed supplement.

Experiment 1. Weight gain, feed intake, and feed efficiency data are presented in Table 3. Steers fed the FE-containing diet had a 4% to 12% higher DM intake but gained wt about 15% slower than steers fed the negative or positive control diets. Feed efficiency (DM:gain) decreased by 17% to 25% in the FE-fed steers, compared to the control groups.

Performance of the steers fed the negative control diet containing 10% crude protein was somewhat surprising, considering the relative light wt (640 lb) at which steers were started on the experimental treatments. Protein requirements for this wt of cattle would be expected to exceed that provided by a 10% crude protein diet. However, the somewhat lower performance of all cattle in this experiment (less than 2.2 lb/head/day) may partially explain the apparently lower protein requirement of the steers used in this experiment.

The diets fed in Experiment 1 did not alter any of the carcass quality measurements (Table 3), although hot carcass wt was lower in steers fed FE. All steers had a quality grade in the high-Good or low-Choice range. Taste panel evaluations revealed that steaks from steers fed the FE diet were not different ($P > .05$) from steaks from steers fed the control diet. Thus, feeding of FE does not appear to have any detrimental effects on the eating qualities of steaks.

Experiment 2. Weights, gains, feed intake, and efficiency data for heifers are presented in Table 4. Period or cumulative ADG were not altered by dietary treatments. In contrast to the previous experiment in steers, feeding FE did not alter ADG or feed efficiency ($P > .05$). DM intake was also not altered by feeding FE or FI. Crude protein intakes were highest in heifers fed the FE, which is a reflection of the slightly higher crude protein content of the FE diet (12.2%), compared with the positive control diet (11.4%). Performance of heifers fed the negative control was similar to heifers fed the positive control diet which contained a soybean meal supplement. Similar performance of these two groups might be expected because the initial wt at the start of the experiment was approximately 827 lb, and a diet containing 10% crude protein should not be limiting for this size of animal.

Reasons for the differences in animal response to dietary FE between Experiments 1 and 2 are not clear. Differences between the two experiments included: 1) sex of animal, and 2) wt at the start of the experiment. It is doubtful that there would be a sex by diet interaction, but differences in initial wt might explain some of the differences, in that heavier animals may adapt more readily to FE.

No differences in performance were observed between heifers fed FI *vs* FE, even though relatively large differences existed between some components of the influent and effluent (Table 2). The amount of TVA decreased, and the percentage of total N present as ammonia increased in FE, compared with FI. However, in terms of total diet DM, these changes would be relatively small because FI or FE provided only about 6.5% of total diet DM (Table 1).

Building location and/or method of feeding did not alter feed intake, feed efficiency, or ADG in Experiment 2 ($P > .05$; data not presented). Thus, similar performance of cattle can be expected, whether they are fed individually using electronic headgates, or in a small-group feeding situation.

As observed in Experiment 1, feeding of FI or FE did not significantly alter carcass quality characteristics. Heifers fed FE and FI were lighter in wt initially and at slaughter than the positive or negative control heifers. The dressing percentage at slaughter was also slightly lower in FE and FI-fed cattle than in controls.

General Conclusions. Because of a limitation in the amount of material available, we have not been able to complete any long-term feeding experiments with dried centrifuged biomass (DCB) used in metabolism studies.

Table 3—Influence of protein level and fermentor effluent on liveweight gain, final wt, feed efficiency, and carcass quality characteristics of steers (Experiment 1)[a]

Item	Control	Negative control	Negative control + effluent
No. of animals	9	10	10
Initial wt[j], lb	663	636	621
Final wt[j], lb	1,013	993	923
Avg daily gain, (lb/head/day)	2.05	2.07	1.76
Adj avg daily gain[j] (lb/head/day)	2.09	1.98	1.72
Dry matter intake, (lb/head/day)	18.1	16.7	18.9
Protein intake, (lb/head/day)	2.16	1.65	2.33
Protein/gain	1.03[g]	0.77[f]	1.27[h]
Dry matter/gain	8.64[f]	7.86[f]	10.37[g]
Hot carcass wt, lb	605.3[e]	592.4[de]	541.3[d]
Dressing %[i]	59.9	58.2	58.8
Marbling[ik]	13.3	10.6	10.3
Quality grade[il]	10.9	9.3	9.2
Adj. fat thickness[i], in	0.57	0.41	0.40
Longissimus area[i], in^2	10.2	10.6	9.9
Kidney, pelvic fat[i], %	3.6	3.4	3.0
Yield grade[i]	3.7	3.0	3.0

[a]Means of nine or ten observations/treatment.
[bc]Means with different superscripts differ (P < .10).
[de]Means with different superscripts differ (P < .05).
[fgh]Means with different superscripts differ (P < .005).
[i]Differences in treatment means are not significant (P < .05).
[j]Adjusted to common dressing percentage.
[k]Marbling score: Slight = 7, 8, 9; Small = 10, 11, 12.
[l]Quality grade score: Good = 7, 8, 9; Choice = 10, 11, 12.

Table 4—Influence of diet on liveweights, avg daily gains, feed intake, feed efficiency, and carcass characteristics of heifers[a]

	Dietary treatments			
	Control	Negative control	Effluent	Influent
Initial wt[f]	870.1	854.7	803.3	801.5
Cumulative				
ADG[f], lb	2.65	2.82	2.80	2.82
Dry matter intake[df] (lb/head/day)	26.2	26.0	23.4	24.0
Crude protein intake[d]	3.5	3.1	7.9	5.3
Dry matter/gain[f]	9.4	8.9	8.2	8.1
Protein/gain	1.3[b]	1.0[b]	2.8[d]	1.8[c]
Hot carcass wt (lb)	665.5[c]	659.5[c]	622.7[b]	622.0[b]
Dressing percentage, %	61.1[c]	60.3[bc]	59.9[b]	59.9[b]
Marbling[ef]	8.6	9.0	8.9	7.4
Quality grade[ef]	8.3	8.4	8.1	7.4
Adj. fat thickness[f], in	0.35	0.31	0.31	0.30
Kidney, pelvic fat[f], %	2.7	2.9	2.5	2.5
Longissimus area[f], in^2	12.8	12.5	12.4	12.1

[a]Means based on twenty observations.
[bc]Means with different superscripts differ (P < .05).
[d]Lb per head per day.
[e]Marbling score: Slight = 7, 8, 9; Small = 10, 11, 12.
Quality grade score: Good = 7, 8, 9; Choice = 10, 11, 12.
[f]Differences in means are not significant (P < .05).

However, in other laboratories, an increased feed requirement per unit of gain and decreased gains in steers fed DCB-containing diets (10.5% of diet DM) has been observed. Because of the relatively high fiber and low digestibility of DCB, utilization of DCB may have to be restricted to maintenance-type diets. The major disadvantage of attempting to utilize the DCB is the amount of nutrients lost during the centrifugation and drying process. Mixing FE with dry diet overcomes the problem of nutrient loss, but new problems are introduced. The amount of DM from the FE that can be used in the diet is limited by the amount of liquid that can be added to the dry diet to obtain a final product that is approximately 35% DM. The maximum DM that we could add to the diet from the FE was approximately 5% to 7% of the diet DM. This level of biomass DM would not be expected to affect performance; however, in the first experiment with steers, a 15% decrease in performance was observed, although this was not observed in the second experiment with heifers.