Project Summary

Do heifer finishing implants affect beef tenderness

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Background

According to a 1999 survey of the U.S. commercial cattle feeding industry (NAHMS, 2000), over 97% of all cattle produced in U.S. feedlots receive one or more implants during finishing. The number of implants administered to feedlot cattle depends upon the animals' placement weights and the projected duration of the finishing period. Heavyweight feeder cattle, fed fewer than 130 days, usually receive only one finishing implant. Lighter-weight cattle, requiring finishing periods of 130 days or longer, typically receive two sequential finishing implants, with the terminal implant administered 70 to 120 days before harvest. Very lightweight calves, projected to require 230 or more days of finishing, sometimes receive three implants during finishing (Nichols et al., undated publication). However, based on industry survey results, only about 6% of the cattle entering U.S. feedlots weighing less than 700 pounds would receive more than two implants (NAHMS, 2000).

Sequential implanting produces additive effects on weight gain (Duckett and Andrae, 2001), so that additional performance advantages are realized with each successive implant. In a review of the effects of implants on carcass characteristics, Duckett (2004) reported that a single finishing implant increased hot carcass weight by approximately 5 to 6%, whereas use of two finishing implants (in an implant/re-implant sequence) increased carcass weight by approximately 8%. However, repetitive use of implants has been shown to increase the rate of skeletal maturation (Platter et al., 2003; Scheffler et al., 2003) and often reduces marbling (Morgan, 1997). Duckett (2004) reported that, compared to a non-implanted control, use of a single finishing implant (estrogen or estrogen plus androgen) reduced marbling score by approximately 4 to 5%, and that use of two sequential finishing implants decreased marbling score by about 7 to 12%. Recent studies (Platter et al., 2003; Scheffler et al., 2003) have documented a relationship between the number of implants used during the growing and finishing phases of production and beef tenderness. In these studies, tenderness decreased (i.e., shear force values increased) as the number of implants increased.

Campbell et al. (2005) listed 28 different implant products currently available for use in growing and finishing cattle. The extensive list of approved cattle implants includes a broad array of products ranging from very low-dosage implants designed for calves and light-weight stocker cattle to very high-potency implants for use in finishing steers and heifers. Hormonal ingredients approved for use in cattle implants include estrogens: estradiol 17-β (E2), estradiol benzoate (EB), or zeranol (Z); androgens: trenbolone acetate (TBA) or testosterone propionate (TP); and progesterone (P). Implants used for finishing steers typically contain an estrogen (E2, EB + P, or Z) or a combination of estrogen plus androgen (E2 + TBA or EB + TBA), whereas implants most frequently used for finishing heifers include an androgen (TBA) or a combination of estrogen plus androgen (E2 + TBA, EB + TBA, or EB + TP). In addition, finishing heifers frequently are fed melengestrol acetate (MGA) – primarily to suppress estrus, although MGA also stimulates growth by inducing a hyper-estrogenic state and increasing circulating levels of growth hormone (Anderson, 1991).

Implants designed for use in finishing heifers differ in relative potency depending upon dosages of estrogen and (or) androgen. Commercially available androgenic implants for heifers contain 200 mg of TBA. Combination implants for feedlot heifers that include both E2 and TBA, contain a 10:1 ratio of androgen to estrogen and with dosages ranging from 8 to 20 mg E2 and from 80 to 200 mg TBA (Campbell et al., 2005). As dosages of E2 plus TBA increase, anabolic potency increases. Heifer implant products that contain both EB and TP include 20 mg EB and 200 mg TP (Campbell et al., 2005), and are considered moderate in strength (Montgomery et al., 2001).

Previous research involving steers suggests that implant programs involving a single high-dosage combination implant (20 mg E2, 200 mg TBA); an implant/re-implant sequence including an estrogenic implant (36 mg Z or 14 mg E2), followed by a high-dosage combination implant (20 mg E2 + 200 mg TBA); or two successive mid-dose combination implants (24 mg E2 + 120 mg TBA, followed by 24 mg E2 + 120 mg TBA) can reduce beef tenderness (Tatum, 2006). The effects of dosage rates of estrogen and androgen on tenderness of beef produced by heifers have not been investigated. More comprehensive information concerning the effects of various heifer implants on beef quality characteristics is needed to assist beef producers in designing more effective implant strategies for finishing heifers.

Methodology

Animals and Experimental Treatments

Five hundred Continental × British crossbred feeder heifers (mean weight = 348 kg), projected to require approximately 140 days on feed prior to harvest, were obtained from a single backgrounding operation in western Nebraska and transported to a large commercial cattle feedlot in north central Colorado in early June 2005. Following a 5-day acclimation period, the heifers were weighed individually (on-test weight), tagged with two uniquely numbered ear tags, and vaccinated for infectious bovine rhinotracheitis (IBR) virus and bovine viral diarrhea (BVD) virus types I and II (Titanium 3, Agri Laboratories, LTD., St. Joseph, MO).

Before leaving the processing chute, each heifer was assigned randomly to one of twelve experimental treatments. Treatment groups included a non-implanted, negative control group and eleven different implant treatments (including four single-implant protocols and seven implant/re-implant protocols), which were chosen specifically to deliver cumulative dosages of trenbolone acetate (TBA) and estradiol 17-β (E2) ranging from 0 to 400 mg TBA and 0 to 40 mg E2 during the finishing period (Table 1). Heifers assigned to the eleven treatments that involved implanting received their respective initial implants before leaving the processing chute. Implants were administered using industry-recommended procedures for proper implant placement and sanitation of the implant-site and implant applicator needles (Zero Defect Implanting, Vetlife, Inc., Des Moines, IA).

Immediately following initial processing, heifers were sorted into two feeding groups (pens) based on initial weight: Pen 1 consisted of heifers with initial weights of 340 kg or greater (n = 291), while Pen 2 consisted of heifers with initial weights less than 340 kg (n = 209). For this study, animal (rather than pen) served as the experimental unit. Correspondingly, heifers representing all twelve experimental treatments were commingled and fed together in each pen. Because cattle were assigned to treatments randomly as they were moved through the processing facility, numbers of heifers representing each treatment were not perfectly balanced between pens or within each pen.

Cattle Management

Cattle management practices (i.e., diets, health programs, and marketing dates) were specified by the feedlot management staff and were not modified for the experiment. Heifers in both pens received a finishing diet consisting of 74.74% steam-flaked corn, 9.34% corn silage; 7.30% dried distiller's grain, 5.66% liquid supplement and 2.96% tallow (% DM basis), which was dispensed three times daily to provide cattle with ad libitum access to feed. Rumensin and Tylan (Elanco Animal Health, Indianapolis, IN) were mixed in the diet at inclusion rates of 360 mg×hd-1×d-1 and 90 mg×hd-1×d-1, respectively, and melengestrol acetate (Upjohn Pharmacia, Kalamazoo, MI) was fed at an inclusion rate of 0.5 mg×hd-1×d-1. All heifers scheduled to receive a second implant (Table 1) were re-implanted 85 days before harvest. Heifers were harvested on October 19, 2005 (Pen 1) and November 2, 2005 (Pen 2), after 135 and 149 days on feed, respectively. Due to

concerns about carcass bruising and the possibility of increasing the incidence of dark cutting carcasses, the commercial cooperator, who owned the cattle, would not permit collection of individual off-test weights. All experimental procedures involving live cattle were reviewed and approved by the Colorado State University Animal Care and Use Committee (Project Approval Number: 05-073A-01).

Carcass Data Collection and Sampling Methods

Heifers were harvested at a large commercial beef packing facility utilizing conventional humane procedures. Individual animal identity was maintained throughout the harvest process to facilitate collection of individual carcass grade data. Following a 48-hour chill, a trained panel of evaluators (Colorado State University personnel) recorded measurements or estimates of hot carcass weight (HCW), fat thickness, adjusted fat thickness, longissimus muscle area (LMA), and percent kidney, pelvic, and heart (KPH) fat. A USDA-AMS grading supervisor assigned scores for marbling, skeletal maturity, and lean maturity and recorded the incidence and severity of lean quality defects (i.e., dark cutting characteristics and blood splash).

For cattle in the second harvest group, color of the longissimus muscle of each carcass was evaluated using a Hunter Miniscan XE Plus handheld spectrophotometer equipped with a 6mm aperture (Hunter Associates Laboratories, Inc., Reston, VA) to determine values for CIE L* (brightness; 0 = black, 100 = white), a* (redness/greenness; positive values = red, negative values = green), and b* (yellowness/blueness; positive values = yellow, negative values = blue) following procedures of the Commission Internationale de l'Eclairage (CIE, 1976). Unexpected instrument malfunctions prevented measurement of longissimus muscle color for cattle in the first harvest group.

Following carcass data collection, a boneless strip loin (Institutional Meat Purchasing Specifications #180; USDA, 1990) was labeled, removed from each carcass, and immediately transported to the Meat Laboratory at Colorado State University for further processing. Boneless strip loins were fabricated into five sections (each 5.5 cm wide) beginning at the anterior end of the strip loin. Each section was assigned randomly to one of five postmortem aging treatments (3, 7, 14, 21, or 28 days), individually vacuum packaged, aged for the appropriate period of time at 2°C, and then placed in frozen storage (-20°C). Frozen samples were cut into 2.54-cm-thick steaks using a band saw (Model 400, AEW Thurne, Inc., Norwich, England). Individual steaks were vacuum packaged, immediately returned to the freezer, and stored for approximately 50 days until Warner-Bratzler shear force (WBSF) analysis was conducted.

Tenderness Measurements

Frozen steaks were allowed to thaw for 36-hours at 2°C and then cooked on an electric conveyor grill (Model TBG-60, Magikitch'n, Inc., Quakertown, PA) to a target internal temperature of 70°C. Steaks were cooked for a constant time of 6 min, 05 sec at a setting of 176°C for the top and bottom heating platens with the platen height set at 1.85 cm. Peak internal temperature was recorded for each steak using a Type K thermocouple (Model 34040, Atkins Technical, Inc., Gainesville, FL). After cooking, steaks were allowed to equilibrate to room temperature (20-22°C) and 6 to 10 cores (1.27 cm diameter) were removed parallel to the muscle fiber orientation. Each core was sheared once perpendicular to the muscle fiber orientation using an Instron load frame (Model 4443, Instron Corporation, Canton, MA) fitted with a Warner-Bratzler shear head (settings: crosshead speed = 200 mm/min, load cell capacity = 100 kgf). A single peak shear force was calculated for each core using series IX software (Instron Corporation, Canton, MA). Individual-core, peak shear force values were averaged to assign a peak shear force value for each steak.

Statistical Analysis

Individual animal served as the experimental unit for all statistical analyses. Data for carcass traits were analyzed using the PROC MIXED procedures of SAS (Version 9.1, SAS Institute, Cary, NC). Statistical models for carcass traits included the random effect of pen and fixed effects of implant treatment and on-test weight, which was included in the model as a covariate.

Data for Warner-Bratzler shear force values were analyzed as repeated measures, using the PROC MIXED procedures of SAS. The statistical model included fixed effects of implant treatment, aging period, and the implant treatment x aging interaction, along with the random effects of pen and individual animal within implant treatment. Statistical models for Warner-Bratzler shear force value also included cooked steak peak-temperature as a covariate. The repeated statement designated aging period as the repeated variable and options specified for subject and type, were individual animal and spatial power, respectively. When a significant ($P < 0.05$) F-test was observed, multiple comparisons of treatment means were performed using t-tests.

The study design included several a priori comparisons (planned contrasts) to examine effects associated with the number of implants administered during finishing and to compare effects of specific dosage rates of E2 and TBA. Additional analyses partitioned treatment effects into the following non-orthogonal contrasts: Contrast 1 – No implants vs. a single finishing implant (Treatment 1 vs. Treatments 2, 3, 4, and 5); Contrast 2 – A single finishing implant vs. two sequential finishing implants (Treatments 2, 3, 4, and 5 vs. Treatments 6, 7, 9, and 12); Contrast 3 – A low-dose (8:80) combination implant vs. a moderate-dose (14:140) combination implant as the initial implant in a two-implant program (Treatments 8 and 10 vs. Treatments 9 and 11); Contrast 4 – A moderate-dose (14:140) combination implant vs. a high-dose (20:200) combination implant as the terminal implant in a two-implant program (Treatments 8 and 9 vs. Treatments 10 and 11); and Contrast 5 – Use of TBA alone vs. use of E2 + TBA (Treatments 2 and 6 vs. Treatments 5 and 12).

Frequency distributions of USDA quality grades were analyzed using the PROC FREQ procedures of SAS. If the overall $\chi 2$ statistic was significant, differences in frequencies between treatment groups were tested for significance using Fisher's exact test. All comparisons were tested using a comparisonwise significance level of $\alpha = 0.05$.

Findings

Pair-wise Treatment Comparisons

Results showing the effects of implant treatment on carcass composition and quality are presented in Tables 2 and 3, respectively. Implant treatment did not affect adjusted fat thickness or predicted percentage of empty body fat (Table 2), suggesting that, in this study, cattle in various treatment groups were compared at similar mean compositional endpoints.

Compared with the non-implanted control (Treatment 1), all but three of the implant treatments (Treatments 2, 3, and 4) increased ($P < 0.05$) hot carcass weight and longissimus muscle area (Table 2). Due to larger longissimus muscle areas (Table 2), heifers in some of the more aggressive implant treatments (Treatments 9, 10, and 11) had lower (i.e., improved) yield grades ($P < 0.05$) than did non-implanted heifers (Treatment 1) or heifers in several of the less aggressive implant treatment groups (Treatments 2, 3, 4, and 7). Treatment differences in percentage of kidney pelvic and heart fat, though statistically significant, were small in magnitude and practically unimportant (Table 2).

Implant treatment did not affect scores for skeletal or lean maturity (Table 3); however, the effect of implant treatment on marbling score approached significance ($P = 0.0861$) and was of sufficient magnitude to influence ($P < 0.05$) the percentage of carcasses grading Choice & Prime (Table 3). Compared with the non-implanted control, none of the implant treatments significantly reduced quality grade performance (Table 3). However, heifers implanted with the highest

cumulative dosages of estrogen plus androgen (Treatments 9, 10, 11, and 12) produced significantly fewer carcasses grading Choice & Prime than did heifers receiving one androgenic implant or two lower-dose combination implants (Treatments 2 and 7, respectively). In addition, heifers in Treatments 9 and 12 (implanted twice with comparatively high dosages of estrogen plus androgen) produced lower ($P < 0.05$) percentages of carcasses grading Choice & Prime, than did heifers in Treatments 3 and 5 (implanted a single time with either low or high dosages of estrogen plus androgen). Implant treatment did not affect frequencies of lean quality defects (dark-cutters or blood splash) or longissimus CIE L*, a*, and b* color values (data not presented in tabular form). The effect of implant treatment on longissimus Warner-Bratzler shear force (WBSF) was influenced by length of the postmortem aging period as indicated by a significant ($P < 0.0001$) interaction between Treatment and Aging. Least squares means for longissimus WBSF corresponding to the Treatment × Aging interaction effect are presented in Table 4.

Implanting heifers a single time during finishing (Treatments 2, 3, 4, and 5) had no effect on WBSF (Table 4); however, use of two implants containing both E2 and TBA (Treatments 7 through 12) resulted in higher ($P < 0.05$) 3-day WBSF values when compared with the non-implanted control group. As postmortem aging increased, the effects of the various implant treatments on WBSF were gradually diminished, so that by 28 days postmortem, only the most aggressive implant treatment (Treatment 12) had higher ($P < 0.05$) WBSF values than the control group (Table 4). These findings suggest that postmortem aging may be effective for mitigating tenderness problems associated with some, but not all, heifer implant programs.

Planned Contrasts

Morgan (1997), following a review of several studies, concluded that both the number and potency of implants administered during finishing influence beef carcass quality characteristics and meat tenderness, and suggested that implant programs involving the use of high-potency implants, administered multiple times, produce the most pronounced, adverse effects on beef quality. Planned contrasts comparing effects of the number and potency of implants administered during finishing on carcass yield grade traits, quality grade characteristics, and longissimus shear force are summarized in Tables 5, 6 and 7, respectively.

Number of Implants. Commercially finished heifers requiring 130 to 140 days on feed could receive either one or two implants during finishing, depending upon the management strategy and marketing goals of the cattle feeder. The first contrast presented in Tables 5 and 6 (no implants vs. one implant) showed that, in this study, use of a single finishing implant increased ($P = 0.025$) hot carcass weight by an average of 7.9 kg (Table 5), without affecting mean marbling score, percent Choice & Prime, or WBSF (Tables 6 and 7). Heifers receiving a single implant produced carcasses with slightly more advanced ($P = 0.052$) skeletal maturity (Table 6) than did heifers that were not implanted (A66 vs. A60, respectively); however, all other carcass traits were similar for the two groups. Compared with a single implant program, use of two sequential implants resulted in an additional increase ($P = 0.008$) in hot carcass weight of 6 kg (Contrast number 2, Table 5). Moreover, re-implanting increased ($P < 0.0001$) longissimus muscle area, reduced ($P = 0.024$) the percentage of KPH fat, and improved ($P = 0.004$) mean yield grade (Table 5). However, heifers receiving two finishing implants produced a lower ($P = 0.046$) percentage of carcasses grading Choice & Prime (Contrast 2, Table 6) and had higher ($P < 0.05$) longissimus WBSF values at all postmortem aging times (Contrast 2, Table 7), compared with heifers that received only one implant during finishing.

Implant Potency. The third and fourth contrasts in Tables 5 and 6 compared effects of implant/re-implant programs utilizing initial and terminal implants differing in potency. The third contrast compared carcass traits for heifers receiving either a low-dose (8 mg E2: 80 mg TBA) or

moderate-dose (14 mg E2:140 mg TBA) combination implant as the initial implant in a two-implant sequence, while the fourth contrast compared moderate-dose (14 mg E2:140 mg TBA) and high-dose (20 mg E2:200 mg TBA) terminal implants. Heifers receiving the lower-dose initial implant produced carcasses with slightly more youthful lean maturity scores ($P = 0.029$); however, none of the other carcass characteristics differed between the two groups (Contrast 3, Tables 5 and 6). Carcass yield and quality grade characteristics were not significantly affected by use of moderate- vs. high-dose terminal implants (Contrast 4, Tables 5 and 6).

Heifers receiving the lower-dose initial implant had slightly lower ($P = 0.09$) WBSF values at 7 days postmortem than did heifers that received the higher-dose initial implant; however, WBSF values for the two groups were not statistically different at other postmortem aging times (Contrast 3, Table 7). Use of moderate- vs. high-dose terminal implants had no effect on WBSF regardless of aging time (Contrast 4, Table 7).

TBA vs. E2 + TBA. Contrast 5 compared the effects of single-ingredient implants (TBA only) with combination implants (containing both E2 and TBA) used once or twice. In this contrast, the TBA dosage was constant, so that the two groups differed only with respect to the inclusion of E2. Cattle administered implants containing a combination of E2 plus TBA had larger ($P = 0.046$) longissimus muscle areas than did cattle implanted with trenbolone acetate only (Table 5). Additionally, carcasses from heifers administered implants containing a combination of E2 plus TBA had lower ($P = 0.004$) mean marbling scores than did carcasses produced by heifers implanted with TBA only (Table 6). All other carcass traits were similar for the two groups (Tables 5 and 6). Heifers that received implants containing a combination of E2 plus TBA produced steaks that had higher WBSF values after 3 ($P = 0.001$), 7 ($P = 0.001$), 14 ($P = 0.003$), and 21 ($P = 0.045$) days of postmortem aging, compared with heifers receiving TBA alone. However, mean WBSF values for the two groups did not differ ($P = 0.247$) when steaks were aged for 28 days (Contrast 5, Table 7). The widespread use of implants containing TBA frequently is cited as a root cause of reduced quality grade performance and decreased beef tenderness. In this study, TBA, when used alone (in heifers fed MGA), produced no negative effects on beef quality or tenderness. However, quality grade performance and beef tenderness were negatively affected when high dosages of E2 were combined with TBA.

Duckett and Andrae (2001) reported a moderately strong relationship ($r^2 = .68$) between the increase in longissimus muscle area and the reduction in marbling associated with use of certain anabolic implants, and suggested that implant programs that cause a reduction in marbling do so by increasing the size of the longissimus muscle, thereby diluting the intramuscular fat content of the muscle (Duckett et al., 1999). Moreover, Duckett (2004) observed that reductions in tenderness observed for some implant treatments typically are correlated with increases in longissimus area and speculated that such increases in WBSF may stem from an increase in muscle fiber size resulting from the anabolic effects of implants. Results of the present study seem to support these concepts. In this study, treatment groups showing the greatest increases in longissimus area also had among the lowest percentages of percent Choice & Prime and among the highest longissimus WBSF values (particularly at 3, 7, and 14 days postmortem).

Implant Programs

Effective implant programs improve growth performance with minimal effects on carcass quality and beef tenderness. The information in Tables 8 and 9 is provided to assist beef producers in designing effective implant programs for yearling feeder heifers. Data in these tables compare the four single-implant programs (Table 8) and seven two-implant programs (Table 9) evaluated in this study with respect to the change each elicited in a) hot carcass weight, b) longissimus muscle area, c)

percentage Choice & Prime, and d) longissimus WBSF, when compared with the non-implanted control.

Among the single implant programs (Table 8), Treatment 5 (20 mg E2:200 mg TBA) resulted in the greatest increase in hot carcass weight and LMA, without reducing carcass grade performance or tenderness. Treatment 2 (0 mg E2:200 mg TBA) might be a viable strategy for cattle feeders who are trying to maximize percent Choice & Prime; however, it should be noted that the 7.8 kg increase in carcass weight for this treatment did not differ statistically from the control group (Table 8).

All of the two-implant programs significantly increased carcass weight and LMA (Table 9). Treatments 6, 7, and 8 increased mean carcass weight from 12.3 to 17.3 kg without adversely affecting carcass quality or tenderness. Though not statistically significant (compared to the control), the magnitude of the reductions in percent Choice & Prime observed for Treatments 9 through 12, are noteworthy. Moreover, Treatments 9, 11, and 12 significantly increased 14-day WBSF, suggesting that producers who are interested in interested in designing best management practices for the production of consistently tender beef should avoid sequential use of moderate- to high-dose combination implants for heifers.

Values for WBSF presented in Tables 8 and 9 reflect tenderness differences after a postmortem aging period of 14 days. Aging for longer periods of time could reduce the magnitude of the effects on WBSF of several of the implant programs.

Implications

This study was conducted to compare the effects of eleven different heifer finishing implant programs (involving implants containing different dosages of androgen and estrogen, administered either once or twice during finishing) on beef carcass quality and longissimus tenderness. The various treatment groups were compared at similar mean compositional endpoints (i.e., similar predicted percentage of empty body fat). Eight of the eleven implant programs compared in this study increased carcass weight and longissimus muscle area compared with a non-implanted control group. Implant treatment did not affect scores for skeletal or lean maturity; however, heifers implanted with the highest cumulative dosages of estrogen plus androgen produced significantly fewer carcasses grading Choice & Prime than did heifers receiving one androgenic implant or two lower-dose combination implants. Implant treatment did not affect frequencies of lean quality defects (dark-cutters or blood splash). Use of a single finishing implant had no effect on longissimus Warner-Bratzler shear force (WBSF); however, use of two implants containing both E2 and TBA resulted in higher 3-day WBSF values when compared with the non-implanted control group. As postmortem aging increased, the effects of the various implant treatments on WBSF were gradually diminished, so that by 28 days postmortem, only the most aggressive implant treatment (20 mg E2 plus 200 mg TBA, implanted twice) had higher WBSF values than the control group. These findings suggest that postmortem aging may be effective for mitigating tenderness problems associated with some, but not all, heifer implant programs. Results of this study identified several heifer implant strategies that were effective for enhancing growth performance without reducing carcass quality or beef tenderness and underscore the importance of using carefully designed growth management programs.

Table 1. Experimental design outlining the number of heifers in each treatment group, the frequency of implants administered during finishing, and the dosage rates of estradiol 17-β (E_2) and trenbolone acetate (TBA) received by heifers in each treatment group

			Dosage, mg					
			First Implant		Second Implant		Cumulative	
Experimental treatment group	Number of Heifers	Number of Implants	E_2	TBA	E_2	TBA	E_2	TBA
1	42	0	0	0	0	0	0	0
2	41	1	0	200	0	0	0	200
3	42	1	8	80	0	0	8	80
4	41	1	14	140	0	0	14	140
5	41	1	20	200	0	0	20	200
6	41	2	0	200	0	200	0	400
7	42	2	8	80	8	80	16	160
8	41	2	8	80	14	140	22	220
9	40	2	14	140	14	140	28	280
10	42	2	8	80	20	200	28	280
11	44	2	14	140	20	200	34	340
12	43	2	20	200	20	200	40	400

Table 2. Effects of implant treatment on carcass yield grade characteristics and predicted percentage of empty body fat

		Trait [a]					
Treatment Group	Number of heifers	Adjusted fat thickness, cm	Hot carcass weight, kg	LMA [a], cm^2	Kidney, pelvic and heart fat, %	Yield grade	Predicted empty body fat [b], %
1	42	1.79 ± 0.09	357.2 ± 10.5^{v}	87.0 ± 1.83^{v}	2.10 ± 0.06^{z}	3.35 ± 0.13^{xyz}	31.4 ± 0.64
2	41	1.91 ± 0.09	364.9 ± 10.5^{vwxy}	88.1 ± 1.86^{vw}	2.08 ± 0.06^{yz}	3.47 ± 0.13^{z}	32.4 ± 0.65
3	42	1.87 ± 0.09	362.7 ± 10.5^{vw}	89.3 ± 1.84^{vwx}	2.05 ± 0.06^{yz}	3.35 ± 0.13^{xyz}	31.9 ± 0.64
4	41	1.92 ± 0.09	364.6 ± 10.5^{vwx}	89.1 ± 1.85^{vw}	1.98 ± 0.06^{wxyz}	3.42 ± 0.13^{yz}	32.0 ± 0.64
5	41	1.87 ± 0.09	368.1 ± 10.5^{wxyz}	92.2 ± 1.85^{wxy}	1.95 ± 0.06^{wxy}	3.23 ± 0.13^{wxyz}	31.7 ± 0.64
6	41	1.79 ± 0.09	369.5 ± 10.5^{wxyz}	93.4 ± 1.85^{xyz}	1.85 ± 0.06^{w}	3.09 ± 0.13^{wxy}	31.4 ± 0.65
7	42	1.95 ± 0.09	373.0 ± 10.5^{xyz}	93.1 ± 1.83^{wxyz}	2.03 ± 0.06^{xyz}	3.33 ± 0.13^{xyz}	32.1 ± 0.64
8	41	1.87 ± 0.09	374.5 ± 10.5^{z}	93.3 ± 1.85^{xyz}	1.97 ± 0.06^{wxyz}	3.24 ± 0.13^{wxyz}	31.7 ± 0.65
9	40	1.75 ± 0.09	373.6 ± 10.5^{yz}	96.4 ± 1.87^{z}	1.93 ± 0.06^{wxy}	2.94 ± 0.13^{w}	30.8 ± 0.65
10	42	1.74 ± 0.09	367.9 ± 10.5^{wxyz}	95.5 ± 1.83^{yz}	2.00 ± 0.06^{wxyz}	2.95 ± 0.13^{w}	30.7 ± 0.64
11	44	1.78 ± 0.09	372.6 ± 10.5^{xyz}	96.9 ± 1.81^{z}	2.03 ± 0.06^{xyz}	2.97 ± 0.13^{w}	31.0 ± 0.63
12	43	1.84 ± 0.09	368.4 ± 10.5^{wxyz}	95.1 ± 1.82^{yz}	1.90 ± 0.06^{wx}	3.05 ± 0.13^{wx}	31.2 ± 0.64
Treatment effect (P > F)	---	P = 0.6653	P = 0.0030	P < 0.0001	P = 0.0366	P = 0.0133	P = 0.2186

[a] Least squares means ± SEM

[a] LMA= longissimus muscle area

[b] Calculated using the procedures of Guiroy et al., (2001)

[v,w,x,y,z], Within a column, means lacking a common superscript differ (P < 0.05)

Table 3. Effects of implant treatment on carcass maturity, marbling score, and the percentage of carcasses grading U.S. Choice or higher

		Trait [a]			
Treatment Group	Number of heifers	Bone maturity [b]	Lean maturity [b]	Marbling score [c]	Choice & Prime, %
1	42	160 ± 6.2	163 ± 8.6	418 ± 19.3	57^{wxyz}
2	41	163 ± 6.2	163 ± 8.6	454 ± 19.4	71^{z}
3	42	166 ± 6.2	164 ± 8.6	431 ± 19.3	62^{xyz}
4	41	167 ± 6.2	164 ± 8.6	413 ± 19.4	49^{wxyz}
5	41	168 ± 6.2	167 ± 8.6	417 ± 19.4	63^{yz}
6	41	164 ± 6.2	166 ± 8.6	432 ± 19.4	54^{wxyz}
7	42	163 ± 6.2	164 ± 8.6	424 ± 19.3	67^{z}
8	41	165 ± 6.2	162 ± 8.6	417 ± 19.4	56^{wxyz}
9	40	172 ± 6.3	168 ± 8.6	407 ± 19.5	43^{wxy}
10	42	169 ± 6.2	163 ± 8.6	395 ± 19.3	38^{w}
11	44	166 ± 6.2	165 ± 8.6	413 ± 19.1	39^{wx}
12	43	166 ± 6.2	164 ± 8.6	396 ± 19.2	37^{w}
Treatment effect ($P > F$)	---	$P = 0.5480$	$P = 0.1425$	$P = 0.0861$	$P = 0.0073$

[a] Least Squares means ± SEM
[b] 100 = A^{00}, 200 = B^{00}
[c] 300 = $Slight^{00}$, 400 = $Small^{00}$, 500 = $Modest^{00}$
[w,x,y,z] Means within a column lacking a common subscript differ ($P < 0.05$).

Table 4. Least squares means (± SEM) showing the effect of the Treatment × Aging interaction[a] on Warner-Bratzler shear force of the longissimus muscle

		Postmortem aging period, days				
Treatment Group	Number of heifers	3	7	14	21	28
1	42	4.67 ± 0.13^{v}	4.22 ± 0.13^{uv}	3.80 ± 0.13^{vwx}	3.33 ± 0.13^{xy}	3.27 ± 0.13^{xy}
2	41	4.51 ± 0.13^{v}	4.22 ± 0.13^{uv}	3.59 ± 0.13^{v}	3.36 ± 0.13^{xy}	3.24 ± 0.13^{xy}
3	42	4.57 ± 0.13^{v}	4.06 ± 0.13^{u}	3.56 ± 0.13^{v}	3.26 ± 0.13^{x}	3.13 ± 0.13^{x}
4	41	4.67 ± 0.13^{v}	4.33 ± 0.13^{uvw}	3.84 ± 0.13^{vwx}	3.45 ± 0.13^{xyz}	3.23 ± 0.13^{xy}
5	41	4.74 ± 0.13^{vw}	4.37 ± 0.13^{uvw}	3.71 ± 0.13^{vw}	3.44 ± 0.13^{xyz}	3.19 ± 0.13^{xy}
6	41	4.65 ± 0.13^{v}	4.30 ± 0.13^{uv}	3.73 ± 0.13^{vw}	3.43 ± 0.13^{xyz}	3.39 ± 0.13^{xyz}
7	42	5.03 ± 0.13^{wx}	4.47 ± 0.13^{vwx}	3.87 ± 0.13^{vwxy}	3.51 ± 0.13^{xyz}	3.26 ± 0.13^{xy}
8	41	5.06 ± 0.13^{wxy}	4.66 ± 0.13^{wxy}	4.05 ± 0.13^{wxyz}	3.67 ± 0.13^{yz}	3.39 ± 0.13^{xyz}
9	40	5.41 ± 0.13^{yz}	4.87 ± 0.13^{yz}	4.20 ± 0.13^{yz}	3.74 ± 0.13^{z}	3.50 ± 0.13^{yz}
10	42	5.31 ± 0.13^{xyz}	4.73 ± 0.13^{xy}	4.11 ± 0.13^{xyz}	3.62 ± 0.13^{yz}	3.42 ± 0.13^{xyz}
11	44	5.46 ± 0.13^{z}	5.00 ± 0.13^{yz}	4.21 ± 0.13^{yz}	3.77 ± 0.13^{z}	3.36 ± 0.13^{xyz}
12	43	5.56 ± 0.13^{z}	5.09 ± 0.13^{z}	4.36 ± 0.13^{z}	3.76 ± 0.13^{z}	3.66 ± 0.13^{z}

[a] Treatment x Aging interaction effect: $P < 0.0001$

[u,v,w,x,y,z] Means within a column lacking a common superscript differ ($P < 0.05$).

Table 5. Pre-planned contrasts showing the effects of number of implants and dosages of estradiol 17-β and trenbolone acetate on carcass yield grade traits

	Trait[a]				
Contrast	Adjusted fat thickness, cm	Hot carcass weight, kg	LMA, cm^2	Kidney, pelvic and heart fat, %	Yield grade
1. No implants vs. one implant[b]					
No implants	1.79	357.2	87.0	2.10	3.35
One implant	1.89	365.1	89.7	2.02	3.37
P > F	*P* = 0.2312	*P* = 0.0249	*P* = 0.1044	*P* = 0.1508	*P* = 0.8923
2. One vs. two implants[c]					
One implant	1.89	365.1	89.7	2.02	3.37
Two implants	1.83	371.1	94.5	1.93	3.10
P > F	*P* = 0.2905	*P* = 0.0078	*P* < 0.0001	*P* = 0.0240	*P* = 0.0039
3. Initial implant dosage[d]					
Low-dose (8:80)	1.81	371.2	94.4	1.99	3.10
Moderate-dose (14:140)	1.77	373.1	96.7	1.98	2.96
P > F	*P* = 0.5979	*P* = 0.5424	*P* = 0.1314	*P* = 0.9719	*P* = 0.3010
4. Terminal implant dosage[e]					
Moderate-dose (14:140)	1.81	374.1	94.9	1.95	3.09
High-dose (20:200)	1.76	370.3	96.2	2.02	2.96
P > F	*P* = 0.5339	*P* = 0.2324	*P* = 0.3561	*P* = 0.2565	*P* = 0.3144
5. TBA vs. E_2 + TBA[f]					
TBA	1.85	367.2	90.8	1.97	3.28
E_2+ TBA	1.86	368.3	93.7	1.93	3.14
P > F	*P* = 0.9682	*P* = 0.7395	*P* = 0.0460	*P* = 0.4597	*P* = 0.2835

[a] Least squares means
[b] Treatment 1 (non-implanted control) contrasted with Treatments 2, 3, 4, and 5 (1 finishing implant)
[c] Treatments 2, 3, 4, and 5 (1 finishing implant) contrasted with Treatments 6, 7, 9, and 12 (2 finishing implants)
[d] Treatments 8 and 10 (low-dose initial implant) contrasted with Treatments 9 and 11 (moderate-dose initial implant)
[e] Treatments 8 and 9 (moderate-dose terminal implant) contrasted with Treatments 10 and 11 (high-dose terminal implant)
[f] Treatments 2 and 6 (TBA alone) contrasted with Treatments 5 and 12 (E_2 + TBA)

Table 6. Pre-planned contrasts showing the effects of number of implants and dosages of estradiol 17-β and trenbolone acetate on carcass quality grade traits

	Trait[a]			
Contrast	Skeletal Maturity	Lean Maturity	Marbling Score	U.S. Choice & Prime, %
1. No implants vs. one implant[b]				
No implants	160	163	418	57
One implant	166	165	429	61
P > F	*P* = 0.0520	*P* = 0.4383	*P* = 0.4167	*P* = 0.7242
2. One vs. two implants[c]				
One implant	166	165	429	61
Two implants	167	166	415	50
P > F	*P* = 0.7317	*P* = 0.4759	*P* = 0.1094	*P* = 0.0465
3. Initial implant dosage[d]				
Low-dose (8:80)	167	163	406	47
Moderate-dose (14:140)	169	167	410	40
P > F	*P* = 0.5377	*P* = 0.0294	*P* = 0.7661	*P* = 0.4372
4. Terminal implant dosage[e]				
Moderate-dose (14:140)	169	165	412	49
High-dose (20:200)	168	164	404	38
P > F	*P* = 0.5896	*P* = 0.6317	*P* = 0.5249	*P* = 0.1633
5. TBA vs. E_2 + TBA[f]				
TBA	164	165	443	62
E_2+ TBA	167	166	407	50
P > F	*P* = 0.2137	*P* = 0.5512	*P* = 0.0042	*P* = 0.1211

[a] Least squares means
[b] Treatment 1 (non-implanted control) contrasted with Treatments 2, 3, 4, and 5 (1 finishing implant)
[c] Treatments 2, 3, 4, and 5 (1 finishing implant) contrasted with Treatments 6, 7, 9, and 12 (2 finishing implants)
[d] Treatments 8 and 10 (low-dose initial implant) contrasted with Treatments 9 and 11 (moderate-dose initial implant)
[e] Treatments 8 and 9 (moderate-dose terminal implant) contrasted with Treatments 10 and 11 (high-dose terminal implant)
[f] Treatments 2 and 6 (TBA alone) contrasted with Treatments 5 and 12 (E_2 + TBA)

Table 7. Pre-planned contrasts illustrating the effects of number of implants and dosages of estradiol 17-β and trenbolone acetate on Warner-Bratzler shear force values at each aging period

	Postmortem aging period, days[a]				
Contrast	3	7	14	21	28
1. No implants vs. one implant[b]					
No implants	4.72	4.23	3.81	3.32	3.25
One implant	4.65	4.25	3.68	3.37	3.18
P > F	*P* = 0.7227	*P* = 0.8948	*P* = 0.3448	*P* = 0.6907	*P* = 0.5201
2. One vs. two implants[c]					
One implant	4.65	4.25	3.68	3.37	3.18
Two implants	5.19	4.69	4.04	3.61	3.44
P > F	*P* < 0.0001	*P* < 0.0001	*P* < 0.0001	*P* = 0.0016	*P* = 0.0003
3. Initial implant dosage[d]					
Low-dose (8:80)	5.21	4.70	4.09	3.64	3.39
Moderate-dose (14:140)	5.45	4.94	4.21	3.75	3.42
P > F	*P* = 0.1363	*P* = 0.0895	*P* = 0.3069	*P* = 0.2779	*P* = 0.7736
4. Terminal implant dosage[e]					
Moderate-dose (14:140)	5.27	4.77	4.13	3.70	3.43
High-dose (20:200)	5.39	4.87	4.17	3.69	3.38
P > F	*P* = 0.4576	*P* = 0.5072	*P* = 0.7735	*P* = 0.9554	*P* = 0.6262
5. TBA vs. E_2 + TBA[f]					
TBA	4.63	4.26	3.67	3.39	3.30
E_2+ TBA	5.16	4.72	4.04	3.60	3.41
P > F	*P* = 0.0012	*P* = 0.0012	*P* = 0.0025	*P* = 0.0454	*P* = 0.2469

[a] Least squares means
[b] Treatment 1 (non-implanted control) contrasted with Treatments 2, 3, 4, and 5 (1 finishing implant)
[c] Treatments 2, 3, 4, and 5 (1 finishing implant) contrasted with Treatments 6, 7, 9, and 12 (2 finishing implants)
[d] Treatments 8 and 10 (low-dose initial implant) contrasted with Treatments 9 and 11 (moderate-dose initial implant)
[e] Treatments 8 and 9 (moderate-dose terminal implant) contrasted with Treatments 10 and 11 (high-dose terminal implant)
[f] Treatments 2 and 6 (TBA alone) contrasted with Treatments 5 and 12 (E_2 + TBA)

Table 8. Comparison of single-implant programs showing changes in carcass weight, longissimus muscle area, percentage of carcasses grading Choice and Prime, and Warner-Bratzler shear force of the longissimus muscle expressed as the mean difference[a] from the non-implanted control

					Trait[b]			
Treatment group	Number of heifers	Initial Dosage,	Re-implant Dosage,	Cumulative Dosage, E_2:TBA	Hot carcass weight, kg	LMA[c], cm^2	U.S. Choice & Prime , %	14-day WBSF[d], kg

		E_2:TBA	E_2:TBA					
Control (1)	42	0:0	0:0	0:0	357.2	87.0	57	3.80
2	41	0:200	0:0	0:200	7.8	1.1	14	-0.21
3	42	8:80	0:0	8:80	5.6	2.3	5	-0.24
4	41	14:140	0:0	14:140	7.5	2.0	-8	0.04
5	41	20:200	0:0	20:200	11.0[z]	5.2[z]	6	-0.09

[a] Difference = (mean of implanted – mean of non-implanted)
[b] Least squares means
[c] LMA= longissimus muscle area
[d] Warner-Bratzler shear force value at 14-days postmortem aging (positive values reflect decreased tenderness)
[z] Differs from control ($P < 0.05$)

Table 9. Comparison of two-implant programs showing changes in carcass weight, longissimus muscle area, percentage of carcasses grading Choice and Prime, and Warner-Bratzler shear force of the longissimus muscle expressed as the mean difference[a] from the non-implanted control

					Trait[b]			
Treatment group	Number of heifers	Initial Dosage, E_2:TBA	Re-implant Dosage, E_2:TBA	Cumulative Dosage, E_2:TBA	Hot carcass weight, kg	LMA[c], cm^2	USDA Choice and Prime , %	WBSF[d], kg
Control (1)	42	0:0	0:0	0:0	357.2	87.0	57	3.80[wx]
6	41	0:200	0:200	0:400	12.3[z]	6.4[z]	-3	-0.07
7	42	8:80	8:80	16:160	15.8[z]	6.1[z]	10	0.07
8	41	8:80	14:140	22:220	17.3[z]	6.3[z]	-1	0.25
9	40	14:140	14:140	28:280	16.4[z]	9.3[z]	-14	0.40[z]
10	42	8:80	20:200	28:280	10.7[z]	8.5[z]	-19	0.31
11	44	14:140	20:200	34:340	15.5[z]	9.8[z]	-18	0.41[z]
12	43	20:200	20:200	40:400	11.2[z]	8.1[z]	-20	0.56[z]

[a] Difference = (mean of implanted – mean of non-implanted)
[b] Least squares means
[c] LMA= longissimus muscle area
[d] Warner-Bratzler shear force value at 14-days postmortem aging (positive values reflect decreased tenderness)
[z] Differs from control ($P < 0.05$)

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