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A randomized trial and multisite pooled trial analyses comparing effects of two hormonal implant programs and differing days-on-feed on carcass characteristics and feedlot performance of beef heifers

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ABSTRACT

Research objectives were to evaluate effects of two implant programs for beef heifers fed three different durations (days-on-feed; DOF) on carcass weight and composition (primary outcomes) and feedlot performance (secondary outcomes) at commercial feedlots. Data from a randomized trial in Kansas were analyzed separately and also pooled with data from two previously published trials conducted in Texas. Heifers were randomly allocated to pens within a block, and pens were randomized to treatments in a 2 × 3 factorial randomized complete block design. Implant programs were IH + 200 – an initial Revalor-IH implant [80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2)] and a re-implant after a mean of 98-d (± 10.8 SD) with Revalor-200 (200 mg TBA and 20 mg E_2), or XH – Revalor-XH, a single extended-release implant (200 mg TBA and 20 mg E_2). Heifers were fed to a baseline endpoint (BASE; pooled mean 166-d ± 11.9 SD), +21, or +42 additional DOF. A total of 10,583 crossbred heifers with mean initial body weight (BW) 315 kg (± 20.1 SD) were enrolled in 144 pens in 24 blocks (treatment replications) across the three trials. General and generalized linear mixed models accounting for clustering of trials, blocks, and pens were used to test for effects of treatments, with significance set at $\alpha = 0.05$. The only implant program × DOF interaction in pooled analyses was for dry matter intake (DMI; $P < 0.01$); IH + 200 heifers had lower mean DMI than XH when fed +42 DOF. Gain:feed was higher for IH + 200 compared to XH with dead and removed animals excluded ($P < 0.01$) or included ($P = 0.03$). For IH + 200, hot carcass weight (HCW) increased ($P < 0.01$), USDA Yield Grade (YG) distributions shifted towards lower numerical categories ($P < 0.01$), and Prime carcasses decreased while Select increased compared to XH ($P < 0.01$). For each incremental increase in DOF, final BW ($P < 0.01$) and HCW increased ($P < 0.01$), while daily gain ($P < 0.01$) and gain:feed ($P < 0.01$) decreased. Categories of YG were affected by DOF ($P < 0.01$); there were fewer YG 1 and 2 and more YG 4 and 5 carcasses for +42 compared to BASE and +21. USDA Quality Grade (QG) distributions differed by DOF ($P < 0.01$); each incremental increase in DOF resulted in more Prime and fewer Select carcasses. Without meaningful interactions, tested implant programs likely have a consistent effect when heifers are fed to similar DOF, while changes in HCW, QG, and YG may influence marketing decisions when extending DOF.

Key words: days-on-feed, estradiol, feedlot, heifers, implant, trenbolone acetate

INTRODUCTION

Use of hormonal implants in heifers dates back to 1947, with first federal approval for commercial application in 1957 (Montgomery et al., 2001). This technology is now a standard in the US beef industry, for the primary purposes of improving weight gain and feed efficiency (Reinhardt and Wagner, 2014; Smith and Johnson, 2020). A survey of US feedlots in 2011 indicated that 92.3% of cattle weighing less than 317.5 kg at feedlot arrival received at least one implant, with 79.9% receiving two or more; 94.3% of cattle weighing greater than or equal to 317.5 kg at feedlot arrival received at least one implant, with 29.8% receiving two or more (USDA-NAHMS, 2013). For some producers, the practice of re-implanting cattle may impose labor constraints, and may cause cattle stress from handling and processing. Additionally, upcoming guidance regarding the practice of re-implanting cattle will impact its use beginning in June 2023 (FDA, 2021). Newer technologies aim to provide an alternative to re-implanting, allowing cattle to be implanted only once at feedlot arrival but still receive constant delivery from hormonal implants throughout a longer feeding period. One such long-lasting implant for use in heifers is Revalor-XH (Merck Animal Health, De Soto, KS), which contains a combination of four uncoated [80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2) total] and six coated (120 mg TBA and 12 mg E_2 total) implant pellets (FOIS, 2017). The uncoated component allows TBA and E_2 to discharge and have bioavailability immediately after application, while the polymer coated portion

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breaks-down and does not discharge these compounds until approximately 70 d after initial application.

As changes in carcass composition may be expected when comparing Revalor-XH to a more traditional re-implant program (Smith et al., 2020), it may also be important to evaluate optimal days-on-feed (DOF) when using differing implant programs. Including a serial harvest treatment factor is a method for estimation of incremental dressing percentage (incremental carcass gain/incremental live gain), the estimated proportion of live weight gain that results in carcass weight gain (Streeter et al., 2012). Multiple research trials have been performed to address these questions in beef heifers, and have been summarized independently (Smith et al., 2019; Ohnoutka et al., 2021). The importance of reproducible research in the animal sciences has been discussed by Bello and Renter (2018), and is also a critical aspect of postlicensure evaluation of pharmaceutical products. By conducting similar randomized controlled trials at multiple study locations, scope of inference and external validity of results can increase (Tempelman, 2009; Bello and Renter, 2018). For these reasons, an additional commercial feedlot trial with similar treatment and design structures as the Smith et al. (2019) trials was performed in Kansas. This also allows for pooling of data across multiple trials and location, yielding more robust analyses with broader generalizability. These data could be highly valuable to producers as they consider implant programs and optimal DOF for marketing finishing heifers.

Thus, the primary objective of this research was to evaluate effects of two implant programs and three varying DOF on carcass composition (weight, quality, and yield). The secondary objective was to evaluate how these factors may affect other production components including live performance and health.

MATERIALS AND METHODS

The primary randomized controlled trial (Kansas trial) described herein was performed at a commercial feedlot in central Kansas. Methodology and results from this trial are detailed independently, but also are combined in a pooled analysis with two previously published trials (Smith et al., 2019) in a second facet of this publication. Like the trials reported by Smith et al. (2019), Institutional Animal Care and Use Committee approval was not acquired as the research was conducted at a commercial research feedlot, which followed practices described in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2020).

Kansas Trial

Study population Crossbred beef heifers (N = 3,125) were received at a commercial feedlot in central Kansas between November 25, 2018 and December 21, 2018, with heifers enrolled in the study between December 5 and December 27, 2018. The specific feedlot used was not chosen randomly but out of convenience, due to willingness to participate, and history of conducting randomized controlled trials. Heifers were purchased from sale barns located in Kansas, Oklahoma, Nebraska, Missouri, and Iowa. Heifers ineligible for inclusion were those recognizably lame, ill, pregnant, or of extreme heavy or light body weight (BW) at the time of initial processing, resulting in the exclusion of 41 animals. The final population used for trial enrollment included 3,084 heifers which had an initial BW of 309 kg [± 6.4 kg (1 SD)].

Treatment structure and experimental design A 2 × 3 factorial treatment arrangement was used in a randomized complete block design. Factor 1 was implant program, which had two treatments, Revalor-IH + Revalor-200 (IH + 200) or Revalor-XH (XH). Heifers in the IH + 200 treatment were implanted at trial enrollment with Revalor-IH (Merck Animal Health), which is an uncoated implant containing 80 mg TBA and 8 mg E_2, and re-implanted with approximately 94 DOF remaining with Revalor-200 (Merck Animal Health), which is an uncoated implant containing 200 mg TBA and 20 mg E_2. Heifers in the XH treatment were implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 (uncoated), and a coated component containing an additional 120 mg TBA and 12 mg E_2. Pens of heifers administered XH were implanted only once, and were not removed from their home pens to be reprocessed partway through the feeding period.

Factor 2 was DOF, which had three treatments, baseline (BASE), +21, or +42; mean DOF for each treatment was 179, 200, and 221, respectively, with an SD of 4.7 d. Within a block, heifers in the BASE treatment were harvested based on predictions made by the company marketing group for when the pen would reach an ideal finish weight and fat deposition targeting approximately 15% to 20% USDA Yield Grade (YG) four carcasses (i.e., a "normal" harvest endpoint for heifers typically fed in the feedlot). Heifers in the +21 treatment were fed for an additional 21 d, and heifers in the +42 treatment were fed for an additional 42 d compared to the BASE treatment in each block.

Heifers were blocked by arrival date and source, and a block consisted of six adjacent pens of similar size with all treatment combinations represented. Once enough animals were received to fill all pens within a block, heifers were systematically allocated into pens by moving a group to the processing area, and sorting three-animals at a time into each of six pens within a block, until the desired count per pen was achieved (mean of 86 animals per pen, range 74 to 115 depending on block); this process was performed by feedlot personnel. Within a block, pens were randomly assigned to treatment by use of a random number generating function within an Excel spreadsheet (Microsoft, Redmond, WA). Thus, pen was the experimental unit for all outcomes. Treatments assigned to pens were concealed from feedlot personnel who allocated heifers to pens. All pens in a block were managed identically aside from treatment interventions (implant program and DOF). Heifers were enrolled in the trial from December 5 to December 27, 2018. There was a total of 6 blocks and 36 pens. While no formal calculations of sample size were performed, this study population was assumed to adequately measure and reproduce anticipated effect magnitudes based on results from previous studies that were later published by Smith et al. (2019).

Cattle management Upon arrival heifers were given ad libitum access to fresh water and long-stemmed hay, and were later fed a common growing ration for approximately 10 d prior to trial initiation. Heifers were processed according to standard feedlot procedures, which included: identification with color-coordinated dual ear-tags containing a lot number and unique animal number, a four-way (containing modified live virus components for bovine viral diarrhea type 1, infectious bovine rhinotracheitis, parainfluenza 3, and bovine respiratory syncytial virus; Pyramid-4; Boehringer Ingelheim, St. Joseph, MO) or five-way (containing modified live viral components for bovine viral diarrhea types 1 and 2, infectious bovine rhinotracheitis, parainfluenza 3, bovine respiratory syncytial virus, as well as avirulent live cultures of *Mannheimia haemolytica* and *Pasteurella multocida*; Vista Once; Merck Animal Health) antiviral vaccine (consistent within block), an autogenous bacterin vaccine specific for foot-rot (Newport Laboratories, Inc., Worthington, MN), an internal parasiticide injection (Dectomax; Zoetis Animal Health, Parsippany, NJ), an oral anthelmintic (Safeguard; Merck Animal Health), a topical insecticide (Clean-Up; Bayer HealthCare LLC, Animal Health Division, Shawnee Mission, KS), and a metaphylactic injection of tildipirosin (Zuprevo; Merck Animal Health). All pharmaceutical products were administered according to manufacturer labels. In addition, depending on implant program treatment, heifers were administered Revalor-IH or Revalor-XH under the skin of the posterior aspect of the ear. Pens were weighed on a large platform scale to measure initial pen weight, which was divided by the number of animals enrolled in the pen for pen-level mean initial BW. As previously mentioned, at approximately 94 d prior to harvest, heifers in the IH + 200 treatment were removed from their home pens, and re-implanted with Revalor-200. As typical in many commercial production systems the re-implant program included additional procedures; heifers in the IH + 200 treatment also were revaccinated with a five-way viral vaccine and five-strain *Leptospira* bacterin (Vista 5 L5; Merck Animal Health), and were re-administered a topical insecticide (Clean-Up; Bayer HealthCare LLC, Animal Health Division) at the time of re-implant. Heifers in XH groups were not reprocessed and remained in their home pens.

Heifers were housed in 36 dirt-surfaced pens providing approximately 34.5-cm bunk space and 21-m^2 pen space per animal. Each pen had an automatic waterer which supplied well water ad libitum. After initial processing and at the time of trial initiation, pens were fed a starter diet (Table 1), and were gradually transitioned to the steam-flaked corn (SFC) finishing diet using a series of "steps" that blended the two diets in different proportions over 23 d for ruminal adaptation to a high-concentrate diet. Finishing diets were formulated to meet the nutritional requirements of beef cattle (NASEM, 2016). Heifers were fed thrice daily at approximately 0700, 1000, and 1350 hours. Feed bunks were managed to encourage ad libitum consumption, in that only trace residual feed remained at the time of 0700 hours feed deliveries. A tornado damaged the feed mill during the trial, which no longer allowed the steam-flaking of grains. This required the primary finishing diet to be reformulated, which resulted in the dry-rolled corn (DRC) finishing diet to be fed starting on May 11, 2019, until the end of the trial; implications of this change are discussed in greater detail in the results and discussion sections. Daily feed deliveries were recorded and summed for the total amount of dry-feed delivered to each pen over the trial period, and mean dry matter intake (DMI) per animal per day was then estimated at the pen-level by dividing total dry-feed delivered by animal days (where animal days includes days for trial fallouts up until their day of removal or death).

Animals in each pen were observed daily by a trained animal care taker. Heifers were observed for lameness, anorexia, dull eyes, labored breathing, low-hanging ears, coughing, diarrhea, nasal discharge, and general well-being. Heifers experiencing any of these clinical signs were removed from the pen and evaluated further. Once restrained at the hospital site, BW, rectal temperature, and lung-score via stethoscope were measured. Heifers were treated based on the combination of clinical signs observed in the pen and results from chute side diagnostics. Treatment regimens for specific diagnoses were identical for all trial cattle and followed protocols established by the feedlots veterinary consultant, with all products administered followed manufacturer labels and guidelines. In general, heifers were treated and returned to their home pen the same day. However, in some cases, the heifer was kept in a hospital recovery pen until well enough to be returned to the home pen. Heifers that were treated three times or that would not respond to therapy were removed from the trial and documented with a removal reason and BW. Pens were monitored for mortalities on a daily basis, and upon occurrence, identification number, pen number, date, and cause of death were recorded. A necropsy was performed on all animals when the cause of death was not apparent. Animal-level records of morbidity and mortality data were collapsed at the pen-level for binomial data structure.

Shipping and harvest When pens reached their ship-date, determined by DOF treatment within block, pens were

Table 1. Dietary ingredient formulations and calculated nutrient composition of starter and finisher rations fed to feedlot heifers during the experimental period of the Kansas trial

Item	Starter	SFC finisher[‡,§]	DRC finisher[‡,§]
Ingredient[†], % dry matter			
Steam-flaked corn	35.1	66.9	-
Dry-rolled corn	-	-	64.0
Wet distiller's grains with soluble	19.5	16.5	18.7
Alfalfa hay	29.7	-	-
Corn silage	12.0	3.6	4.8
Corn stalks	-	5.2	4.6
Tallow	-	3.1	3.2
Supplement[¶]	3.7	4.7	4.7
Nutrient composition			
Dry matter, %	53.3	60.7	61.6
Crude protein, %	18.4	15.0	15.3
Calcium, %	0.96	0.70	0.70
Phosphorus, %	0.37	0.31	0.39
Sulfur, %	0.25	0.21	0.21
NE_m, Mcal/45.4 kg	80.7	100.6	98.7
NE_g, Mcal/45.4 kg	52.4	68.8	69.1

[†]Feed additives were dispensed directly into the feed truck using Micro-Weigh Systems (Micro Beef Technologies, Amarillo, TX).
[‡]Steam-flaked corn (SFC) finisher was fed as the primary finishing diet until a change to the dry-rolled corn (DRC) finisher was required due to feed-mill damage suffered after a tornado. DOF treatments were baseline BASE, +21, and +42, and the DRC finishing diet was fed for the final 28 or 42, 49 or 63, and 70 or 84 d, respectively, for each treatment.
[§]Finisher diets were formulated to provide 50 g BactaShield (Legacy Animal Nutrition, Wamego, KS), 365 mg of monensin (Elanco Animal Health, Greenfield, IN), 75 mg of tylosin phosphate (Elanco Animal Health), and 0.4 mg of melengestrol acetate (Zoetis Animal Health, Parsippany, NJ) per animal daily. For the last 28 DOF, 250 mg of ractopamine hydrochloride (Zoetis Animal Health) per animal daily were delivered.
[¶]A liquid protein supplement (molasses and urea based) containing 69.7% crude protein (67.1% nonprotein nitrogen).

weighed as a group on a large platform scale for determination of final BW. A 4% pencil shrink was applied to total pen weights, and thus final calculations of pen-level average final BW, average daily gain (ADG), and gain:feed were adjusted for shrink. Live performance metrics were calculated on a dead and removed animals excluded or included basis. The difference between these calculations was for final BW and ADG (and thus subsequent calculations for gain:feed). On a dead and removed animals excluded basis final BW was: total pen weight/ *N* heifers completing the live trial phase; while on a dead and removed animals included basis final BW was: total pen weight/ *N* heifers initially enrolled in the trial. On a dead and removed animals excluded basis ADG was: (mean final BW – mean initial BW)/ DOF; while on a dead and removed animals included basis ADG was: (total final pen weight – total initial pen weight)/ animal days.

Heifers were loaded on trucks and transported approximately 233 km to a commercial abattoir. Heifers were shipped for harvest between June 7 and August 2, 2019, as determined by DOF treatment within block. When at the abattoir, trained personnel from the Beef Carcass Research Center (West Texas A&M University, Canyon, TX) identified and tracked carcasses through the facility, to correctly match animal and pen identification numbers with carcass identification tags used by the abattoir for the collection of carcass data. Hot carcass weight (HCW) was measured on the day of harvest for each carcass, which was averaged to create a pen-level mean. A dichotomous variable was created for heavyweight carcasses (HCW > 476 kg) based on individual carcass HCW, and was collapsed at the pen-level for binomial data structure. Percent dressed yield was calculated at the pen-level by dividing the mean pen HCW by the mean pen final BW (with dead and removed animals excluded). After a minimum 24-h chill period, carcasses were graded with a camera system wherein carcass-level ribeye area (REA), 12th-rib fat thickness, marbling score, and calculated YG were measured; these continuous outcomes were then averaged at the pen-level. Percent empty body fat (EBF) was estimated at the pen-level using calculations described by Guiroy et al. 2001. United States Department of Agriculture (USDA) Yield and Quality Grades (YG and QG, respectively) also were determined at this time, with these outcomes kept at the carcass-level.

Blinding statement Blinding was not specifically implemented in the trial, as treatments were within the bounds of normal feedlot operation, and no subjective measurements were taken other than standard health monitoring. A custom processing crew administered implants at trial initiation, and were directed which implant to use for each pen as it was processed. Additionally, it would not be possible to blind processors when heifers in the IH + 200 treatment were re-implanted, as those in the XH treatment were never removed from their home pens to be reprocessed. Daily caregivers such as pen-riders or cattle feeders were not made aware of study treatments or objectives. Assessment of primary objective outcomes (carcass characteristics) at the abattoir was technically a blinded activity, as this was performed by packing plant employees unaware of treatments given (or even that cattle were part of a trial). Blinding was not used in the data analysis stage.

Statistical analyses For all analyses, pen was the experimental unit; fixed effects were implant program, DOF, and their two-way interaction; and block was included as a random intercept. General and generalized linear mixed models (LMM and GLMM, respectively; Proc GLIMMIX SAS 9.4; SAS Institute Inc., Cary, NC) were fit to evaluate treatment effects on outcomes of interest. Continuous outcomes (e.g., BW, ADG, HCW) were modeled using LMM assuming a Gaussian distribution with an identity link function using restricted maximum likelihood estimation, and a Kenward-Roger degrees of freedom adjustment. Bounded variables (e.g., dressed yield, calculated YG) were also modeled this way as their values displayed central tendency and reasonably met LMM model assumptions. Conditional and marginal plots of studentized residuals were produced to assess assumptions of normality and homoscedasticity. Variables fitting a binomial distribution (e.g., morbidity, % heavyweight carcasses) were modeled using GLMM with a logit link function. These models were first run with a Laplace approximation to assess overdispersion, and then rerun with pseudo-likelihood estimation technique and Kenward-Roger's degrees of freedom method. Estimates were back-transformed to probabilities for interpretation. For both Gaussian and binomial variables, model adjusted means and corresponding SEM are reported, and a Tukey-Kramer adjustment to account for multiplicity was used for all pairwise comparisons. Ordinal variables with a multinomial distribution (QG and YG) were fit with a cumulative logit link function, used residual pseudo-likelihood estimation, a Kenward-Roger degrees of freedom adjustment, and had a proportional odds assumption on the ordinal nature of the data. As these data were structured at the carcass-level, an additional random intercept of pen within block was included to account for the lack of independence between carcasses within a pen. A likelihood ratio test was used to assess if distributions of ordinal outcomes differed for fixed effects. If significant, preplanned contrasts were performed for pairwise comparisons of DOF treatments. Values reported for multinomial models are raw frequency statistics (% and *n*). Statistical significance for all outcomes was set a priori at $\alpha = 0.05$. Instances of marginal significance ($0.05 < P \leq 0.10$) were noted but not interpreted due to the inflated risk of Type I error.

Pooled trial analyses Additional analyses were performed on combined data from the Kansas trial and two similar trials performed at a commercial research feedlot in Texas. Results from the Texas trials were summarized independently as exp. 1 and exp. 2 by Smith et al. (2019). The three trials were deemed suitable for pooling because of identical treatment and design structure, as well as similar research conduct and cattle populations (type). A descriptive comparison of the three trials is in Table 2. For greater detail on the two separate Texas trials, the reader is referred to Smith et al. (2019).

Statistical analyses of the pooled data were performed as described above for the Kansas trial analyses, with a few exceptions. Only variables that were measured in all three trials were included in the pooled analyses (e.g., camera data of carcass measurements were not available for Smith et al. (2019) exp. 1, so those outcomes were excluded). Linear and quadratic orthogonal polynomial contrasts were performed for main effects of DOF (in the absence of a significant two-way interaction) on final BW (with dead and removed animals excluded) and HCW. Random intercepts used in the pooled analyses accounted for trial, and block within trial for Gaussian and binomial outcomes. For ordinal outcomes

Table 2. Description of studies used in the pooled analyses of data from three commercial feedlot trials evaluating effects of two implant programs and differing DOF on feedlot performance and carcass characteristics of beef feedlot heifers[*,†,‡]

Trial	Dates of enrollment	Blocks[§], *N*	Pens, *N*	Animals, *N*	Animals per pen, mean (range)	Baseline DOF[¶], mean (± 1 SD)	Initial BW, kg/animal (± 1 SD)
Smith et al. (2019) exp. 1	Jul 23 to Sep 1, 2015	9	54	3,780	70 (70 to 70)	172 (4.4)	309 (6.4)
Smith et al. (2019) exp. 2	Mar 20 to May 8, 2018	9	54	3,719	69 (65 to 70)	152 (1.1)	337 (8.9)
Kansas trial	Dec 5 to Dec 27, 2018	6	36	3,084	86 (74 to 115)	179 (4.7)	291 (8.9)

*Three commercial feedlot trials were conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), enrolling a total of 10,583 crossbred beef heifers, which were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations (within a block within a trial).
†Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.
‡Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.
§Blocks are analogous to the number of 2 × 3 factorial treatment replications.
¶Mean DOF for the BASE treatment group within the DOF treatment factor, with other groups being +21 or +42 additional days.

(QG and YG), an additional random intercept for pen was included to account for carcass-level data structure. Statistical significance for all outcomes was again set a priori at $\alpha = 0.05$, with marginal significance ($0.05 < P \leq 0.10$) noted.

RESULTS

Kansas Trial Results

The number of pens analyzed for feedlot performance and health outcomes for the Kansas trial was consistent with the number of pens enrolled (*N* = 36; Table 3). For BASE, +21, and +42, the DRC finishing diet was fed for the final 28 or 42, 49 or 63, and 70 or 84 d, respectively. This is because within each DOF treatment, heifers were harvested on 1 of 2 dates. As a percent of the total feeding period, the DRC diet was fed for a mean (± 1 SD) of 20% (4.0), 28% (3.3), or 35% (3.6) for BASE, +21, and +42, respectively. Differences in the number of heifers enrolled versus the number completing the live animal phase of the trial affected calculations of feedlot performance on the basis of dead and removed animals included or excluded (Table 3). There were no significant two-way interactions (*P*-values ≥ 0.10), therefore, only main effects for implant program and DOF are reported.

For the implant program treatment, there was no evidence of differences in initial BW ($P = 0.94$) or mean daily DMI ($P = 0.47$) between treatments. On a dead and removed animals excluded basis, mean final BW per heifer was 7 kg greater for IH + 200 heifers compared to XH ($P < 0.01$). While DMI was similar, increased final BW resulted in both ADG ($P < 0.01$) and gain:feed ($P < 0.01$) to be greater for the IH + 200 group compared to XH. On the basis of dead and removed animals included, significant differences were not observed between implant programs for final BW ($P = 0.45$), ADG ($P = 0.36$), or gain:feed ($P = 0.20$). There was no evidence of differences between implant programs for morbidity ($P = 0.98$), mortality ($P = 0.70$), animals removed from the trial ($P = 0.30$), or total fallouts (heifer mortalities plus removals; $P = 0.26$).

There were not significant differences in initial BW ($P = 0.83$) or DMI ($P = 0.70$) between different DOF groups (Table 3). Calculated on the basis of dead and removed animals excluded, there was a DOF effect on final BW ($P < 0.01$), where for each increase of 21 DOF, final BW increased by approximately 18 kg. Both ADG ($P < 0.01$) and gain:feed ($P < 0.01$) were affected by DOF with both outcomes decreasing as DOF increased. On a dead and removed animals included basis, final BW increased with each incremental increase in DOF ($P < 0.01$). However, there was no evidence for an impact of DOF on ADG ($P = 0.14$), and gain:feed differences were only marginally significant ($P = 0.06$). There was no evidence of a difference in morbidity between DOF treatments ($P = 0.32$). There was an effect of DOF on mortality ($P = 0.02$), where a greater proportion of heifers died in the BASE group compared to +21. There was marginal significance for an effect of DOF on the probability of heifers being removed from the trial ($P = 0.08$). The main effect of DOF was associated with the total number of trial fallouts ($P = 0.05$), however, after adjustment for multiplicity, there were no significant differences for any pairwise DOF comparisons.

There were no significant implant program × DOF interactions on carcass characteristics (Table 4), therefore, only main effects are reported. The number of pens analyzed was consistent with the number enrolled (*N* = 36). The discrepancy between the number of carcasses (Table 4) and the number of heifers completing the live phase of the trial (Table 3) is due to events incurred at the abattoir causing carcasses to be lost. Condemnations by the USDA, and carcasses that could not be successfully identified and tracked through the plant were the primary reasons for discrepancies. The IH + 200 heifers had 6 kg heavier HCW ($P < 0.01$) than XH, although there was no evidence for a difference in dressed yield between the two implant programs ($P = 0.11$). Ribeye areas were 3.7 cm^2 larger for IH + 200 than XH ($P < 0.01$), and IH + 200 carcasses were also leaner, as indicated by reduced 12th-rib fat thickness ($P < 0.01$), marbling scores ($P = 0.02$), and lower calculated YGs ($P < 0.01$). Furthermore, there was a 1.8% increase in calculated EBF for XH carcasses compared to IH + 200 ($P < 0.01$). Distributions within ordered categories of YG differed between implant programs ($P < 0.01$); the distribution for IH + 200 carcasses had a shift toward more YG 1 and 2 carcasses as compared to XH carcasses where there was a shift towards more YG 4 and 5 carcasses. Distributions within ordered categories of QG also differed between implant programs ($P < 0.01$) with fewer carcasses grading Select and more grading Prime for XH heifers compared to IH + 200.

Table 3. Model adjusted means and standard errors of the mean (SEM) from the Kansas trial demonstrating the main effects of two implant programs and three differing DOF on pen-level feedlot performance and health related outcomes of feedlot heifers*

	Implant program†				Days-on-feed‡					P-value
Item	IH + 200	XH	SEM	*P*-value	BASE	+21	+42	SEM	*P*-value	Implant × DOF
Heifers enrolled, *N*	1,542	1,542	-	-	1,027	1,027	1,030	-	-	-
Heifers completing trial, *N*	1,450	1,463	-	-	956	973	984	-	-	-
Initial body weight, kg	291	291	3.8	0.94	292	291	291	3.8	0.83	0.10
Dry matter intake, kg/d	9.19	9.23	0.079	0.47	9.17	9.24	9.22	0.084	0.70	0.46
Deads and removals excluded										
Final body weight§, kg	568	561	2.9	< 0.01	546[a]	564[b]	582[c]	3.1	< 0.01	0.48
Average daily gain, kg	1.39	1.35	0.020	< 0.01	1.42[a]	1.37[b]	1.32[c]	0.020	< 0.01	0.27
Gain:feed	0.151	0.147	0.0014	< 0.01	0.155[a]	0.148[b]	0.143[c]	0.0015	< 0.01	0.18
Deads and removals included										
Final body weight§, kg	543	540	5.9	0.45	518[a]	545[b]	562[c]	6.3	< 0.01	0.57
Average daily gain, kg	1.27	1.25	0.042	0.36	1.28	1.27	1.24	0.043	0.14	0.57
Gain:feed	0.138	0.136	0.0027	0.20	0.139	0.137	0.134	0.0028	0.06	0.58
Morbidity¶, % (SEM)	16.5 (2.38)	16.5 (2.39)	-	0.98	16.9 (2.51)	15.2 (2.33)	17.5 (2.58)	-	0.32	0.21
Mortality, % (SEM)	2.4 (0.53)	2.2 (0.49)	-	0.70	3.4[a] (0.74)	1.5[b] (0.43)	2.3[a,b] (0.58)	-	0.02	0.50
Removals, % (SEM)	2.9 (0.84)	2.3 (0.69)	-	0.30	2.9 (0.88)	3.3 (0.98)	1.8 (0.61)	-	0.08	0.84
Total fallouts‖, % (SEM)	5.5 (1.21)	4.6 (1.05)	-	0.26	6.4 (1.45)	4.8 (1.16)	4.1 (1.01)	-	0.05	0.77

*Trial was conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), where crossbred beef heifers (*N* = 3,084) were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations within a block. There were of 36 pens total resulting in six treatment simple effect replications (all combinations of implant program × DOF), 18 replications of implant program main effects, and 12 replications of DOF main effects.
†Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.
‡Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint determined by marketing groups, or +21 or +42 additional DOF.
§A 4% pencil shrink was applied to the total weight of each pen prior to calculations of final BW on the bases of deceased and removed heifers included or excluded.
¶The proportion of heifers that were pulled and treated at least one time for any reason.
‖Total fallouts are heifers that died during the trial (accounted for in mortality) plus those that were removed from the trial for health related reasons (accounted for in removals).
a,b,cDiffering superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

Also in Table 4 are main effects of DOF on carcass characteristics. HCW increased with increasing DOF ($P < 0.01$), as there was a 12 kg increase moving from BASE to +21, and an additional 18 kg increase moving from +21 to +42. Dressed yield was also affected by DOF ($P < 0.01$), where heifers fed +42 had a greater dressed yield than BASE and +21. Ribeye areas increased with each incremental increase in DOF ($P < 0.01$). There was an effect of DOF on mean 12th-rib fat thickness ($P < 0.01$) and marbling score ($P < 0.01$), as both increased when comparing BASE to +21 and +42. Calculated YG was affected by DOF ($P = 0.03$), evidenced by an increase when comparing +42 to BASE. Calculated EBF was impacted by DOF ($P < 0.01$), where the percentage increased for +21 and +42 compared to BASE. The heavyweight carcass variable (HCW > 476 kg) was excluded from the results, as just three carcasses were over this threshold and could not be appropriately analyzed. The effect of DOF on carcass distributions within ordered categories of YG was marginally significant ($P = 0.07$). DOF affected distributions of QG ($P < 0.01$), evidenced by a shift towards more Prime carcasses and fewer Choice and Select carcasses in the +21 and +42 groups compared to BASE.

An additional exploratory analysis was performed to evaluate changes in live final BW and HCW gain in the pooled trials, where orthogonal polynomial contrasts were performed to test for linear and quadratic effects of increasing DOF (Fig. 1). There was no evidence that live or carcass weight gain increased in a quadratic manner ($P = 0.94$ or 0.20, respectively), but rather, increases were linear ($P < 0.01$) when feeding heifers an additional 42 DOF (Fig. 1). Estimated incremental dressing percentage calculated as HCW ADG/ live ADG [which corresponds to the ratio between the two linear functions (Fig. 1)] over an extended 42-d feeding period in this trial was 83.3%, meaning an estimated 83.3% of live BW gain was converted to carcass weight gain over this timeframe.

Pooled Trial Results

The total number of pens used for analyses of all live feedlot performance and health outcomes was consistent with the total number of pens enrolled across all trials ($N = 144$; Table 5). The number of heifers enrolled and completing the trial phase for each treatment affected calculations of feedlot performance on a dead and removed animals included or excluded basis. Only main effects where no significant two-way interactions occurred are reported in Table 5, while outcomes resulting in an implant program × DOF interaction are reported elsewhere (DMI; Fig. 2).

For the implant program treatment effect, there was no evidence of a difference in initial BW to start the trials ($P = 0.69$). On a dead and removed animals excluded basis, effects of implant program on final BW ($P = 0.15$) and ADG ($P = 0.25$) were not significant, while gain:feed increased slightly (1.3%)

Table 4. Model adjusted means and standard errors of the mean (SEM) from the Kansas trial demonstrating the main effects of two implant programs and three differing DOF on pen-level carcass characteristics of beef feedlot heifers*

	Implant program†				Days-on-feed‡					P-value
Item	IH + 200	XH	SEM	P-value	BASE	+21	+42	SEM	P-value	Implant × DOF
Carcasses, *N*	1,444	1,453	-	-	948	966	983	-	-	-
Hot carcass weight, kg	367	361	2.0	< 0.01	350[a]	362[b]	380[c]	2.1	< 0.01	0.48
Dressed yield, %	64.57	64.38	0.151	0.11	64.02[a]	64.22[a]	65.20[b]	0.163	< 0.01	0.98
Ribeye area, cm^2	86.71	82.97	0.523	< 0.01	82.45[a]	84.90[b]	87.16[c]	0.600	< 0.01	0.29
12th-rib fat thickness, cm	1.70	1.78	0.048	0.01	1.65[a]	1.78[b]	1.80[b]	0.051	< 0.01	0.53
Marbling score§	568	582	7.2	0.02	555[a]	582[b]	588[b]	7.7	< 0.01	0.21
Calculated yield grade	3.36	3.56	0.079	< 0.01	3.37[a]	3.49[a,b]	3.53[b]	0.082	0.03	0.30
Empty body fat¶, %	31.66	32.24	0.323	< 0.01	31.21[a]	32.12[b]	32.53[b]	0.335	< 0.01	0.39
USDA Yield Grade‖, % (*N*)	-	-	-	< 0.01	-	-	-	-	0.07	0.42
1	7.20 (104)	3.99 (58)			4.85 (46)	6.42 (62)	5.49 (54)			
2	27.15 (392)	21.61 (314)			27.43 (260)	21.84 (211)	23.91 (235)			
3	41.69 (602)	41.91 (609)			44.41 (421)	42.75 (413)	38.35 (377)			
4	20.57 (297)	26.91 (391)			20.78 (197)	24.84 (240)	25.53 (251)			
5	3.39 (49)	5.57 (81)			2.53 (24)	4.14 (40)	6.71 (66)			
USDA Quality Grade‖, % (*N*)	-	-	-	< 0.01	*x*	*y*	*y*	-	< 0.01	0.46
Prime	14.96 (216)	18.79 (273)			10.86 (103)	19.57 (189)	20.04 (197)			
Choice	77.98 (1126)	76.12 (1106)			82.17 (779)	74.12 (716)	74.97 (737)			
Select	6.72 (97)	4.82 (70)			6.86 (65)	6.11 (59)	4.37 (43)			
Other	0.35 (5)	0.28 (4)			0.11 (1)	0.21 (2)	0.61 (6)			

*Trial was conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), where crossbred beef heifers (N = 3,084) were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations within a block. There were of 36 pens total resulting in six treatment simple effect replications (all combinations of implant program × DOF), 18 replications of implant program main effects, and 12 replications of DOF main effects.
†Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.
‡Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.
§Scores ranging from 500 to 599 indicate a Modest degree of marbling.
¶Estimated EBF using calculations described by Guiroy et al. (2001).
‖Overall *P*-value tests the null hypothesis that the proportions of carcasses distributed across ordinal categories are equal for all treatments groups within a treatment factor (implant program or DOF); values are raw frequency statistics (% and *N*).
a,b,cDiffering superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.
x,yDiffering letters within row indicate significant difference ($P \leq 0.05$) from preplanned contrasts comparing distributions of ordinal outcomes for DOF factor.

for IH + 200 heifers compared to XH ($P < 0.01$). On a dead and removed animals included basis, there was no evidence for a difference between implant programs on final BW (P = 0.18) and ADG (P = 0.28), but gain:feed improved 1.4% for IH + 200 heifers compared to XH heifers ($P < 0.01$). There were no significant effects of implant program on morbidity (P = 0.63), mortality (P = 0.29), animals removed from trials (P = 0.32), or total fallouts (P = 0.96).

Main effects of the DOF treatment from the pooled trial analyses are also reported in Table 5. There was no evidence of a difference in initial BW between DOF treatments (P = 0.36). On the basis of dead and removed animals excluded, final BW increased with each additional 21 DOF increase ($P < 0.01$). Conversely, ADG ($P < 0.01$), and gain:feed ($P < 0.01$), decreased with each incremental increase in DOF. Similar observations can be made when calculated with dead and removed animals included, as final BW increased ($P < 0.01$), while ADG ($P < 0.01$) and gain:feed ($P < 0.01$) decreased with incremental increases in DOF. There was no evidence for a difference in morbidity (P = 0.58) or mortality (P = 0.47) with differing DOF. However, an effect of DOF on animals removed from trials was observed (P = 0.03); with BASE having a smaller proportion of removals than +21 (Table 5). Proportions of total trial fallouts were not significantly different between DOF groups (P = 0.70).

Implant program × DOF interactions occurred for daily DMI (Fig. 2; P = 0.02). DMI for XH heifers was greater than IH + 200 when fed an additional 42 DOF, while there was no evidence of differences between implant programs within BASE or +21 DOF groups.

Treatment factors in the pooled trial analyses did not result in any significant two-way interactions for carcass characteristics; therefore, main effects of implant program and DOF are reported in Table 6. Similar to the Kansas trial, the discrepancy between the number of carcasses (Table 6) and number of heifers completing the live phase (Table 5) is due to events incurred at the abattoir. All pens enrolled (N = 144) were accounted for in carcass data analyses.

For the implant program factor, mean HCW increased by 2 kg ($P < 0.01$), and dressed yield was higher for IH + 200 pens compared to XH ($P < 0.01$). The proportion of heavyweight carcasses were not significantly impacted by implant program ($P = 0.47$). The distribution of carcasses within ordered categories of YG shifted ($P < 0.01$) with IH + 200 carcasses having more YG 1 and 2, and fewer YG 4 and 5 carcasses compared to XH. Distributions of QG also shifted ($P < 0.01$) with more Prime, and fewer Choice and Select carcasses in the XH program compared to IH + 200.

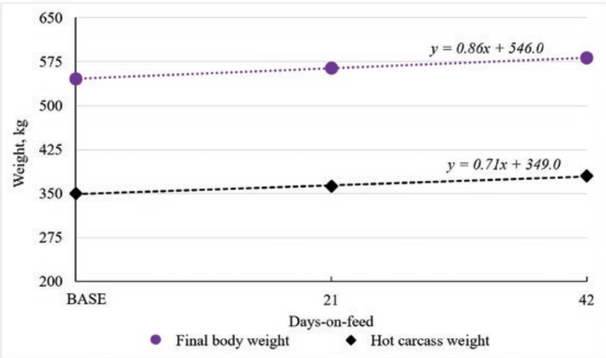

Figure 1. Kansas trial model adjusted means and linear functions for main effects of DOF on final BW (dead and removed animals excluded) and HCW of beef feedlot heifers. Treatments in the DOF factor were cattle harvested at a baseline (BASE) endpoint, +21, or +42 additional DOF. *P*-values for the implant program × DOF interaction on final BW and HCW were 0.48 for both outcomes, thus DOF results are main effect means over levels of the implant program factor. For final BW: quadratic effect of DOF, $P = 0.94$; linear effect of DOF, $P < 0.01$; SEM = 3.1. For HCW: quadratic effect of DOF, $P = 0.20$; linear effect of DOF, $P < 0.01$; SEM = 2.1.

When feeding heifers additional DOF, HCW increased by 16 kg with each incremental 21-d increase in DOF ($P < 0.01$; Table 6). Dressed yield also increased by increasing heifer DOF ($P < 0.01$). There was an effect of DOF on the proportion of heavyweight carcass ($P < 0.01$); heifers fed +42 DOF were more likely to have carcasses greater than 476 kg compared to BASE and +21 (Table 6). The YG distribution shifted for different DOF categories ($P < 0.01$); frequency of YG 1, 2, and 3 carcasses decreased while YG 4 and 5 carcasses increased for +42 heifers when compared to BASE and +21 (Table 6). Distributions within ordered categories of QG changed ($P < 0.01$), evidenced by increasing numbers of Prime carcasses with fewer Select with each incremental increase in DOF.

Orthogonal polynomial contrasts for linear and quadratic effects of increasing DOF on live BW and HCW gain were performed for exploratory purposes (Fig. 3). There was no evidence that final BW or HCW increased in a quadratic manner ($P = 0.15$ and 0.93, respectively). Final BW and HCW increased linearly ($P < 0.01$) with increasing DOF. The slope of the linear functions represents live and carcass ADG, respectively. The

Table 5. Model adjusted means and standard errors of the mean (SEM) from pooled analyses of data from three commercial feedlot trials evaluating effects of two implant programs and differing DOF on feedlot performance and health related outcomes of beef feedlot heifers*

	Implant program†				Days-on-feed‡					*P*-value
Item	IH + 200	XH	SEM	*P*-value	BASE	+21	+42	SEM	*P*-value	Implant × DOF
Heifers enrolled, *N*	5,291	5,292	-	-	3,526	3,527	3,530	-	-	-
Heifers completing trials, *N*	5,122	5,123	-	-	3,421	3,407	3,417	-	-	-
Initial body weight, kg	313	312	13.3	0.69	313	313	312	13.3	0.36	0.91
Deads and removals excluded										
Final body weight§, kg	586	584	10.1	0.15	563^{a}	586^{b}	605^{c}	10.1	< 0.01	0.39
Average daily gain, kg	1.46	1.45	0.039	0.25	1.50^{a}	1.45^{b}	1.40^{c}	0.040	< 0.01	0.47
Gain:feed	0.154	0.152	0.0021	< 0.01	0.158^{a}	0.153^{b}	0.148^{c}	0.0021	< 0.01	0.27
Deads and removals included										
Final body weight§, kg	573	571	15.0	0.18	552^{a}	573^{b}	591^{c}	15.1	< 0.01	0.74
Average daily gain, kg	1.38	1.37	0.059	0.31	1.43^{a}	1.37^{b}	1.32^{c}	0.059	< 0.01	0.59
Gain:feed	0.146	0.144	0.0042	0.03	0.151^{a}	0.144^{b}	0.140^{c}	0.0042	< 0.01	0.25
Morbidity¶, % (SEM)	6.0 (3.37)	5.8 (3.26)	-	0.63	5.7 (3.18)	5.8 (3.26)	6.4 (3.54)	-	0.58	0.70
Mortality, % (SEM)	1.2 (0.43)	1.4 (0.51)	-	0.29	1.3 (0.51)	1.1 (0.40)	1.5 (0.56)	-	0.47	0.52
Removals, % (SEM)	1.6 (0.66)	1.4 (0.57)	-	0.32	1.3^{a} (0.53)	1.9^{b} (0.79)	$1.4^{a,b}$ (0.57)	-	0.03	0.93
Total fallouts‖, % (SEM)	2.8 (1.08)	2.8 (1.08)	-	0.96	2.6 (1.02)	3.0 (1.16)	2.8 (1.10)	-	0.70	0.70

*Three commercial feedlot trials were conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below†) and DOF (three levels, described below‡), enrolling a total of 10,583 crossbred beef heifers, which were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations (within a block within a trial). Across thethree trials there were 144 pens total resulting in 24 treatment simple effect replications (all combinations of implant program × DOF), 72 replications of implant program main effects, and 48 replications of DOF main effects.
†Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.
‡Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.
§A 4% pencil shrink was applied to the total weight of each pen prior to calculations of final BW on the bases of deceased and removed heifers included or excluded.
¶The proportion of heifers that were pulled and treated at least one time for any reason.
‖Total fallouts are heifers that died during the trial (accounted for in mortality) plus those that were removed from the trial for health related reasons (accounted for in removals).
a,b,cDiffering superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.

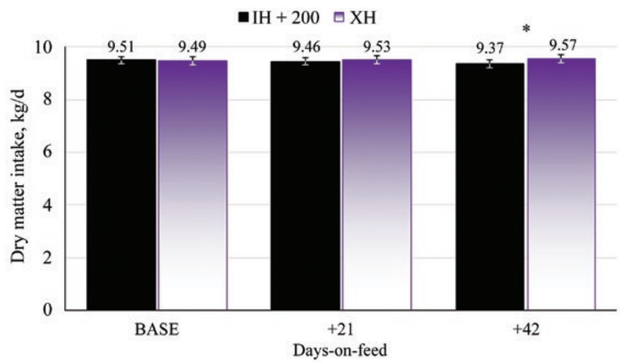

Figure 2. Model adjusted means and standard errors of the mean (SEM) comparing the interaction between treatment factors (implant program and DOF) and their effects on daily DMI of beef feedlot heifers. Treatments in the implant program factor were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E^2. Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF. Implant program × DOF, $P = 0.02$, and SEM = 0.142. An asterisk (*) indicates a significant difference ($P \leq 0.05$) between implant programs within DOF category, after adjustment for multiple comparisons.

ratio between carcass and live ADG is incremental dressing percentage, also referred to as carcass transfer (Streeter et al., 2012). In the pooled trials, estimated incremental dressing percentage over a 42-d extended feeding period was 76.2%, or, 0.76 kg HCW gain per 1 kg live BW gain.

DISCUSSION

Across the three trials, BASE DOF was determined primarily by initial BW of study populations, and marketing decisions of an ideal finish weight. Heifers in the Kansas trial were harvested at a lighter final BW on average compared to exp. 1 and exp. 2 reported by Smith et al. (2019). However, in the Kansas trial, there were greater proportions of USDA Choice and Prime, as well as YG 4 and 5 carcasses, indicating there may have been some differences in frame-size across trials or genetic propensity for fat deposition, which altered BASE finish weights. It is also possible that the dietary change from SFC to DRC partway through the Kansas trial created some additional variability. While the SFC finishing diet was fed for the same number of days for all DOF treatments, the change to DRC could have affected cattle performance near the end of the trial, as SFC-based finishing diets have been reported to improve ADG by 5.4%, and feed efficiency by 12% when compared to dry-processed corn (Zinn et al., 2002). This could have hampered the rate of growth following the dietary change for +21 and +42; however, the observed linear increases in BW and HCW for incremental increases in DOF may suggest that performance losses were minimal (perhaps aided by the concurrent feeding of ractopamine for the final 28 DOF).

In comparison to published results from the Smith et al. (2019) experiments, greater effects of implant programs on live heifer performance (dead and removed animals excluded) were observed in the Kansas trial. In the Kansas trial, IH + 200 had greater final BW and ADG than XH, while there was no evidence of differences for these variables in individually analyzed Smith et al. (2019) experiments. Evidence of a gain:feed improvement for IH + 200 heifers occurred in the Kansas trial and Smith et al., (2019) exp. 1, but not exp. 2. Results from comparisons of carcass characteristics between implant programs generally agreed between the Kansas trial and Smith et al. (2019) trials. There was greater evidence for a HCW difference in the Kansas trial than in Smith et al. (2019); but all three trials seem to support the effect of IH + 200 heifers producing leaner carcasses than XH, while XH led to overall improvements in QG. For the DOF treatment factor, live performance (dead and removed animals excluded) was very similar across the three trials; all demonstrated increased final BW, and decreased ADG and gain:feed with additional DOF. There were no significant effects of DOF on DMI in the Kansas trial or Smith et al. (2019) exp. 2, while Smith et al. (2019) exp. 1 observed decreased DMI in heifers fed additional DOF, and marginal significance for an implant program × DOF interaction. DOF impacts on carcass characteristics were comparable between the Kansas trial and Smith et al. (2019) trials, as HCW, and outcomes related to muscle and fat all increased with additional DOF. Estimated incremental dressing percent for heifers fed an additional 42 d in the Kansas trial was 83.3%, while Smith et al. (2019) reported 79.6% and 72.5% in exp.1 and exp. 2, respectively. Again, this is the estimated proportion of live weight gain that resulted in carcass weight gain. Differences in these estimates could potentially be attributed to differences in total DOF [Kansas trial heifers and Smith et al. (2019) exp. 1 heifers were the most similar, while Smith et al. (2019) exp. 2 had the shortest total DOF], seasonal effects, frame-size, body composition, and other factors associated with individual trials.

By performing pooled analyses, the scope of inference from these three trials is broadened, statistical power to detect differences improves, as does the accuracy of mean treatment effect estimates (Tempelman, 2009; Bello and Renter, 2018). Findings in the pooled trial analyses indicate that differences in finishing heifer live weight gain may not be expected between the two implant programs, which would agree with a six-trial pooled analysis of similar implant programs (Smith et al., 2020). Note that the two Texas trials from Smith et al. (2019) were included in the Smith et al. (2020) dataset. Slight improvements in gain:feed were observed here, which has not been consistently reported in the literature. Greater gain:feed is expected in implanted cattle compared to nonimplanted controls (Reinhardt and Wagner, 2014; Smith and Johnson, 2020), and a meta-analysis suggested that greater total doses of anabolic hormones may improve feed efficiency in feedlot steers (Reinhardt and Wagner, 2014). However, this effect has not been frequently observed in heifers (Hilscher et al., 2016; Smith et al., 2020; Ohnoutka et al., 2021). DMI has increased routinely in implanted cattle compared to nonimplanted controls (Bartle et al., 1992; Herschler et al., 1995; Parr et al. 2011a, 2011b). Some research indicates that different hormonal doses from different implant programs may not impact DMI in heifers (Hilscher et al., 2016; Ohnoutka et al., 2021), while others have reported reduced intake in re-implanted heifers who receive greater total anabolic hormonal doses than those administered a single, semicoated implant [IH + 200 vs. XH equivalent; Smith et al., 2020)]. The interactive effect of implant program × DOF on DMI in the current pooled

Table 6. Model adjusted means and standard errors of the mean (SEM) from pooled analyses of data from three commercial feedlot trials evaluating main effects of two implant programs and differing DOF on carcass characteristics of beef feedlot heifers[*]

	Implant program[†]				Days-on-feed[‡]					*P*-value
Item	IH + 200	XH	SEM	*P*-value	BASE	+21	+42	SEM	*P*-value	Implant × DOF
Carcasses, *N*	5,085	5,093	-	-	3,388	3,389	3,401	-	-	-
Hot carcass weight, kg	377	375	6.0	< 0.01	360[a]	376[b]	392[c]	6.0	< 0.01	0.27
Dressed yield, %	64.44	64.18	0.119	< 0.01	63.91[a]	64.19[b]	64.84[c]	0.126	< 0.01	0.61
Carcasses > 476 kg, % (SEM)	0.19 (0.131)	0.13 (0.090)	-	0.47	0.04[a] (0.039)	0.12[a] (0.087)	0.73[b] (0.433)	-	< 0.01	0.92
USDA Yield Grade[§,¶], % (*N*)	-	-	-	< 0.01	*x*	*x*	*y*	-	< 0.01	0.49
1	7.85 (399)	5.52 (281)			6.65 (225)	7.52 (255)	5.88 (200)			
2	31.21 (1587)	26.09 (1328)			31.46 (1065)	29.06 (985)	25.43 (865)			
3	41.32 (2101)	42.02 (2139)			43.87 (1485)	41.52 (1407)	39.64 (1348)			
4	16.83 (856)	21.94 (1117)			15.86 (537)	18.68 (633)	23.61 (803)			
5	2.79 (142)	4.42 (225)			2.16 (73)	3.22 (109)	5.44 (185)			
USDA Quality Grade[§], % (*N*)	-	-	-	< 0.01	*x*	*y*	*z*	-	< 0.01	0.71
Prime	7.53 (383)	9.6 (489)			5.81 (197)	9.12 (309)	10.76 (366)			
Choice	78.09 (3971)	77.71 (3958)			78.54 (2661)	77.54 (2628)	77.62 (2640)			
Select	12.66 (644)	11.07 (564)			14.76 (500)	11.92 (404)	8.94 (304)			
Other	1.71 (87)	1.61 (82)			0.89 (30)	1.42 (48)	2.68 (91)			

[*]Three commercial feedlot trials were conducted as a 2 × 3 factorial in a randomized complete block design with treatment factors of implant program (two levels, described below[†]) and DOF (three levels, described below[‡]), enrolling a total of 10,583 crossbred beef heifers, which were randomly allocated to one of six pens (a block), and pens were randomly assigned to one of the six factorial treatment combinations (within a block within a trial). Across the three trials there were 144 pens total resulting in 24 treatment simple effect replications (all combinations of implant program × DOF), 72 replications of implant program main effects, and 48 replications of DOF main effects.
[†]Implant treatments were: IH + 200 = implanted at trial enrollment with Revalor-IH (Merck Animal Health, De Soto, KS), an uncoated implant containing 80 mg trenbolone acetate (TBA) and 8 mg estradiol (E_2), and re-implanted after approximately 90 DOF with Revalor-200 (Merck Animal Health), an uncoated implant containing 200 mg TBA and 20 mg E_2; or XH = implanted only at trial enrollment with Revalor-XH (Merck Animal Health), a two-component implant with 80 mg TBA and 8 mg E_2 uncoated, and a coated component containing an additional 120 mg TBA and 12 mg E_2.
[‡]Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint (determined by marketing groups), or +21 or +42 additional DOF.
[§]Overall *P*-value tests the null hypothesis that the proportions of carcasses distributed across ordinal categories are equal for all treatments groups within a treatment factor (implant program or DOF); values are raw frequency statistics (% and *N*).
[¶]*N* = 3 carcasses excluded from one pen from Smith et al. (2019) exp. 1 due to missing YG data.
[a,b,c]Differing superscripts within row for DOF indicate significant difference ($P \leq 0.05$) after adjustment for multiple comparisons.
[x,y]Differing letters within row indicate significant difference ($P \leq 0.05$) from preplanned contrasts comparing distributions of ordinal outcomes for DOF factor.

analyses, where IH + 200 heifers fed +42 DOF consumed less feed on average than their XH counterparts, is difficult to explain biologically, and one that may warrant further investigation. It is unclear why this observation would occur in only +42 heifers but not BASE or +21, but the magnitude of this effect could have implications related to feed costs if multiplied across large populations of heifers.

Differences between implant programs for HCW and dressed yield were variable between Kansas and Smith et al. (2019) trials when analyzed separately, but were significant after the data were pooled and the corresponding effective sample size was larger. Shifts in QG and YG distributions between implant programs were consistent across individual trials and the pooled analyses. Smith and Johnson (2020) summarized known mechanisms for changes in carcass composition with different hormonal implant concentrations and strategies. Greater levels of TBA and E_2 lead to increased muscle synthesis and decreased fat deposition, which may alter optimal marketing points due to changes in QG and YG distributions. Overall, IH + 200 heifers had heavier, higher dressing, leaner carcasses, evidenced by shifts in QG and YG compared to XH. This observation was also noted by Smith et al., (2020). It should be recognized that the proportion of heavyweight carcasses that would commonly incur discounts in a grid-based pricing system (USDA, AMS) were not significantly impacted by implant programs in finishing heifers. Thus, if selling heifers on a grid, net revenue between the two programs will likely center around premiums and discounts

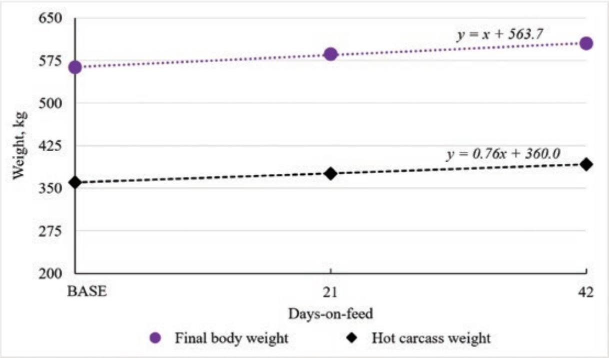

Figure 3. Pooled trials model adjusted means and linear functions for main effects of DOF on final BW (dead and removed animals excluded) and HCW of beef feedlot heifers. Treatments in the DOF factor were heifers harvested at a baseline (BASE) endpoint, +21, or +42 additional DOF. *P*-values for the implant program × DOF interaction on final BW and HCW were 0.39 and 0.27, respectively, thus DOF results are main effect means over levels of the implant program factor. For final BW: quadratic effect of DOF, $P = 0.15$; linear effect of DOF, $P < 0.01$; SEM = 10.1. For HCW: quadratic effect of DOF, $P = 0.93$; linear effect of DOF, $P < 0.01$; SEM = 6.0.

incurred for QG and YG distributions, after accounting for HCW. It is important to note that outside of DMI, there were no other significant two-way interactions, meaning that there was no evidence to suggest that carcass compositions between implant programs differ when harvested at similar DOF.

It should be noted that total amounts of TBA and E_2 administered to heifers differed between implant program treatments, with IH + 200 receiving 80 mg more TBA and 8 mg more E_2 throughout the feeding period compared to XH. The process of re-implanting cattle may result in added handling stress, and also provides the opportunity to administer vaccines, anthelmintics, parasiticides, or other compounds that would not be given to cattle that are not reprocessed. This was the case in the Kansas trial, however, Smith et al. (2019) experiments did not administer any products to re-implanted cattle besides Revalor-200. Use of additional products with a re-implant program is likely the more common scenario in commercial settings. Research to isolate the effects of the implants themselves would require an alternative approach; however, the objective herein was to evaluate the implant programs as a whole, reflecting program application in a commercial production setting. Thus, while observed implant program effects in this study may be largely explained by differences in hormonal payout from the implants, there were other concurrent factors that cannot be separated and may have affected outcomes.

Live feedlot performance results of serially harvested beef cattle from the pooled analyses were consistent with previous research, indicating increased final BW, but decreased ADG and gain:feed with additional DOF (Sissom et al., 2007; Rathmann et al., 2012; Ohnoutka et al., 2021). Increases in carcass weight, dressed yield, and observed shifts in QG and YG distribution from incremental DOF increases also were expected based on the literature (Sissom et al., 2007; Rathmann et al., 2012; Ohnoutka et al., 2021). There was greater risk of incurring heavyweight discounts for carcasses weighing greater than 476 kg for heifers fed +42 DOF. It is worth noting that these heifers were never sorted by BW and frame-size into more homogenous groups, a common practice for some producers. For heifers, this allows feeding for extended DOF to primarily reduce the number of YG 4 and 5 carcasses, and to a lesser degree, the number of heavyweight heifers that may incur discounts in a grid-based pricing system. Exploratory analyses of polynomial functions for additional DOF indicated increases of both final BW and HCW were linear, and not quadratic. Similar analyses by Ohnoutka et al. (2021) indicated linear increases of these variables in feedlot heifers. In the pooled analyses, mean estimated incremental dressing percentage for heifers fed 42 d beyond a target final body composition for each trial and location was 76.2%, meaning that for every 1 kg of live weight gain, 0.76 kg of carcass weight was added. Incremental dressing percentage has been estimated in numerous trials with a serial harvest component; values are often variable (Streeter et al., 2012; Walter et al., 2018; Smith et al., 2019; Ohnoutka et al., 2021; Word et al., 2021), and may be influenced by sex, cattle type, diet, and total DOF. Wilken et al. (2015) suggested that in steers, the proportion of live weight transferred to the carcass may approach 100% as DOF continue to increase.

The majority of cattle in the United States are sold on a carcass basis, rather than live (USDA, AMS). With that being the case, importance of live animal performance metrics, like ADG and gain:feed may become deceiving as cattle are fed for longer DOF. As DOF increase, and ADG and gain:feed seemingly decrease, it is easy to perceive that cattle are becoming less efficient; the paradox, however, is where gained weight is deposited. While rate of live gain may slow, rate of carcass gain may continue to increase (Wilken et al., 2015). Much of the live weight gain that occurs early in the feeding period is deposited in non-carcass components, including the gastrointestinal tract with its contents, other visceral organs, blood, hide, and the head; as cattle age and weight increases, proportions of these components decrease, while muscle, and particularly fat deposition increase (Berg and Butterfield, 1968; Buckley et al., 1990; Coleman et al., 1995; Owens et al., 1995; Honig et al., 2022). Thus, while rates of live weight gain seem to decline when feeding heifers beyond their "target" DOF, it appears that the majority of gained weight is being deposited on the carcass (in a linear manner), rather than to less valuable components of the animal.

Morbidity, mortality, and cattle removal data have not been frequently reported in published research with objectives regarding implant programs and different DOF. Evidence for a difference in these health related variables between implant programs was not observed in the Kansas trial or the pooled analyses, which would agree with Smith et al. (2020). The observed effects of DOF on mortality and total fallouts in the Kansas trial were unexpected as it is counterintuitive that heifers fed the fewest DOF would have the greatest mortality. Cumulative pen-level morbidity and mortality would presumably increase for groups of heifers fed for longer DOF; Vogel et al. (2015) indicated that pen mortality averaged 0.26% in the last 30 DOF for feedlot heifers. Mortality and total fallouts were not published in Smith et al. (2019), but when data from all three trials were pooled, these outcomes were not significantly affected by DOF. However, the pooled results indicated that the proportion of heifers removed (culled) increased when comparing BASE to +21, with no significant difference comparing BASE or +21 to +42. It is likely that a much larger population of heifers may be needed to better estimate health risks imposed by feeding heifers for longer DOF.

Pooling data from similar randomized controlled trials performed at different sites and years helps to improve external validity of findings. Still, there are limitations to consider. These trials were performed in a similar region, and effects could differ in others, due to factors such as climate, management, cattle type, and diet composition. A critical variable that was beyond the scope of this paper is a comprehensive economic analyses. While changes in carcass characteristics and heifer performance were described, decision making around implant programs and DOF is likely limited without knowing how their outcomes affect net returns from heifer sales. Future research should evaluate cost effectiveness of these interventions, taking into account sale basis (dressed or live), and temporal changes in feed cost, fed cattle price, and premiums and discounts incurred for changes in carcass characteristics.

CONCLUSIONS

Overall, effects of implant programs were not impacted by differing DOF. Heifers in an IH + 200 program had improved gain:feed, and produced heavier, leaner carcasses with less intramuscular fat than XH. These performance differences may be important when considering that certain re-implant programs will soon be restricted (FDA, 2021). Feeding heifers for additional DOF expectedly increased live and carcass weight gains, with a sacrifice in live feedlot performance metrics. While QGs improved by extending DOF, there was a shift towards more high YG (4 and 5) carcasses, indicating a possible tradeoff between premiums and discounts applied in a grid-based pricing system. Future research should evaluate economic impacts of changing carcass characteristics that result from feeding additional DOF, as this information is critical for producers to make informed marketing decisions.

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Conflict of interest statement

Co-authors MS and JH are employed by Merck Animal Health, but were not involved in data collection or analyses. Experimental treatments involved only Merck Animal Health products, therefore, no competitive interest was present. There are no conflicts of interest to disclose.

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