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Effects of extended days on feed on rate of change in performance and carcass characteristics of feedlot steers and heifers and Holstein steers

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ABSTRACT

Objective: We analyzed data from feedlot studies in which beef steers and heifers and Holstein steers were fed for extended days beyond the typical slaughter date with the objective of determining the rate of change in selected performance and carcass measurements over the extended feeding periods.

Materials and Methods: Performance and carcass measurements from 7 experiments with beef steers, 6 experiments with beef heifers, and 2 experiments with Holstein steers, representing a total of 687 pen observations, were analyzed. Cattle were fed high-grain diets and managed under industry-standard conditions. All experiments included extended days on feed as a factor (0- to 62-d range for steers; 0- to 42-d range for heifers; and 0- to 56-d range for Holsteins), and several experiments included β-agonist and implant program comparisons. Key variables analyzed included DMI, ADG, final shrunk BW, hot carcass weight, and various measures of carcass fatness, yield, and quality. Mixed-model statistical methods were used to evaluate β-agonist and implant programs and their interaction with extended days on feed, as well as the overall rate of change in performance and carcass measurements with extended days on feed, adjusting for random intercept effects of studies.

Results and Discussion: Feeding control diets versus zilpaterol (2 steer studies) or ractopamine diets (2 steer studies) resulted in effects consistent with the published literature. Interactions between extended days on feed and β-agonist or implant program treatments were noted for less than 5% of the variables examined. Similarly, for the overall analyses within class of cattle, interactions between extended days on feed and dietary or implant treatments were rare (2.5% of variables evaluated). Slope values in the overall analyses for all 3 classes of cattle were generally significant ($P \leq 0.03$ for 85% of the variables analyzed), reflecting increased final shrunk BW and hot carcass weight, greater carcass fatness, and shifts toward higher QG and YG with extended days on feed.

Implications and Applications: Producers selling cattle on a carcass basis could use our slope data to estimate changes in carcass weight with extended days on feed, as well as potential premiums and discounts that could be used in profit–loss projections.

Key words: beef cattle, days on feed, Holstein steers, performance, carcass characteristics

INTRODUCTION

The length of the feeding period (days on feed; **DOF**) for feedlot cattle depends on a variety of factors, but input costs, animal performance, and marketing strategy (live or carcass basis) are key factors in profitability. External factors also can influence DOF decisions. For example, during the COVID-19 pandemic, closures, or decreased capacity of meatpacking plants, along with decreased demand for meat products forced producers to extend feeding periods. In addition, starting in the early to mid 2000s, the cattle feeding industry began to switch from a predominantly live negotiated basis of selling finished cattle to various carcass-based marketing strategies. This change to carcass-based selling often resulted in longer DOF for finished cattle, a trend that has steadily increased over time. In a summary of experiments conducted at the University of Nebraska, Wilken et al. (2015) reported that when selling cattle on a carcass basis, feeding cattle longer increased gain of hot carcass weight (**HCW**) and thereby profit potential. Nonetheless, because cattle fed for ex-

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†Three of the authors are employed by Merck Animal Health, the sponsor of the experiments summarized in this article. These authors provided background information and experimental details on the conduct of the studies included in the article but were not involved in the statistical analyses of the data, which was conducted by the first author. The first author has not declared any conflicts of interest.

tended periods have decreased feed efficiency, increased fatness, and greater marbling scores (Wilken et al., 2015), carcass-based marketing strategies can be affected by discounts and premiums. Thus, it is important for producers to have information on rate of change in performance and carcass characteristics to project economic effects of extending DOF. In the present manuscript, we report on the statistical analyses of 15 experiments involving beef steers, beef heifers, and Holstein steers to determine the rate of change in selected performance and carcass variables as affected by extended DOF.

MATERIALS AND METHODS

Data used in this article were generated from previous experiments sponsored by Merck Animal Health that were primarily conducted at commercial feedlot research facilities. Pen-level animal performance and carcass data that had been provided to Merck Animal Health as a component of study final reports from these experiments were used for the analyses reported in this article. Thus, no live animals were used by the authors, and Institutional Animal Care and Use Approval was not necessary.

Study Descriptions

The overall data set consisted of performance and carcass measurements from 7 experiments with beef steers, 6 experiments with beef heifers, and 2 experiments with Holstein steers. Pen was the experimental unit in all studies. Characteristics of the experiments are summarized in Table 1. All studies involved extended periods of feeding, and many studies also included β-agonist or implant treatments in a factorial arrangement as noted in Table 1. Except for study 14 (Panhandle Research and Extension Center, Scottsbluff, NE; Ohnoutka et al., 2021; Exp. 2) and study 16 (Texas Tech University Burnett Center Research Feedlot, Lubbock; Vasconcelos et al., 2008), the studies were conducted in commercial feedlots or commercial-scale research feedlots. In addition to studies 14 and 16, study 4 (Winterholler et al., 2007), study 6 (Rathmann et al., 2012), study 8 (Sissom et al., 2007; Exp. 2), and studies 13 and 17 (Smith et al., 2019; Exp. 1 and 2, respectively) have been published in the scientific literature; all other studies were summarized in unpublished final study reports submitted to Merck Animal Health.

Cattle were fed corn-based diets, with steam-flaked corn in all studies except studies 14 (dry-rolled corn) and 18 (steam-flaked corn initially, followed by dry-rolled corn). Most diets included distillers grains (wet or dry), wet corn gluten feed, or both, and diets were formulated to meet or exceed NASEM (2016) nutrient requirements. Management followed standard industry practices in terms of space allowance and animal care. When cattle were slaughtered at the designated DOF for a given experiment, carcass data were collected on individual animals and summarized at a pen level for analyses.

Performance and Carcass Data Set

The data set used for analyses was compiled in a spreadsheet from individual study reports. Performance and carcass variables that were consistently available for the 15 studies were included. Key performance measurements were initial and final shrunk BW, DOF, ADG, DMI, and F:G. Carcass variables included DP, HCW, percentages of cattle in various QG [Prime, Choice, Select, and not graded (No Roll)], percentages of cattle in various YG categories (1 through 5), calculated YG, fat thickness at the 12th rib, LM area, and marbling score (40 = Small^0). Estimated empty body fat was calculated using the equation of Guiroy et al. (2001). Variables that were ultimately analyzed included those considered of practical value in determining optimal slaughter dates for marketing cattle and included DMI, ADG, F:G, final shrunk BW, HCW, DP, 12th-rib fat, LM area, marbling score, percentage of Choice carcasses, calculated YG, percentages of carcasses in YG 3 and YG 4 and 5 categories, and percentage of empty body fat.

As noted previously, many studies included feed additive (β-agonist) or implant treatment comparisons; however, inconsistency in non-DOF treatment structures across the studies limited the number of valid direct comparisons of feed additives or implants. Ultimately, 2 studies with steers that compared control versus zilpaterol × DOF, 2 studies with steers that compared control versus ractopamine × DOF, and 3 studies with heifers that compared an initial Revalor-IH (80 mg of trenbolone acetate and 8 mg of estradiol) with a Revalor-200 (200 mg of trenbolone acetate and 20 mg of estradiol) reimplant versus a single Revalor-XH (200 mg of trenbolone acetate and 20 mg of estradiol in an extended-release formulation; Revalor implants are products of Merck Animal Health) × DOF were analyzed to estimate average treatment effects across studies.

Statistical Methods

A randomized complete block design was used in all studies in the data set, except study 16, which employed a completely random design. The blocking factor was generally arrival time at the facility. For the summary analyses conducted herein, block effects, which were defined as random in all studies, were not included in statistical models. Thus, in models where feed additive and implant treatments were evaluated, differences among pens within treatment represented the error term for testing treatment effects.

Slaughter dates were determined by the investigators, with the typical or "normal or optimal" date based on visual appraisal of the cattle, historical expectations for similar types of cattle, or both; thus, the slaughter dates were not based on a standardized value such as a particular final shrunk BW or ultrasound measurement of body fatness. In all studies, investigators considered DOF as a fixed treatment effect. In the current analyses, extend-

Table 1. General characteristics of the 15 experiments used in the data analyses

Study no.	Location[1]	Total initial no.	Pens per treatment	Additive or implant comparison[2]	Slaughter range, d	Min. DOF[3]	Overall average: Initial BW, kg	Final sBW,[4] kg	ADG, kg	DMI, kg	HCW,[5] kg	Choice, %	YG
Steers													
1	TXP	3,730	9	None	0, 14, 28, 42, 56	113	333	606	1.71	8.83	398	52.1	2.67
2	WKS	3,830	6	C vs. Z	0, 21, 42	117	331	591	1.59	9.72	382	45.1	2.38
3	TXP	2,088	4	XS vs. IS-S	0, 21, 42	167	316	615	1.59	9.50	394	52.2	3.27
4	TXP	2,250	4	C vs. R	0, 21, 42	148	311	588	1.63	8.88	374	42.0	2.89
7	WKS	2,122	4	C vs. R	0, 21, 42	176	252	525	1.35	6.78	335	28.8	2.69
16	TXP	560	7	C vs. Z	0, 21, 41, 62	136	339	602	1.58	8.74	397	42.8	2.71
20	TXP	6,840	9	XS vs. XS-200	0, 14, 28, 42	164	377	695	1.71	10.27	451	71.5	3.59
Heifers													
6	TXP	3,380	6	C vs. Z	0, 21, 40	125	307	545	1.62	8.71	350	66.7	2.83
8	TXP	2,323	8	C vs. R	0, 21, 41	127	285	518	1.55	8.50	331	40.8	2.29
13	TXP	3,780	9	XH vs. IH-200	0, 21, 42	166	309	594	1.48	9.58	383	78.4	—
14	NEP	720	6	C vs. XH vs. 200–200	0, 14, 28, 42	150	281	589	1.80	11.71	372	—	4.10
17	TXP	3,719	9	XH vs. IH-200	0, 21, 42	150	337	595	1.49	9.59	381	78.0	3.31
18	WKS	3,084	6	XH vs. IH-200	0, 21, 42	172	291	564	1.37	9.36	364	77.3	3.46
Holsteins													
11	SAZ	2,760	8	None	0, 28, 56	80	524	662	1.23	9.40	417	73.9	2.48
12	WOK	1,046	7	None	0, 28	318	164	642	1.41	7.89	402	57.0	2.80

[1]TXP = Texas Panhandle; WKS = western Kansas; NEP = Nebraska Panhandle; SAZ = southern Arizona; WOK = western Oklahoma.

[2]C vs. Z = control versus zilpaterol; XS vs. IS-S = Revalor-XS versus Revalor-IS/Revalor-S combination; C vs. R = control versus ractopamine; XS vs. XS-200 = Revalor-XS versus Revalor-XS/Revalor-200 combination, with the reimplant at 120 d on feed or 80 d before slaughter; XH vs. IH-200 = Revalor-XH versus Revalor-IH/Revalor-200 combination; C vs. XH vs. 200–200 = control versus Revalor-XH versus Revalor-200/Revalor-200 combination. Revalor is a registered trademark of Merck Animal Health.

[3]Minimum days on feed.

[4]sBW = shrunk BW.

[5]HCW = hot carcass weight.

ed DOF was treated as dependent variable in all models rather than a fixed effect. Specifically, for the purposes of analyzing the rate of change in performance and carcass measurements with extended DOF, the shortest period in each experiment was set at zero, with subsequent periods defined by the additional days beyond the d 0 baseline. In some studies (studies 1, 2, 3, 6, 7, 11, 14, 16), one or more initial slaughter dates was considered less than optimal for the cattle, whereas in other studies (studies 4, 8, 12, 13, 17, 18, 20) the initial slaughter date was considered typical for the cattle. Thus, the 0 DOF starting point used in the current analyses does not necessarily represent the perceived typical or optimal slaughter date for a particular experiment.

The Mixed procedure of SAS (SAS Institute Inc.) was used for all analyses. In the 3 comparisons noted previously that involved β-agonist feed additives and implant program treatments, the initial statistical model included the random effect of study, the effect of extended DOF, the fixed effect of additive or implant, and the interaction of the extended DOF with additive or implant treatment.

The analyses to evaluate the overall effect of extended DOF on the rate of change (slope) in performance and carcass characteristics was done within each cattle category (steers, heifers, and Holstein steers). Because implant program or β-agonist treatments varied across studies and were functionally confounded with the study effect, models to evaluate the effect of DOF did not include implant program or β-agonist effects. Thus, various models were compared to evaluate random slope and intercept effects of extended DOF, as well as the quadratic effect of extended DOF. Final models were determined by evaluation of Akaike's information criterion (AIC) values (smaller is better) among the various models that were considered.

RESULTS AND DISCUSSION

Feed Additive and Implant Effects

Although not the primary objective of our analyses, we believe it is important to demonstrate that the responses in our data set to β-agonists and implants were consistent with data in the literature. Thus, summarized responses to feed additives and implant programs are shown in Tables 2 through 4. As noted previously, 2 steer studies were included in each of the β-agonist versus control comparisons (zilpaterol: Table 2; ractopamine: Table 3). Three studies with heifers were included in the comparison of the implant programs (Revalor-IH/Revalor-200 vs. Revalor-XH; Table 4).

Initial models for these analyses tested the effect of treatment, extended DOF, and the interaction of extended DOF with treatment. For the zilpaterol comparison, only one variable (marbling score; $P = 0.046$) showed evidence of an interaction; for all other variables, the P-value was greater than 0.24. For the ractopamine comparison, no variable showed evidence of an interaction ($P > 0.52$). Finally, one variable (DMI; $P = 0.023$) showed an inter-

Table 2. Effects of extended days on feed and feeding the β-agonist zilpaterol on performance and carcass characteristics of beef steers: 2-study summary

Item[1]	Extended days slope	*P*-value[2]	Treatment: Control	Treatment: Zilpaterol	SE[3]	*P*-value[4]
DMI, kg	0.0028	0.137	9.27	9.22	0.50	0.633
ADG, kg	−0.0024	<0.001	1.54	1.60	0.02	<0.010
F:G	0.0102	<0.001	6.02	5.79	0.32	<0.001
Final sBW, kg	1.1528	<0.001	594.1	602.1	3.54	0.061
HCW, kg	0.9184	<0.001	381.7	398.2	2.48	<0.001
DP, %	0.0249	<0.001	64.2	65.9	0.32	<0.001
12th-rib fat, cm	0.0043	<0.001	1.31	1.14	0.13	<0.001
LM area, cm^2	0.0032	0.853	90.5	99.5	0.71	<0.001
Marbling score	0.1030	<0.001	43.1	39.6	1.34	<0.001
Choice, %	0.3061	<0.001	54.1	38.5	3.15	<0.001
Calculated YG	0.0122	<0.001	2.87	2.40	0.17	<0.001
YG 3, %	0.2828	<0.001	34.8	20.9	6.51	<0.001
YG 4 and 5, %	0.1209	0.001	6.9	3.1	1.31	0.017
eEBF, %	0.0480	<0.001	29.1	27.7	0.75	<0.001

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = Small^0; eEBF = estimated empty body fat (Guiroy et al., 2001).

[2]*P*-value for the slope of the extended days on feed effect.

[3]Standard error of the LSM, n = 46 to 102 pens/treatment.

[4]*P*-value for the difference between means for control and zilpaterol.

Table 3. Effects of extended days on feed and feeding the β-agonist ractopamine on performance and carcass characteristics of beef steers: 2-study summary

Item[1]	Extended days slope	*P*-value[2]	Treatment: Control	Treatment: Ractopamine	SE[3]	*P*-value[4]
DMI, kg	0.0010	0.514	7.81	7.85	1.05	0.367
ADG, kg	−0.0029	<0.001	1.46	1.51	0.14	0.002
F:G	0.0107	<0.001	5.32	5.17	0.23	0.002
Final sBW, kg	0.9617	0.002	551.9	560.9	7.07	0.375
HCW, kg	0.7862	<0.001	351.1	357.6	19.63	0.003
DP, %	0.0303	<0.001	63.6	63.8	0.16	0.377
12th-rib fat, cm	0.0033	0.002	1.18	1.18	0.30	0.949
LM area, cm^2	0.0955	<0.001	88.1	89.7	2.58	0.011
Marbling score	0.0569	<0.001	38.0	37.7	1.52	0.496
Choice, %	0.1803	0.005	36.2	34.6	6.64	0.440
Calculated YG	0.0076	<0.001	2.81	2.78	0.10	0.610
YG 3, %	0.1872	0.002	31.1	30.9	5.42	0.913
YG 4 and 5, %	0.1426	<0.001	9.4	7.5	1.99	0.170
eEBF, %	0.0323	<0.001	27.5	27.6	1.75	0.623

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = Small^0; eEBF = estimated empty body fat (Guiroy et al., 2001).

[2]*P*-value for the slope of the extended days on feed effect.

[3]Standard error of the least squares means, n = 24 pens/treatment.

[4]*P*-value for the difference between means for control and ractopamine.

Table 4. Effects of extended days on feed and implant programs on performance and carcass characteristics of beef heifers: 3-study summary

Item[1]	Extended days slope	*P*-value[2]	Implant program[3]: Rev-IH/Rev-200	Implant program[3]: Rev-XH	SE[4]	*P*-value[5]
DMI, kg	−0.0013	0.270	9.47	9.55	0.08	0.047
ADG, kg	−0.0024	<0.001	1.46	1.45	0.04	0.378
F:G	0.0104	<0.001	6.54	6.63	0.13	0.012
Final sBW, kg	0.9788	<0.001	587.8	586.1	1.89	0.537
HCW, kg	0.7600	<0.001	377.2	374.6	6.06	0.013
DP, %	0.0222	<0.001	64.5	64.2	0.12	0.005
12th-rib fat, cm	0.0048	<0.001	1.75	1.83	0.05	0.004
LM area, cm^2	0.1045	<0.001	91.2	88.3	4.91	<0.001
Marbling score	0.0686	<0.001	54.0	54.5	3.25	0.421
Choice, %	−0.0149	0.637	78.2	77.8	0.76	0.758
Calculated YG	0.0054	<0.001	3.29	3.48	0.08	<0.001
YG 3, %	−0.0979	0.003	41.4	42.2	1.24	0.456
YG 4 and 5, %	0.2622	<0.001	19.9	26.4	2.54	<0.001
eEBF, %	0.0369	<0.001	31.9	32.4	0.20	0.003

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = Small^0; eEBF = estimated empty body fat (Guiroy et al., 2001).

[2]*P*-value for the slope of the extended days on feed effect.

[3]Rev-IH/Rev-200 = initial implant of Revalor-IH with a Revalor-200 reimplant; Rev-XH = initial implant with Revalor-XH and no reimplant. Revalor is a registered trademark of Merck Animal Health.

[4]Standard error of the least squares means, n = 72 pens/treatment.

[5]*P*-value for the difference between means for implant treatments.

action in the implant comparison; for all other variables, the P-value was greater than 0.10. The nature of the 2 interactions that were observed (slightly different rates of change over time between treatments) were consistent with differences between the overall LSM for treatments. Thus, given the very limited evidence of an interaction of extended DOF with treatments, the interaction term was excluded from final models. Nonetheless, the lack of interactions is an important finding that is consistent with the results of the individual studies that made up the data set, none of which found evidence of major interactive effects of extended DOF and β-agonist or implant program treatments. Readers also should note that although the slope for extended DOF is reported in Tables 2 through 4 for completeness of presentation, these slope values are not recommended for practical application because they are only based on subsets of the overall analyses, which are reported in a subsequent section.

The effects on performance and carcass characteristics of feeding zilpaterol in our 2-study summary (Table 2) were remarkably consistent with previously reported values in the literature. For example, in a comprehensive meta-analysis with both steers and heifers that involved 26 to 31 studies depending on the variable, Lean et al. (2014) reported weighted mean differences (zilpaterol minus control) for final shrunk BW, DMI, ADG, HCW, fat thickness at the 12th rib, LM area, and DP of 8.15 kg, −0.12 kg, 0.15 kg, 15.18 kg, −0.11 cm, 8.01 cm^2, and 1.71%, respectively. Comparable treatment differences in our summary were 8.0 kg, −0.05 kg, 0 kg, 16.5 kg, −0.17 cm, 8.96 cm^2, and 1.77%, respectively. Except for DMI, ADG, and 12th-rib fat thickness, all differences in our summary were within the 95% confidence limits reported by Lean et al. (2014).

Similar to our results with zilpaterol, the effects of feeding ractopamine on performance and carcass characteristics (Table 3) were consistent with data in the literature. In their meta-analysis of steer and heifer data that involved 40 to 54 experiments depending on the variable (Lean et al., 2014), weighted mean differences (ractopamine minus control) for final shrunk BW, DMI, ADG, HCW, fat thickness at the 12th rib, LM area, and DP were 7.57 kg, −0.003 kg, 0.19 kg, 6.18 kg, −0.003 cm, 1.84 cm^2, and 0.28%. In our 2-study summary, comparable values were 9.0 kg, 0.04 kg, 0 kg, 6.5 kg, 0 cm, 1.61 cm^2, and 0.14%. Except for ADG, all values from our summary were within the 95% confidence limits for each variable reported by Lean et al. (2014). The agreement between the results of our 2-study summaries for both zilpaterol and ractopamine compared with the values noted in the meta-analyses of Lean et al. (2014) based on scores of studies reflects the consistency with which these feed additives affect performance and carcass characteristics of feedlot beef cattle.

Three studies with beef heifers were included in the comparison of Revalor-IH/Revalor-200 versus Revalor-XH (Table 4). Key changes in performance and carcass characteristics included lower DMI ($P = 0.047$), improved F:G ($P = 0.012$), greater HCW ($P = 0.013$), greater DP ($P = 0.005$), lesser 12th-rib fat ($P = 0.004$), greater LM area ($P < 0.001$), a lesser calculated YG ($P < 0.001$), a lesser percentage ($P < 0.001$) of YG 4 and 5 carcasses, and a lesser percentage of calculated estimated empty body fat ($P = 0.003$) for heifers implanted with Revalor-IH and reimplanted with Revalor-200 versus Revalor-XH. Carlson et al. (2020) compared the same 2 implant programs and reported no differences in carcass-adjusted final BW, DMI, ADG, and feed efficiency, which contrasts our results in terms of DMI and F:G. Nonetheless, on a carcass-adjusted BW basis, heifers treated with Revalor-IH/Revalor-200 had greater G:F than those implanted with Revalor-XH (Carlson et al., 2020). Also similar to our summary, Carlson et al. (2020) noted greater LM area and no difference in marbling score in heifers implanted with the Revalor-IH/Revalor-200 combination versus Revalor-XH. In contrast to our findings, Carlson et al. (2020) reported no differences in HCW, DP, and 12th-rib fat between implant programs. In another study, Carlson et al. (2021) compared Revalor-IH/Revalor-200 and Revalor-XH, with an additional treatment of Revalor-200 alone. Live-basis performance did not differ among treatments, but as in our summary, heifers implanted with Revalor-IH and reimplanted with Revalor-200 had greater ($P \leq 0.05$) HCW and LM area than those implanted with Revalor-XH. In both Carlson et al. (2020) and Carlson et al. (2021), heifers implanted with the Revalor-IH/Revalor-200 combination had a shift ($P \leq 0.05$) toward a lower distribution of YG categories than those implanted with Revalor-XH, which is consistent with the decreased calculated YG and decreased percentage of YG 4 and 5 carcasses with Revalor-IH/Revalor-200 noted in our summary. Recently, Smith et al. (2020) reported on a pooled analysis of 6 trials comparing an initial Revalor-IH implant followed by reimplanting with Revalor-200 versus Revalor-XH in heifers fed from 153 to 193 DOF. Our studies 13 and 17 were included in their analysis. Although DMI was increased with Revalor-XH, heifer ADG and F:G were not altered by implant strategy. The Revalor-IH/Revalor-200 treatment slightly increased HCW, LM area, and DP and resulted in a leaner distribution of YG, whereas higher QG distributions were evident with the Revalor-XH treatment. The authors hypothesized that Revalor-XH might be well suited for producers selling heifers on a live basis, whereas those selling on a carcass basis might be able to take advantage of the increased HCW and leaner YG distribution with the Revalor-IH/Revalor-200 program. Given the agreement among our findings and those of Carlson et al. (2020, 2021) and Smith et al. (2020), and the lack of interactions of these implant programs with DOF, producers should be able to conduct a fairly accurate economic analysis on the decision to extend DOF with either implant program.

Rate of Change with Extended DOF

As noted previously, although extended DOF was a consistent factor among the 15 studies (Table 1) in the data set, implant program and β-agonist treatments varied, with only those presented in Tables 2 through 4 allowing for statistical evaluation of overall treatment responses. Thus, in terms of evaluating overall effects of extended DOF on performance and carcass measurements across studies, treatments were confounded with study in most cases. As a result, models to evaluate the overall rates of change with extended DOF did not include the fixed effects of β-agonist, implant program treatments, or both. Nonetheless, to ensure this approach would not lead to invalid findings associated with potential interactions of treatments with extended DOF, performance and carcass measurements in individual studies were tested for the treatment × extended DOF interaction. The 2 Holstein steer studies in the data set did not include β-agonist or implant program treatments, but among the 6 steer studies that included a β-agonist or implant program treatment, only one variable (percentage of YG 3 carcasses in study 20; $P = 0.004$) showed an interaction, with no evidence of an interaction ($P > 0.10$) for the remaining 83 variables. Similarly, among the 6 heifer studies in the data set, 3 variables [DP in study 8 ($P = 0.046$); calculated YG in study 14 ($P = 0.039$); percentage of YG 3 carcasses in study 17 ($P = 0.003$)] showed evidence of an interaction. As the frequency of significant interactions was less than would be expected with an α-level of 0.05 to protect against Type I errors, we conclude that ignoring treatment effects in models to evaluate the rate of change with extended DOF was an appropriate analytical strategy.

As noted previously, various models were assessed to evaluate effects of extended DOF, with the model AIC values compared to determine the best fit. Specifically, the 3 models we compared included (1) linear and quadratic effects of extended DOF, with random slope and intercept effects for studies; (2) linear and quadratic effects of extended DOF, with a random intercept effect for studies; and (3) linear effects of extended DOF, with a random intercept effect for studies. For all but 2 of the 14 variables evaluated, the model with a linear effect for extended DOF and a random intercept term for study yielded the least AIC value. For the 2 variables that had a lower AIC with the more complex models (percentage of Choice carcasses and percentage of YG 4 and 5 carcasses), the AIC of the simpler model was functionally equal (increased by less than 0.04%). Thus, the slope values and confidence limits reported in Tables 5 through 7 are based on models with a linear effect of extended DOF and a random intercept effect for studies.

Slope values and associated 95% confidence limits for the various performance and carcass measurements are shown in Table 5 (beef steers), Table 6 (beef heifers), and Table 7 (Holstein steers). For the 7 studies with beef steers, all slope values were significant ($P < 0.03$) except for LM area, which approached significance ($P = 0.073$). Changes were in the expected directions (e.g., increased DMI, decreased ADG, greater F:G, greater final shrunk BW and HCW, increased DP, greater fatness, and increased marbling score, with associated shifts in percentage of Choice carcasses and shifts in the YG categories to higher values). Responses with beef heifers were similar to those noted with steers in terms of significance ($P < 0.025$), apart from DMI and percentage of YG 3 carcasses, which were not significantly affected by extended DOF ($P > 0.87$). For Holstein steers (Table 7), the slope coefficients for ADG, FG, and percentage of YG 4 and 5 carcasses were not significant ($P \geq 0.065$), whereas all other variables had significant slope coefficients ($P \leq 0.03$). Although slopes for final shrunk BW and HCW were similar for Holstein steers versus beef steers and heifers, noteworthy differences were evident in the magnitude of the slope for marbling score (0.1158 vs. 0.0872 and 0.0810 marbling score units/d) and percentage of Choice carcasses (0.4227 vs. 0.2789 and 0.0660%/d) for Holstein steers versus beef steers and heifers, respectively. The extent to which the estimated empty body fat calculation of Guiroy et al. (2001) is applicable to Holstein steers is open to question, but the confidence limits on the slope for extended DOF were close to overlapping with beef steer and heifer values.

To our knowledge, no other studies in the literature have evaluated the rate of change (slope) for performance and

Table 5. Effects of extended days on feed on performance and carcass characteristics of beef steers: 7-study summary

Item[1]	Extended days slope	*P*-value[2]	Lower 95% CI	Upper 95% CI
DMI, kg	0.0025	0.026	0.0003	0.0046
ADG, kg	−0.0024	<0.001	−0.0029	−0.0018
F:G	0.0097	<0.001	0.0083	0.0111
Final sBW, kg	1.1815	<0.001	1.0771	1.2859
HCW, kg	0.9228	<0.001	0.8457	0.9999
DP, %	0.0251	<0.001	0.0204	0.0298
12th-rib fat, cm	0.0053	<0.001	0.0043	0.0064
LM area, cm^2	0.0239	0.073	−0.0026	0.0503
Marbling score	0.0872	<0.001	0.0676	0.1067
Choice, %	0.2789	<0.001	0.1933	0.3644
Calculated YG	0.0123	<0.001	0.0105	0.0141
YG 3, %	0.1800	<0.001	0.1078	0.2523
YG 4 and 5, %	0.2385	<0.001	0.1840	0.2930
eEBF, %	0.0502	<0.001	0.0437	0.0568

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = Small^0; eEBF = estimated empty body fat (Guiroy et al., 2001).

[2]*P*-value for the slope of the extended days on feed effect. Based on 373 pens of steers over 0 to 62 extended days on feed.

Table 6. Effects of extended days on feed on performance and carcass characteristics of beef heifers: 6-study summary

Item[1]	Extended days slope	*P*-value[2]	Lower 95% CI	Upper 95% CI
DMI, kg	0	0.990	−0.0019	0.0019
ADG, kg	−0.0031	<0.001	−0.0036	−0.0026
F:G	0.0123	<0.001	0.0105	0.0140
Final sBW, kg	1.0724	<0.001	0.9854	1.1594
HCW, kg	0.8580	<0.001	0.7983	0.9178
DP, %	0.0297	<0.001	0.0246	0.0348
12th-rib fat, cm	0.0069	<0.001	0.0058	0.0079
LM area, cm^2	0.0916	<0.001	0.0677	0.1155
Marbling score	0.0810	<0.001	0.0576	0.1043
Choice, %	0.0660	0.023	0.0091	0.1228
Calculated YG	0.0093	<0.001	0.0076	0.0110
YG 3, %	0.0047	0.871	−0.0526	0.0621
YG 4 and 5, %	0.2551	<0.001	0.1944	0.3157
eEBF, %	0.0502	<0.001	0.0435	0.0569

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = Small^0; eEBF = estimated empty body fat (Guiroy et al., 2001).

[2]*P*-value for the slope of the extended days on feed effect. Based on 276 pens of heifers over 0 to 42 extended days on feed.

Table 7. Effects of extended days on feed on performance and carcass characteristics of Holstein steers: 2-study summary

Item[1]	Extended days slope	*P*-value[2]	Lower 95% CI	Upper 95% CI
DMI, kg	0.0077	<0.001	0.0041	0.0113
ADG, kg	0.0002	0.911	−0.0032	0.0036
F:G	−0.0038	0.775	−0.0304	0.0228
Final sBW, kg	1.3026	<0.001	1.0349	1.5704
HCW, kg	0.8906	<0.001	0.7060	1.0748
DP, %	0.0107	0.024	0.0015	0.0200
12th-rib fat, cm	0.0018	0.019	0.0003	0.0030
LM area, cm^2	0.0342	0.013	0.0077	0.0613
Marbling score	0.1158	<0.001	0.0827	0.1489
Choice, %	0.4227	<0.001	0.2946	0.5508
Calculated YG	0.0033	0.028	0.0004	0.0062
YG 3, %	0.1541	0.030	0.0158	0.2923
YG 4 and 5, %	0.0487	0.065	−0.0033	0.1006
eEBF, %	0.0323	<0.001	0.0211	0.0434

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = Small^0; eEBF = estimated empty body fat (Guiroy et al., 2001).

[2]*P*-value for the slope of the extended days on feed effect. Based on 38 pens of Holstein steers over 0 to 56 extended days on feed.

carcass measurements with studies that specifically included extended DOF. Thus, finding values with which to compare our results is challenging. Hicks et al. (1987), May et al. (1992), and Bruns et al. (2004) conducted serial slaughter experiments with 475, 48, and 85 beef steers, respectively. Days on feed in these 3 studies varied from 100 to 142 for Hicks et al. (1987), 0 to 196 for May et al. (1992), and 48 to 252 for Bruns et al. (2004). Thus, final shrunk BW ranged from much less than typical for May et al. (1992) and Bruns et al. (2004) to well above typical, whereas final shrunk BW in the Hicks et al. (1987) study was within industry averages for the time. We used the data from these 3 studies starting from DOF when 12th-rib fat was approximately 0.9 to 1.2 cm to evaluate rate of change in final shrunk BW and carcass measurements. This resulted in using all 4 data points from Hicks et al. (1987; 100, 114, 128, and 142 DOF), 4 data points from May et al. (1992; 112, 140, 168, and 196 DOF), and 3 data points from Bruns et al. (2004; 141, 186.5, and 250 DOF averaged over the 2 yr of the study). Within each study, the lowest DOF was set to zero, the extended DOF intervals were calculated for the additional datapoints, and the slope of the linear regression of various performance and carcass measurements on extended DOF was calculated. Slope values from these 3 experiments are shown in Table 8, along with the corresponding slope values for steers from the present study that are reported in Table 5. Calculated values from these 3 studies are generally in the same range as our slope estimates, although many of the values were slightly outside the 95% confidence limits for our estimates (Table 8). Hicks et al. (1987) used British and Continental yearling steers in their study, May et al. (1992) used Angus × Hereford steers that were approximately 16 mo of age, and Bruns et al. (2004) used purebred Angus steers that averaged 265 d of age. In all 3 studies, cattle had a common nutritional background. An estradiol-based implant was given by Hicks et al. (1987) and May et al. (1992), whereas cattle in the Bruns et al. (2004) study were not implanted. Because the studies in our data set were conducted mostly at commercial feedlots or large-scale research locations, breed, age, and nutritional backgrounds of the cattle used were much more varied than in the Hicks et al. (1987), May et al. (1992), and Bruns et al. (2004) experiments. In addition, implant programs were much more aggressive in the studies used in our data set, and a large percentage of cattle in our data set received a β-agonist before slaughter. Given the differences between our data set and these 3 previous studies, the degree of agreement in slope estimates for extended DOF is somewhat surprising.

For producers who market cattle on a carcass basis, feeding cattle for extended periods increases HCW (Volpi-Lagreca et al., 2021) and can increase profit (Wilken et al., 2015). Wilken et al. (2015) evaluated the concept of

Table 8. Summary of extended days slope values for performance and carcass characteristics of beef steers calculated from 3 literature studies compared with slopes determined in the present study

	Literature study			
Item[1]	Hicks et al. (1987)	May et al. (1992)	Bruns et al. (2004)	Slope estimate from Table 5[2]
Final sBW, kg	1.34	1.31	0.94	1.18 (1.08, 1.29)
HCW, kg	0.99	1.01	0.76	0.92 (0.85, 1.00)
DP, %	0.031	0.025	0.030	0.025 (0.020, 0.030)
12th-rib fat, cm	0.009	0.008	0.009	0.005 (0.004, 0.006)
LM area, cm^2	0.045	0.107	0.048	0.024 (−0.003, 0.050)
Marbling score	0.091	0.007	0.152	0.087 (0.068, 0.107)
Calculated YG	0.016	0.014	0.015	0.012 (0.011, 0.014)

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = $Small^0$.

[2]Values in parentheses are the 95% confidence interval limits from Table 5.

the transfer coefficient (fractional transfer of shrunk BW gain to HCW gain) as a tool to determine efficiency of carcass gain, reporting that the transfer of shrunk BW to the carcass increased linearly with DOF, approaching 90% by the end of the feeding period. In our analyses, the ratio of the slopes of HCW to final shrunk BW would represent an estimate of the transfer coefficient over the period of extended DOF that we evaluated. These estimates were 0.78, 0.80, and 0.68 for steers, heifers, and Holstein steers, respectively, suggesting that transfer of liveweight gain to carcass gain during extended feeding periods beyond normal slaughter dates does not differ greatly among these classes of cattle and that the transfer is reasonably efficient. Moreover, these coefficients are consistent with the increase in DP that has been observed with added DOF (May et al., 1992; Bruns et al., 2004).

APPLICATIONS

Our slope estimates in Tables 5 through 7 should provide producers with a practical means of estimating the effects of extended DOF on performance and carcass measurements. An example of application of these data for a beef steer fed for an additional 42 d beyond a typical feeding period of 150 d is shown in Table 9. The typical feeding period data would be chosen by the user to represent values for these variables that would be expected based on projections or historical data at a particular feedlot. Slope estimates for each variable for steers from Table 5 are multiplied by the selected DOF and added to the typical values chosen by the user. To ensure internal consistency in predicted values, F:G for the extended feeding period was calculated from predicted DMI and ADG values rather than the F:G slope value for steers shown in Table 5. These values provide estimates of performance and carcass measurements for the entire feeding period and illustrate the expected decrease in ADG and increased F:G with extended DOF, as well as the increase in final shrunk BW, HCW, and DP. Measures of carcass fatness also increase, along with expected shifts in QG and YG. These data could be used by producers who are selling cattle on a carcass basis to estimate changes in HCW, along with potential premiums and discounts associated with changes in QG and YG that might affect profit–loss projections. Readers are cautioned that the extended DOF inference space of the slope data should be considered when making

Table 9. Example application of the extended days on feed slope estimates for a feedlot beef steers fed for an additional 42 d beyond a typical feeding period

Item[1]	Typical feeding period	Extended feeding period
Days on feed	150	192
DMI, kg	9.52	9.63
ADG, kg	1.63	1.53
F:G[2]	5.83	6.28
Final sBW, kg	612.2	661.9
HCW, kg	391.8	430.6
DP, %	64	65.1
12th-rib fat, cm	1.27	1.49
LM area, cm^2	96.8	97.8
Marbling score	45.0	48.7
Choice, %	60.0	71.7
Calculated YG	3.0	3.5
YG 3, %	32.0	39.6
YG 4 and 5, %	10.0	20.0
eEBF, %	28.9	31.0

[1]sBW = shrunk BW; HCW = hot carcass weight; marbling score: 40 = $Small^0$; eEBF = estimated empty body fat (Guiroy et al., 2001).

[2]To ensure internal consistency, F:G for the extended feeding period was calculated from predicted DMI and ADG values, not from the F:G slope value shown in Table 5.

such projections (beef steers = 0 to 62 d; beef heifers = 0 to 42 d; and Holstein steers = 0 to 56 d).

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