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Cattle, carcass, economic, and estimated emission impacts of feeding finishing steers lubabegron or ractopamine hydrochloride

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Abstract

Lubabegron (Experior; Elanco, Greenfield, IN, USA) is the first U.S. Food and Drug Administration approved feed additive for reducing gas emissions from feedlot animals or their waste; it does not have live or carcass performance claims. Our primary objective was to determine the effect of lubabegron on feedlot performance and carcass traits in finishing beef steers compared to ractopamine hydrochloride (Optaflexx; Elanco, Greenfield, IN, USA). A commercial feedlot trial using cross-bred beef steers ($n = 2{,}117$; 373 ± 15 kg initial body weight [BW]) was completed with a randomized complete block design. Treatments consisted of two feed additives: (1) OPT targeted to deliver 300 mg/animal/d of ractopamine hydrochloride for 28 ± 7 d out from harvest and (2) EXP targeted to deliver 36 mg/animal/d of lubabegron 56 ± 7 d out from harvest and a 4-d preslaughter withdrawal period. Twenty 70 to 142 hd pens with 10 pens per treatment were used. Cattle were weighed at arrival processing and at harvest and fed for an average of 167 d. Data were used to calculate production metrics, partial budgets, and estimated greenhouse gas emissions using published methods, and were analyzed using linear mixed models with pen as the experimental unit and block as a random intercept. A statistical significance threshold of $\alpha = 0.05$ was determined a priori. There was no evidence for statistically significant differences between treatments for initial BW ($P = 0.70$), health-related outcomes (P values ≥ 0.43), or mobility scores ($P = 0.09$). Cattle-fed EXP had increased final BW, ADG, G:F, and decreased dry matter intake (P values ≤ 0.01) compared to OPT. Carcasses were 11 ± 1.76 kg (hot carcass weight) heavier in EXP group ($P < 0.01$), and differed between treatments for both yield grades (YG) and quality grades distributions (P values ≤ 0.01). Cattle-fed EXP had a shift toward more YG 1 and 2, select and sub-select carcasses compared to OPT, which had as shift toward more YG 3, 4, 5, prime and choice carcasses. With increased beef production and efficiency compared to OPT, the estimated CO_2 equivalent emissions from production were reduced by 6.2% per unit of carcass weight for EXP ($P \leq 0.01$). Estimated net returns/animal shipped were \$56.61 ± 9.37 more for EXP than OPT ($P \leq 0.01$). In conclusion, when cattle were fed for the same total number of days, feeding EXP compared to OPT increased net returns, feedlot performance, and efficiency, but resulted in carcass yield and quality characteristics that may impact marketing programs.

Lay Summary

Lubabegron (Experior), the first Food and Drug Administration approved feed additive for reducing gas emissions from feedlot animals, was studied for its impact on feedlot performance and carcass traits in beef steers compared to feeding ractopamine hydrochloride (Optaflexx). In a commercial feedlot trial with 2,117 cross-bred beef steers, lubabegron (EXP) demonstrated advantages over ractopamine hydrochloride (OPT) in final body weight, average daily gain, feed efficiency, and reduced dry matter intake. Carcasses from EXP were heavier, with shifts towards decreased yield and quality grades. The feeding of EXP resulted in a 6.2% reduction in estimated CO_2 equivalent emissions per unit of carcass weight, and a \$56.61 higher estimated net returns per animal shipped compared to OPT. This study indicates that feeding Experior instead of Optaflexx in commercial feedlot steers enhances feedlot performance and efficiency while influencing carcass characteristics that may impact marketing programs.

Key words: carcass traits, feedlot performance, greenhouse gas emissions, lubabegron, net returns, ractopamine hydrochloride

Introduction

Sustainability and efficiency of beef production are intertwined, with sustainability becoming an increasing interest for stakeholders in the beef industry. Though sustainability can be a broad concept, a simplified definition is that sustainable food production is a balance between environmental responsibility, economic viability, and social acceptability (de Wit et al., 1995; United Nations, 2005). Consumer and stakeholder attention to modern food production systems emissions has intensified (Teeter et al., 2021), particularly for greenhouse gas (GHG) emissions such as NH_3 (Brown et al., 2018). A new feed additive technology, lubabegron (Experior; Elanco, Greenfield, IN, USA, https://elancolabels.com/us/

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experior-10), is the first U.S. Food and Drug Administration (FDA) approved feed additive for reducing gas emissions from an animal or its waste. Lubabegron is approved for reducing NH_3 gas emissions/kg final BW and kg hot carcass weight (HCW) when administered during the last 14 to 91 d on feed. It does not have label claims for impacting live animal or carcass performance.

Lubabegron is a selective β modulator, meaning that it is a β-adrenergic agonist and antagonist (FDA-FIO, 2018), and differs from beta-agonists like ractopamine hydrochloride (Optaflexx; Elanco, Greenfield, IN, USA). One large pen commercial feedlot study demonstrated feeding lubabegron, as compared to a negative control group, resulted in an increase in final body weight (BW) and hot carcass weight (Kube et al., 2021). This study also demonstrated no significant differences in morbidity, animal removals, or mortalities. Additionally, there was no evidence for differences in cattle mobility between treatments. To date, there are no published studies comparing lubabegron to a beta-agonist.

Our primary objective was to determine the effect of lubabegron on live performance and carcass traits in finishing beef steers compared to ractopamine hydrochloride. Secondary outcomes of interest included health outcomes, mobility scores, economic returns, and emissions estimates. Our null hypotheses were that there were no differences in observed performance, carcass, health, mobility, economic, or emission outcomes. This is the first published large pen commercial feedlot comparison of lubabegron and ractopamine hydrochloride in beef steers.

Materials and Methods

The experimental phase of the trial was initiated on August 2, 2022, and completed on February 10, 2023, in central KS. All study procedures were reviewed and approved by Kansas State University's Institutional Animal Care and Use Committee (Approval number IACUC-4785).

Experimental Design

A controlled trial in a randomized complete block design was carried out using cross-bred beef steers ($n = 2{,}081$). Experimental treatments consisted of two different feed additives (1) OPT targeted to deliver 300 mg/animal/d of ractopamine hydrochloride for 28 ± 7 d prior to harvest and (2) EXP targeted to deliver 36 mg/animal/d of lubabegron 56 ± 7 d prior to harvest and a 4-d preslaughter withdrawal period. Treatments were randomly assigned to a pen within a block, and each block represented a single replication of each treatment. Steers were from a single source and blocked by arrival date. Twenty total pens, with 10 pens per treatment were used. Steers were allocated into one of the two pens within a block by sorting five animals at a time until the desired number of animals was reached for each pen. Once filled, pens were weighed in drafts on a platform scale to determine initial BW. Pens were randomly assigned to treatment using the RAND function of Excel (Microsoft, Redmond, WA, USA). Sample size estimates using $\alpha = 0.05$, $\beta = 0.185$, and historical baseline data from the commercial feedlot indicated 10 blocks (2 pens per block, 20 pens) were necessary to demonstrate a 0.06 difference in the probability of carcasses having a quality grade of choice or better. The number of animals per pen were fixed based on the feedlot space per pen but influenced the precision of pen-level estimates for sample size calculations. Aside from treatments administered, all feedlot procedures (including processing, handling, feeding, treating, and harvesting) were consistent for both pens within a block.

Cattle Management, Processing, and Housing

Receiving. Cross-bred beef steers were received between August 2nd and 22nd, 2022, and were sourced from a single ranch in KS. Upon arrival, steers were offered ad libitum access to long-stemmed hay and water. Animals appearing maladjusted, over- or under-conditioned, having behavioral, disease, or appetency problems or conditions were removed from study candidacy.

Processing. After allocation and randomization to experimental pens, steers were processed in accordance with standard feedlot procedures. Processing products and amounts varied slightly but were consistent for pens within a block. At initial processing steers received: an ear tag with a lot number unique to each pen, an ear tag with a number unique to each animal, a five-way viral vaccine (Bovi-Shield Gold 5 [2 mL]; Zoetis Animal Health, Parsipany, NJ) administered subcutaneously (SC), a SC injection of an internal parasiticide (Dectomax [8 or 9 mL]; Zoetis Animal Health), an oral anthelmintic (Safeguard [19, 20, or 23 mL]; Merck Animal Health, DeSoto, KS), and an implant administered SC in the ear containing 100 mg trenbolone acetate and 14 mg estradiol benzoate (Synovex Choice; Zoetis Animal Health). Six pens of steers (all pens in blocks 8, 9, 10) were administered a pour-on insecticide, pyrethroid with IGR (Clean-Up II [30 mL]; Elanco Animal Health). After an average of 84 d on feed (range of 73 to 99 d; identical within blocks), steers received a terminal implant administered SC in the ear containing 200 mg trenbolone acetate and 28 mg estradiol benzoate (Synovex Plus; Zoetis Animal Health).

Housing. Pens were dirt-surfaced, of steel pipe construction, with open-air exposure, and measured on average 2,001 m^2 (range of 1,255 to 2,508 m^2) which provided on average 19 m^2/animal (range of 15 to 25 m^2/animal). Average bunk space per animal was 30.86 cm (range of 25.73 to 36.14 cm). Pens within a block were adjacent to one another and provided similar pen and bunk space per animal. Pens were equipped with an automatic water fountain allowing ad libitum access to fresh well water.

Animal health. All steers were observed daily by experienced animal caretakers that were blinded to treatment group. Steers exhibiting signs of abnormal health (e.g., lameness, depression, anorexia, and respiratory distress) were treated in accordance with feedlot protocols. If pulled from the home pen to a hospital pen, animals were further evaluated. Diagnostics performed chute-side included measurements of BW, rectal temperature, and lung auscultation scores via stethoscope. Steers were then treated according to protocols established by consulting veterinarians based on clinical signs from the pen and chute-side evaluations. In general, steers were treated and returned to home pens on the same day. If an animal required additional recovery time, it could reside in a hospital pen for a maximum of 10 d; if on the 10th d the animal was deemed unfit to return home they would then be removed from the study. Additionally, steers that failed to respond or were unlikely to respond to therapeutic treatment were removed from the study by personnel blinded to treatment groups.

Diet Preparation and Feeding

Diet formulations are described in Table 1. The finishing diet composition was the same for both treatment groups except for the experimental products (EXP and OPT). The finisher diet was formulated to provide 15.91% crude protein, 0.64% calcium, 0.42% phosphorous, 2.19 Mcal/kg net energy for maintenance, and 1.51 Mcal/kg net energy for gain. For the final 28 d ractopamine hydrochloride was included at a target rate of 300 mg/animal/d for OPT and lubabegron was included at a target rate of 36 mg/animal/d for the final 53 d (52 to 54). Daily feed deliveries were summed at the pen level over the feeding period on a dry matter basis and divided by animal days to estimate mean daily dry matter intake (DMI) per animal. Animal-days is the number of cattle multiplied by the total number of days cattle were in the pen, including animal removals and mortalities up until the day of removal or death.

Harvest

On the day of harvest, pens within a block were weighed sequentially in drafts on a platform scale for measurement of final BW and a 4% shrink was applied. Steers were then loaded on trucks and transported approximately 193 km to a commercial abattoir in KS. Steers remained separate by pen throughout shipping and harvest. Mobility scores were collected at the processing plant by trained personnel from a consulting group who were blinded to treatment group. The mobility scoring systems categorized mobility as 1 = normal, walks easily, no apparent lameness or change in gait; 2 = exhibits minor stiffness, shortness of stride, slight limp, still keeps up with normal cattle; 3 = exhibits obvious stiffness, difficulty taking steps, obvious limp, obvious discomfort, lags behind normal cattle; and 4 = extremely reluctant to move even when encouraged by a handler; statue-like (NAMI 2015). Additional variables collected by trained and blinded personnel included HCW, USDA quality grade (QG), USDA yield grade (YG), 12th-rib fat thickness, longissimus muscle area, marbling score, and calculated yield grade. Non-weight measurements were determined with a video image analysis system. Average dressing percentage for each pen was calculated as the total HCW divided by shrunk final BW.

Table 1. Dietary ingredient formulations and calculated nutrient composition of the finishing diet fed to feedlot steers during the experimental period

Item	Finisher[†]
Ingredient, % dry matter	
Steam-flaked corn	71.66
Wet distillers grain	16.67
Corn silage	7.25
Liquid supplement	4.40
Micro ingredients[‡]	0.02
Nutrient composition	
Dry matter, %	58.75
Crude protein, %	15.91
Fat, %	4.50
Calcium, %	0.64
Phosphorus, %	0.42
Sulfur, %	0.21
NE_m[§], Mcal/kg	2.19
NEg[#], Mcal/kg	1.51

[†]Finisher diet was formulated to provide 315 mg/animal/d monensin (Rumensin; Elanco Animal Health), and (depending on experimental treatment) 300 mg/animal/d Optaflexx (Elanco Animal Health) fed during the final 28 d of (average across all pens) and removed 1 d prior to shipment or 36 mg/animal/d Experior (Elanco Animal Health) fed during the final 53 d of (average across all pens) and removed 4-d prior to shipment.
[‡]Feed additives were dispensed directly into the feed truck using Micro-Weigh Systems (Micro Beef Technologies, Amarillo, TX).
[§]NE_m, net energy for maintenance expressed as Mcal/kg.
[#]NE_g, net energy for gain expressed as Mcal/kg.

Economic Assessment

A partial budget was used to evaluate treatment effects on economic returns of feedlot steers using pen-level cumulative (close-out) data from the entire feeding period. Cost parameters in the partial budget were: cattle purchases, processing, treatment antimicrobials, rendering fees (for mortalities), feed, and yardage (accounts for labor and facilities maintenance). Revenue from cattle sales was evaluated on the bases of both live (non-adjusted) sales and dressed sales adjusted for carcass quality-based premiums and discounts. Revenue parameters in the partial budget were: culled animals (sale of animals removed from trial), live cattle sales, and dressed cattle sales adjusted for YG, QG, and over- or under-weight carcasses. A net return value was calculated for each pen, where net return is the difference between total revenue and total variable expenses for that pen. Net returns are the final outcome of the partial budgets.

Cattle purchase price was $174.24/ 45.4 kg (100 lb), and was multiplied by the total initial BW of each pen. This price was the average of weekly prices from the range of dates that animals were enrolled (August 2 to August 22, 2023), sourced from the Livestock Marketing Information Center, Oklahoma City Auction, for medium and large frame #1 feeder steers weighing 364 to 409 kg (800 to 900 lb). The total feed consumed by each pen was multiplied by monthly prices for dry feed, feed markup, and yardage from the Central Plains region, which were averaged into a mean price of $406.95/ 907 kg (2000 lb) dry feed (CattleFax, 2022).

Standardized processing costs were used for all blocks, where products and prices were sourced from PBS Animal Health on December 15, 2022, and dosage to estimate price/animal was calculated based on manufacturer recommendations and a 364 kg animal weight. The processing products and prices per animal were: a modified-live antiviral vaccine at $1.50/animal (Bovi-shield Gold 5, Zoetis), an oral anthelmintic at $1.93/animal (Safeguard, Merck Animal Health), an injectable parasiticide at $2.47/animal (Dectomax, Zoetis Animal Health, Parsippany, NJ), a topical insecticide at $0.97/animal (Clean-up_II, Elanco Animal Health, Greenfield, IN), two ear tags for identification at $1.99/animal (ATag, Allflex, Kenilworth, NJ), initial implant at $3.13/animal (Synovex Choice, Zoetis), a re-implant at $3.82/animal (Synovex Plus, Zoetis), and an assumed $1.50/animal chute charge for equipment and labor at both initial processing and re-implant. The total processing cost per animal was $18.82.

Morbidity costs were estimated at $23.60/treatment charge (USDA-NAHMS, 2013) and were multiplied by the number of animal treatments in each pen. An estimated cost for rendering a dead animal was used for all dead animals, at $38.24 (Horton et al., 2023).

As described by Horton et al., 2021, a percentage of the national dressed breaker cow (over 227 kg) price was used to estimate revenue from animals removed from the trial. Averaged national dressed Breaker cow prices from the USDA—Agricultural Marketing Service (AMS; USDA-AMS LM_CT168, 2023) based on the range of block harvest dates was $153.99/45.4 kg. A regression provided by Tatum et al. 2012, was used to estimate the HCW of removed animals. A percentage of the Breaker cow price was multiplied by the total removed animal HCW from each pen based on HCW category (Horton et al., 2021).

The price for the live sale scenario was $157.77/45.4 kg multiplied by the total shrunk pen BW for estimated revenue for live cattle sales. These numbers are representative values of steers expected to grade over 80% choice, and sold live (free-on-board) based on the average weekly prices of the timeframe the steers were harvested (USDA-AMS LM_CT150, 2023). For dressed-fed cattle sales, the base price was the live-fed price stated above divided by a common 63.5% dressed yield, or $248.46/45.4 kg. Using carcass-based premiums and discounts (YG, QG, and weight) the base dressed revenue was adjusted by using an average of prices reported by the USDA-AMS (USDA-AMS LM_CT169, 2023). The premiums per 45.4 kg for Prime, YG 1, and YG 2 carcasses were $24.20, $5.10, and $2.10, respectively. The discounts per 45.4 kg for Select, Standard, YG 4, YG 5, HCW under 249 kg, and HCW over 476 kg were −$22.60, −$34.60, −$10.10, −$13.80, −$30.80, and −$16.70, respectively. The total revenue from animals sold on a dressed basis was calculated by multiplying the premium and discount prices with the total pen HCW that fell in each category (e.g., Prime price multiplied by Prime HCW). These additions and subtractions from the base dressed revenue contributed to the overall total revenue for the pen. The parameters and prices used in the partial budget are in Appendix Table A.

Production Emissions

As described in the study by Horton et al. (2023), the Uplook 1.0 (Elanco Animal Health) system was used to estimate emissions based on calculated carbon dioxide equivalents (CO_2e). These calculations for greenhouse gas emissions from agricultural practices incorporate methodologies from the U.S. Department of Agriculture USDA (2014), the Intergovernmental Panel on Climate Change (Dong et al., 2019), and the U.S. Environmental Protection Agency (EPA; US EPA, 2022). Briefly, incoming calf estimates were assumed to represent the carbon footprint of animals prior to their arrival at the feedlot. Breed and initial BW were primary factors for incoming calf estimates in addition to estimated enteric methane, manure, fertilizer used for pastures, supplemental feed, and on-farm fuel and electricity usage, including for cattle transport to the feedlot. For this study, these were identical values for animals with equal BW. Differences in BW were assumed to represent differences in days of life (and emissions) prior to the feedyard. The feedlot model inputs were based on data from the feedlot trial and included feed impacts, feedlot energy use, methane and nitrous oxide from manure, animal enteric methane, *n* animals enrolled, total initial BW, animal days, animal removals and mortalities, *n* final animals, final BW, and HCW. The final values of CO_2e were described per unit of beef production (live BW and HCW), and per animal enrolled (Horton et al, 2023).

Statistical Analyses

Data were analyzed as a randomized complete block design. For all analyses pen was the experimental unit with cumulative pen-level outcome data from the entire feeding period to reflect common measures used in commercial feedlots (close-outs). The fixed effect was treatment (EXP or OPT) and block was included as a random intercept term. General and generalized linear mixed models (Proc GLIMMIX SAS 9.4; SAS Institute Inc., Cary, NC) were fit to evaluate treatment effects on response variables of interest. Continuous outcomes (BW, ADG, DMI, and G:F; performance and non-categorical carcass data) were analyzed using linear mixed models. Morbidity and mortality measures were analyzed with binomial distributions and a logit link function with the same fixed and random effects. Categorical (YG, QG, and MS) data were analyzed similarly, but with multinomial distributions and a cumulative logit link function accounting for the ordinal responses (Osterstock et al., 2010). Additionally, data on daily DMI during the last 59 d preharvest was evaluated using a linear mixed model with fixed effects of day, treatment, and treatment × day, and an autoregressive covariance structure to account for repeated measures (within blocks) on pens over time. Model-adjusted means and standard errors are reported (following back-transformation for generalized models). For all analyses, significance was declared between treatments at $\alpha \leq 0.05$.

Results

There was an average of 105 steers/pen (range of 70 to 142). Six pens (3 blocks) were harvested on January 12th, 2023; eight pens (four blocks) were harvested on January 19th, 2023; and the remaining six pens (three blocks) were harvested on February 10th, 2023. The average days on trial was 167 and ranged from 157 to 172. Initial BW did not differ significantly between treatments ($P = 0.70$).

Health and Mobility

There was no evidence of a difference between treatments for any measured health outcomes during the entire feeding period (Table 2); this includes morbidity treatment categories including respiratory, digestive, and other (all $P \geq 0.34$). Mortalities of all categories (respiratory, digestive, other) were not significantly different between treatments either ($P \geq 0.61$). Total removals, both animals that died and those that were removed from the study for health reasons, were 1.61% for EXP and 1.70% for OPT ($P = 0.89$). The animal mobility results are also summarized in Table 2. The distributions of mobility scores for each treatment did not differ significantly ($P = 0.09$). A vast majority of all animals had a score of 1 (2,005/2,081), and over 99% of all animals in the trial scored a 1 or 2 (2,066/2,081).

Feedlot Performance

Feedlot growth performance characteristics are outlined in Table 3. BW gain and feed conversion metrics were calculated using two methods; (1) with dead and removed animals excluded (DRO) and (2) with dead and removed animals included (DRI). Overall, growth performance was improved (P values < 0.05) in cattle receiving EXP compared to OPT (Table 3). Using DRO calculations, final

Table 2. Results of mixed models analyses of cumulative health outcomes and mobility scores from steers that received lubabegron (EXP) or ractopamine hydrochloride (OPT)[†]

	Treatment[‡]		
Item	EXP	OPT	*P*-value
Total morbidity, % (SEM)			
Pulled once	2.45 (0.49)	2.74 (0.52)	0.68
Pulled twice	0.57 (0.23)	0.66 (0.25)	0.83
Pulled three times	0.57 (0.29)	0.41 (0.23)	0.57
Treatment category, % (SEM)			
Respiratory	1.61 (0.39)	1.80 (0.41)	0.79
Digestive	0.17 (0.13)	0.34 (0.20)	0.43
Musculoskeletal/trauma	0.70 (0.31)	0.63 (0.29)	0.84
Other	0.08 (0.08)	0.21 (0.16)	0.34
Mortality, % (SEM)			
Respiratory	0.47 (0.21)	0.28 (0.16)	0.61
Digestive[‖]	—	—	
Musculoskeletal/trauma[‖]	—	—	
Other	0.47 (0.21)	0.47 (0.21)	1.00
Total removals, % (SEM)	1.61 (0.39)	1.70 (0.40)	0.89
Veterinary medicine cost, $/animal			
Processing	13.36 (0.17)	13.42 (0.17)	0.20
Treatment	0.67 (0.18)	0.87 (0.18)	0.42
Mobility score[$], % (*n*)			0.09
1, % (*n*)	95.39 (994)	97.31 (1011)	
2, % (*n*)	3.55 (37)	2.31 (24)	
3, % (*n*)	1.06 (11)	0.38 (4)	
4, % (*n*)	0 (0)	0 (0)	

[†]Trial was conducted as a randomized complete block design at 1 feedlot in Kansas, USA using steer blocks. A total of 2,081 steers were randomly allocated to one of two pens to form a block, and pens were randomly assigned to treatment (EXP or OPT).
[‡]Treatments are: EXP, Experior delivered to target 36 mg/animal/d consumption; and OPT, Optaflexx delivered to target 300 mg/animal/d consumption.
[‖]Data were too sparse for analyses by appropriate statistical models.
[$]Cattle mobility was scored by trained observer using a 4-point scale from the North American Meat Institute (NAMI, 2015) as animals exited trucks into the pen for antemortem inspection at the processing plant. Score 1, normal, walks easily, no apparent lameness, no change in gait; Score 2, exhibits minor stiffness, shortness of stride, slight limp, keeps up with normal cattle; Score 3, exhibits obvious stiffness, difficulty taking steps, obvious limp, obvious discomfort, lags behind normal cattle; Score 4, extremely reluctant to move even when encouraged by a handler, statue-like.

BW increased by 9 kg ($P < 0.01$), ADG increased by 3.26% ($P < 0.01$), DMI decreased by 3.67% ($P = 0.01$), and gain efficiency improved by 6.59% ($P < 0.01$) for cattle receiving EXP compared to OPT (Table 3). During the last 59 d preharvest, daily DMI was significantly associated with the main effects of treatment ($P < 0.01$; EXP = 10.68 ± 0.138, OPT = 11.05 ± 0.138) and study day ($P < 0.01$), but there was no evidence ($P = 0.92$) for treatment by day interaction. Using DRI calculations ADG increased 2.25% ($P = 0.03$), DMI decreased 3.64% ($P = 0.01$), and gain efficiency improved 6.06% ($P < 0.01$) in cattle receiving EXP compared to OPT (Table 3).

Carcass Characteristics

Carcass characteristics are summarized in Table 4. There were differences between treatments for all outcomes except for 12th-rib fat thickness ($P = 0.13$). HCW increased by 10.92 kg ($P < 0.01$), dressing percentage increased by 0.72% ($P < 0.01$), REA increased by 4.51cm^2 ($P < 0.01$), marbling score decreased 23 units (Table 4; $P < 0.01$), and calculated YG decreased 0.19 points ($P < 0.01$) for cattle receiving EXP compared to OPT.

Yield grade distributions were different ($P = 0.01$) between treatments. The EXP cattle had greater frequency of YG 1, 2 , and 3 carcasses compared to OPT, while YG 4 and 5 carcasses were fewer. Quality grade distributions were evaluated using two different methods; (1) using the QG reported by the packing plant or (2) using QG based on marbling score. The latter was done to evaluate upper 2/3 and bottom 1/3 choice distributions. For both methods, the quality grade distributions differed ($P < 0.01$) between treatments. The shifts in the distributions were similar for both methods, where cattle receiving EXP had fewer Prime and Choice carcasses and more Select and sub-select carcasses compared to cattle receiving OPT. Cattle receiving EXP had fewer Prime and Upper 2/3 Choice carcasses, and more Bottom 1/3 Choice, Select, and sub-Select carcasses compared to cattle receiving OPT.

Economic Assessment

Results from the partial budget comparisons between the treatments are in Table 5, where the main budgetary components are shown. The average purchase price per animal did not significantly differ between treatments ($P = 0.70$), due to similar initial BW (Table 5). The OPT cattle had

Table 3. Model adjusted means and standard errors of the mean (SEM) for feedlot performance outcomes from steers that received lubabegron (EXP) or ractopamine hydrochloride (OPT)*

	Treatment†			
Item	EXP	OPT	SEM	*P*-value
Initial body weight, kg	373	374	5	0.70
Dead and removed animals excluded§				
Final body weight‡, kg	680	671	4	<0.01
Dry matter intake, kg/d	11.01	11.43	0.11	0.01
Average daily gain, kg/d	1.84	1.78	0.01	<0.01
Gain:feed	0.167	0.156	0.0018	<0.01
Dead and removed animals included#				
Final body weight‡, kg	671	665	4	0.06
Dry matter intake, kg/d	10.83	11.24	0.10	0.01
Average daily gain, kg/d	1.78	1.74	0.01	0.03
Gain:feed	0.165	0.155	0.0019	<0.01

*Trial was conducted as a randomized complete block design at 1 feedlot in Kansas, USA using steer blocks. A total of 2,081 steers were randomly allocated to one of two pens to form a block, and pens were randomly assigned to treatment (EXP or OPT).
†Treatments are: EXP, Experior delivered to target 36 mg/animal/d consumption; and OPT, Optaflexx delivered to target 300 mg/animal/d consumption.
‡A 4% shrink was applied to final body weight (i.e., body weight × 0.96).
§Performance outcomes calculated on the basis of all animals removed from the trial and mortalities excluded from the denominator.
#Performance outcomes are calculated on the basis where all animals enrolled in the trial are included in the denominator.

Table 4. Model adjusted means and standard errors of the mean (SEM) for carcass characteristics from steers that received lubabegron (EXP) or ractopamine hydrochloride (OPT)*

	Treatment†			
Item	EXP	OPT	SEM	*P*-value
Hot carcass weight, kg	442	431	5.8	<0.01
Dressed yield, %	64.87	64.15	0.15	<0.01
Longissimus muscle area, cm^2	95.74	91.23	0.71	<0.01
12th-rib fat thickness, cm	1.65	1.68	0.03	0.13
Marbling score‡	500	523	4.3	<0.01
Calculated yield grade	3.44	3.63	0.05	<0.01
USDA yield grade§, count (% of treatment group)				0.01
1	34 (3.27)	24 (2.31)		
2	264 (25.38)	199 (19.17)		
3	519 (49.90)	487 (46.92)		
4	194 (18.65)	293 (28.23)		
5	29 (2.79)	35 (3.37)		
USDA quality grade§, count (% of treatment group)				0.01
Prime	26 (2.50)	50 (4.82)		
Choice	856 (82.31)	882 (84.97)		
Select	142 (13.65)	96 (9.25)		
Sub-select	16 (1.54)	10 (0.96)		

*Trial was conducted as a randomized complete block design at 1 feedlot in Kansas, USA using steer blocks. A total of 2,081 steers were randomly allocated to one of the two pens to form a block, and pens were randomly assigned to treatment (EXP or OPT).
†Treatments are: EXP, Experior delivered to target 36 mg/animal/d consumption; and OPT, Optaflexx delivered to target 300 mg/animal/d consumption.
‡Scores ranging from 500 to 600 indicate a modest degree of marbling.
§*P*-value from multinomial (ordinal) regression testing the null hypothesis that the proportions of carcasses distributed across categories are equal between treatments; values are raw frequency statistics.

increased feed and yardage costs of almost \$31 per animal enrolled ($P = 0.02$). On a live sale basis, EXP cattle received approximately \$24 more revenue per animal ($P = 0.03$), and approximately \$31 more per carcass ($P < 0.01$) compared to OPT on a dressed sale basis. The average net return for EXP cattle was almost \$61 more than OPT ($P < 0.01$) on a dressed sale basis, and nearly \$57 more than OPT ($P < 0.01$) on a live sale basis.

Production Emissions

The calculated estimates of carbon dioxide equivalent (CO_2e) emissions from various sources linked to trial cattle production

Table 5. Model adjusted means, mean difference (MD), standard errors of the mean difference (SED), and standard errors of the mean (SEM) for economic outcomes from a partial budget assessment*,‡ of steers that received lubabegron (EXP) or ractopamine hydrochloride (OPT)

Item	Treatment†		MD	SED	SEM	*P*-value
	EXP	OPT				
Purchase cost, \$/animal enrolled‖	1,432.7	1,435.2	−2.44	6.1	19.88	0.70
Feed and yardage cost, \$/animal enrolled$	811.59	842.45	−30.86	11.2	9.96	0.02
Cost of gain, \$/animal enrolled¶	1.25	1.33	−0.09	0.01	0.02	<0.01
Total cost, \$/animal enrolled	2,303.2	2,336.3	−33.15	12.1	20.91	0.02
Live sale basis revenue, \$/animal**	2,366.9	2,343.4	23.46	9.2	13.63	0.03
Dressed sale basis revenue, \$/carcass††	2,339.6	2,308.8	30.76	9.22	12.04	<0.01
Net return—live basis, \$/animal‡‡	63.7	7.1	56.61	9.37	12.94	<0.01
Net return—dressed basis, \$/carcass‡‡	31.4	−29.3	60.67	12.6	13.70	<0.01

*Trial was conducted as a randomized complete block design at 1 feedlot in Kansas, USA using steer blocks. A total of 2,081 steers were randomly allocated to one of two pens to form a block, and pens were randomly assigned to treatment (EXP or OPT).
†Treatments are: EXP, Experior delivered to target 36 mg/animal/d consumption; and OPT, Optaflexx delivered to target 300 mg/animal/d consumption.
‡The partial budget used cattle market prices reflective of the time the trial occurred, August 2022 through February 2023.
‖Feeder steer price = \$172.24/cwt.
$Price includes dry feed, feed markup, and yardage from the central plains; \$406.95/ton.
¶Live fed price for steers = \$157.77.
**Weekly negotiated steer price, live free-on-board, over 80% Choice, from USDA-AMS report (LM_CT150) 5 area weekly weighted average direct slaughter cattle.
††Weekly negotiated steer price, dressed delivered, over 80% Choice, from USDA-AMS report (LM_CT150) 5 area weekly weighted average direct slaughter cattle; used as dressed base price that carcass-based premiums and discounts were then applied to. Weekly premiums and discounts that were applied to actual pen-level carcass weights from each category after accounting for the dressed base price, from USDA-AMS report (LM_CT169) 5 area weekly slaughter cattle—premiums and discounts.
‡‡Net return, total pen revenue—total pen costs; then divided by the number of cattle shipped or carcasses graded.

are displayed in Table 6. In the pre-feedlot, calf production phase there was no evidence of a difference in estimated CO_2e emissions ($P = 0.66$) due to the identical sources and similar initial BW of animals between treatments. For both the feedlot phase and the total lifecycle CO_2e emissions, the OPT cattle generated more estimated CO_2e emissions (per animal enrolled) than the EXP cattle ($P \leq 0.02$). In the finishing phase, OPT-fed cattle produced more estimated CO_2e emissions in feedlot operations ($P = 0.03$; includes emissions associated with the production of dry feed ingredients, commodity trucking, and fuel and utilities), manure ($P = 0.01$), and enteric methane ($P = 0.02$) compared to EXP fed cattle. In total, the factors contributing to the feeding phase emissions resulted in an estimated 69.3 kg more CO_2e emitted for OPT cattle than EXP ($P = 0.02$). Thus, subsequent differences were observed for the total finishing period CO_2e per kg of final BW ($P < 0.01$) and HCW ($P < 0.01$). Finally, the total lifecycle CO_2e estimated emissions were greater for OPT than EXP per animal enrolled ($P < 0.01$), per unit of final BW ($P < 0.01$), and HCW ($P < 0.01$; Table 6).

Discussion

This first publication on commercial feedlot steers fed lubabegron or ractopamine hydrochloride demonstrated significant differences in multiple outcomes of importance to the industry. Lubabegron has no claims for increasing the performance of steers, only for reducing ammonia emissions, yet several important performance differences were demonstrated here. Ractopamine hydrochloride has performance claims of increased rate of weight gain, improved feed efficiency, and increased carcass leanness, but those are in comparison to a negative control.

The approval for the use of lubabegron was completed in two clinical registration studies at differing days (14 or 91) and feeding dosages (1.4 or 5.5 mg·kg^{-1}; FDA-FOI, 2018). The first commercial large pen trial evaluated the health and performance outcomes of cattle fed differing dosages of lubabegron (0, 1.4, 3.5, or 5.5 mg·kg^{-1}) during the last 56 d of the feeding period (Kube et al., 2021). Though the previous studies evaluated different dosages and days of feeding lubabegron, as opposed to comparing to a different product as in the current study, similar outcomes were identified for cattle-fed lubabegron. Previous studies also demonstrated no significant adverse health effects associated with feeding lubabegron (FDA-FOI, 2018; Kube et al., 2021). Cattle mobility was a concern with the expected increased final BWs and was evaluated with the same mobility scoring system used here (NAMI, 2015) in the first commercial large pen study (Kube et al., 2021), which also demonstrated that mobility did not differ significantly between treatments. Factors that have been attributed to fed cattle mobility issues include the intensity of handling, heat stress, transportation and lairage conditions, and subclinical laminitis, in addition to increased slaughter weights and DOF (Bernhard et al., 2014; Burson, 2014; Boyd et al., 2015; Thomson et al., 2015; Hagenmaier et al., 2017a, 2017b; Mijares et al., 2021).

As this is the first known published paper describing a comparison of lubabegron and ractopamine hydrochloride, available literature for comparison is minimal. Though there are no label claims for animal performance for lubabegron, both this study and previous studies (FDA-FIO, 2018; Kube et al., 2021) found an increased BW and HCW for steers fed lubabegron as compared to a negative control or steers fed ractopamine hydrochloride. The previous large pen study also demonstrated a dose–response, where an increasing dosage of lubabegron fed during the last 56 d of the feeding period increased dressing percentage and decreased marbling score, yield grade, and quality grade (Kube et al., 2021). Additionally, performance outcomes for cattle-fed lubabegron compared to a control in a previous large pen study included greater DMI,

Table 6. Model adjusted means and standard errors of the mean (SEM) for calculated estimates of carbon dioxide equivalent (CO_2e) emissions from the production of steers that received lubabegron (EXP) or ractopamine hydrochloride (OPT)[*,†]

Item	Treatment		SEM	*P*-value
	EXP	OPT		
Pre-feedlot calf footprint[‡]				
Per animal enrolled	6,541.1	6,545.6	32.12	0.66
Feedlot finishing footprint[‖], kg CO_2e				
Feedlot operations[$], per animal enrolled	921.7	954.8	10.62	0.03
Manure[¶], per animal enrolled	396.7	414.7	4.84	0.01
Enteric methane[**], kg of CO_2e per animal enrolled	488.5	506.7	5.71	0.02
Total finishing[††], animal enrolled	1,806.9	1,876.2	21.09	0.02
Total finishing[††], per kg final BW	2.69	2.82	0.03	<0.01
Total finishing[††], per kg HCW	4.08	4.35	0.06	<0.01
Total footprint[‡‡], kg CO_2e				
Per animal enrolled	8,348.0	8,421.8	31.07	<0.01
Per kg final BW	12.49	12.76	0.048	<0.01
Per kg HCW	19.26	19.89	0.089	<0.01

[*]Trial was conducted as a randomized complete block design at 1 feedlot in Kansas, USA using steer blocks. A total of 2,081 steers were randomly allocated to one of the two pens to form a block, and pens were randomly assigned to treatment (EXP or OPT).
[†]Treatments are: EXP, Experior delivered to target 36 mg/animal/d consumption; and OPT, Optaflexx delivered to target 300 mg/animal/d consumption.
[‡]Calculated estimate of the total CO_2e generated from each calf (from cow-calf production until feedlot purchase) based on incoming animal weight and breed.
[‖]Calculated estimates of CO_2e generated during the finishing phase (trial period).
[$]Calculated estimates of CO_2e generated from the production of dry feed ingredients, commodity trucking, and fuel and utilities at the feedlot.
[¶]Calculated estimates of the total CO_2e associated with manure, which includes: manure methane, direct manure NO2, indirect manure N_20 from volatilization, and indirect manure N_20 from leaching and runoff.
[**]Calculated estimates of CO_2e enteric methane produced by the animal.
[††]Sum of estimated CO_2e generated during the finishing period from feedlot operations, manure, and enteric methane.
[‡‡]Total calculated estimates of CO_2e from the pre-feedlot calf footprint and finishing period footprint.

ADG, and G:F (Kube et al., 2021). The current study had similar outcomes as Kube et al. (2021) for ADG, G:F, health outcomes, and carcass characteristics, but for EXP compared to OPT rather than compared to a negative control. However, a lower DMI was observed in this study for the lubabegron-fed cattle. When the daily DMI data were evaluated for the last 59 d on feed, the results demonstrated that the difference in the pen-level cumulative (close-out) DMI data from the entire feeding period (Table 3) was not due to an interaction of DMI by days at the end of the feeding period. These results demonstrate that lubabegron can increase animal growth performance, even when being compared to a product that is specifically labeled for growth performance.

The increased net returns for EXP cattle were primarily due to less feed consumed and increased BW and HCW, which also had a positive impact on estimated emissions. In a previous trial, the lubabegron label claim for reduced ammonia emissions was verified with calculated estimated ammonia emissions (Kube et al., 2021) and demonstrated that feeding lubabegron compared to a negative control resulted in decreased ammonia emissions. Although the emissions in this study were estimated CO_2e and there was a different treatment group for comparison, the CO_2e estimates from this study also show decreased emissions compared to ractopamine hydrochloride.

Distinctions in the mechanism of action between lubabegron and ractopamine hydrochloride may explain the observed differences in performance outcomes. While lubabegron has a core structure of phenylethanolamine, ractopamine hydrochloride exhibits a phenethanolamine moiety structure (Dilger et al., 2021). Lubabegron binds and activates β3 receptors found in muscle and adipose tissue and throughout the body but acts as an antagonist to β1 and β receptors (FDA-FOI, 2018). In contrast, ractopamine hydrochloride only binds to β1 and β2 receptors throughout the body including muscle and adipose tissue (FDA-FOI, 2003).

This study was limited to a single feedlot, in one geographic region, with a specific cattle type. While these results may be representative of cross-bred beef steers fed in Central KS, extrapolating these findings to other cattle types, heifers, and different geographic areas necessitates further investigation. Furthermore, the number of days from harvest in which lubabegron may be fed is variable and could subsequently result in variation in observed outcomes.

Lubabegron (Experior) is a new β-modulator feed additive on the market and the potential effects on carcass characteristics, animal performance, mobility, and health and are of interest. There was no evidence that lubabegron had any negative impacts on cattle health or mobility. However, there were important differences between treatments for live and carcass performance. The EXP treatment led to noteworthy enhancements in numerous live performance parameters including FBW, ADG, and DMI, when compared to OPT. In addition, several important carcass attributes were affected, particularly regarding leanness and the distributions of yield and QG. These differences in yield and quality grade distributions could have important implications on a beef producer's grid specifications, total DOF, and targeted FBW. Furthermore, a noteworthy potential environmental implication was observed with a reduction of estimated CO_2e emissions. Thus, EXP has the potential to enhance cattle performance and economic gains, as well as mitigate the carbon footprint associated with cattle production.

Conclusion

In conclusion, when cattle were fed for the same total number of days, feeding EXP compared to OPT increased net returns, feedlot performance, and efficiency in live animals, but resulted in carcass yield and quality characteristics that may impact beef marketing programs. These observed shifts in outcomes potentially could be altered by manipulating the duration of feeding EXP and/or the total DOF. Considering the potential impacts of feeding EXP, it appears prudent to conduct further research aimed at optimizing a specific set of end-point criteria such as HCW and grid marketing targets to harness the potential benefits.

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Conflict of interest statement

One author (NB) is an employee of Elanco Animal Health, but he had no role in the design or implementation of the study; he calculated estimated emissions for de-identified lots (i.e., was masked to treatments). Other authors (DR, BD) have previously received funding from Elanco Animal Health for research or consulting work.

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