Effects of various ractopamine hydrochloride withdrawal periods on performance, health, and carcass characteristics in yearling steers

Tony C. Bryant,[†] Josh I. Szasz,[†] Lois F. G. Pringle,[†] Eddie Crispe,[†] K. Shawn Blood,[‡] Bryan C. Bernhard,[‡] and Heather D. Hughes[‖,1]

[†]Five Rivers Cattle Feeding, Johnstown, CO 80534; [‡]Beef Strategic Technical Services, Zoetis, Parsippany, NJ 07054; and [‖]SciWrite Consulting, LLC, Canyon, TX 79015

ABSTRACT: Ractopamine hydrochloride (RAC) is a β-adrenergic agonist approved for feeding during the last 28 to 42 d prior to cattle slaughter to improve feedlot performance and carcass characteristics. Three thousand crossbred yearling steers (527 ± 2.4 kg; AVG ± SD) were used in two periods to evaluate the effects of various RAC withdrawal times on feedlot performance, health, and carcass characteristics. In Period 1, 6 blocks of 30 pens totaling 1,500 steers were utilized, which was repeated for Period 2. In a randomized complete block design, cattle were assigned to 1 of 5 treatments consisting of 1) No RAC fed (CON), 2) 12-h RAC withdrawal (12-hRAC), 3) 2-d RAC withdrawal (2-dRAC), 4) 4-d RAC withdrawal (4-dRAC), and 5) 7-d RAC withdrawal (7-dRAC). Cattle were fed for a total of 62 d, and applicable treatments were supplemented with 30.0 ppm (dry matter basis) of RAC (average dose = 322 mg per steer per day) for 33 d at the end of the feeding period, corresponding to their respective withdrawal times. Initial body weight (BW) displayed a quadratic curve, with 2-dRAC and 4-dRAC withdrawal periods having the greatest BW. Accordingly, dry matter intake (DMI) responded quadratically (P = 0.034), with 2-dRAC and 4-dRAC treatments demonstrating the greatest DMI. No significant treatment differences ($P \geq 0.641$) were observed in final live BW, average daily gain (ADG), or feed efficiency. Alternatively, when using a common dressing percentage to calculate live BW, cattle on RAC treatments exhibited 7.6 kg additional live BW ($P < 0.001$) compared to CON cattle. Furthermore, carcass-adjusted ADG and feed efficiency did not differ ($P > 0.10$) between RAC treatments but were improved compared to the CON treatment ($P \leq 0.002$). Hot carcass weight (HCW) was on average 4.9 kg greater ($P < 0.001$) for RAC treatments vs. CON, and no differences were detected ($P > 0.10$) among RAC treatments. Within RAC treatments, carcass cutability responded quadratically ($P \leq 0.005$) to withdrawal period, with the 2-dRAC and 4-dRAC treatments containing more Yield Grade 4 and 5 and fewer Yield Grade 1 and 2 carcasses than the other RAC treatments. On the basis of the results of this experiment, feeding RAC improves dressing percentage, HCW, and carcass-adjusted BW, ADG, and feed efficiency. Furthermore, extending the RAC withdrawal period to 7 d does not have a significant impact on cattle performance or health and has minimal effects on carcass characteristics.

Key words: beta-agonist, cattle, ractopamine hydrochloride, withdrawal

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[1]Corresponding author: heather@sciwriteconsulting.com

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INTRODUCTION

Ractopamine hydrochloride (RAC) is a β-adrenergic agonist that is FDA approved for feeding cattle in the United States during the last 28 to 42 d of the finishing period (Davis and Belk, 2018). Beta-agonists are efficacious to promote cattle growth and improve feed efficiency (Kootstra et al., 2005) by binding to β-adrenergic receptors within cellular membranes and stimulating decreased fat synthesis (lipogenesis) and increased fat mobilization (lipolysis; Mersmann, 1998; Dunshea et al., 2005; Johnson, 2014). Simultaneously, these compounds increase muscle mass as a result of increased protein synthesis and decreased muscle protein degradation (Mersmann, 1998; Neumeier and Mitloehner, 2013). Numerous studies have demonstrated improvements in feedlot performance and carcass composition when feeding RAC to finishing beef steers (Scramlin et al., 2010; Bittner et al., 2015; Genther-Shroeder et al., 2016).

The importance of production technologies such as RAC to meet the demands of the growing global population cannot be overstated. On a worldwide level, livestock products account for 28% of protein in diets consumed (USDA-NIFA, 2018), and the population is estimated to reach 9.8 billion people by the year 2050: a 29% increase in approximately 30 yr (Gerland et al., 2014; UN-ESA, 2017). Currently, RAC has a "practical 0-d pre-slaughter withdrawal period" (12 h); however, extended withdrawal periods and their effects on cattle performance have rarely been examined. It may be of interest to cattle producers to understand the effects of various extended withdrawal periods as they develop marketing and/or management decisions, in order to determine what level of flexibility exists while maintaining performance benefits of β-agonists. On the basis of the body of peer-reviewed literature, we hypothesized that RAC would improve feedlot performance and carcass characteristics relative to CON cattle. Furthermore, we hypothesized that extending RAC withdrawal period up to 7 d would not diminish feedlot performance or carcass traits. Limited research exists, which has observed the effects of extended withdrawal periods of β-agonists on feedlot performance, health, and carcass characteristics. Therefore, the objectives of this experiment were to examine the effects on these variables when extending the RAC withdrawal period up to 7 d prior to slaughter, in addition to examining the effects of RAC on feedlot performance and carcass characteristics relative to CON animals.

MATERIALS AND METHODS

Cattle and Processing

One experiment with two periods was conducted for a combined total of 12 blocks, containing 60 pens total, utilizing 3,000 yearling steers at a feedyard in LaSalle, CO. The experiment followed an approved protocol whereby routine management practices of the commercial feedlot are in accordance with 7 United States Code 54 and National Agricultural Statistics Service (2010).

Block assignment for Period 1 began on August 2, 2017, and was completed the next day on August 3, 2017. Cattle were moved to the processing barn, sorted by body weight (BW), and those within a BW range of 477 to 604 kg were considered eligible for Period 1. Upon randomization, all cattle underwent a processing regimen which included vaccination against infectious bovine rhinotracheitis (2 mL, s.c.; Bovi-Shield IBR; Zoetis, Inc., Parsippany, NJ) and placement of a unique EID ear tag and lot tag. At the time of initiation of Period 1, cattle averaged 107 d on feed (DOF) and had previously received a growth implant containing 200 mg trenbolone acetate and 40 mg estradiol (Revalor-XS; Merck Animal Health, Madison, NJ) in addition to standard vaccination and anthelmintic protocol when they were initially processed, approximately 107 d prior to Period 1 initiation.

Block assignment for Period 2 began on October 17, 2017 and was completed the next day on October 18, 2017. As in Period 1, cattle were moved to the processing barn, sorted by BW, and those within a BW range of 499 to 590 kg were considered eligible for Period 2. Upon randomization, all cattle underwent a processing regimen that included vaccination against infectious bovine rhinotracheitis (2 mL, s.c.; Bovi-Shield IBR; Zoetis, Inc.) and placement of a unique electronic identification (EID) ear tag and lot tag. At the time of initiation of Period 2, cattle averaged 55 DOF and had previously received a growth implant containing 200 mg trenbolone acetate, 20 mg estradiol, and 29 mg tylosin tartrate (Component TE-200 with Tylan; Elanco Animal Health, Greenfield, IN) in addition to standard vaccination and anthelmintic protocol when they were initially processed, approximately 55 d prior to Period 2 initiation.

Treatment Assignment and Experimental Design

For Periods 1 and 2, cattle within each pen were assembled from multiple sources, and cattle

from each source were randomly assigned to treatment within a block for a randomized complete block design with pen as experimental unit. A predetermined randomization schedule was used to assign treatments to corresponding groups within blocks. This predetermined pattern was utilized for all groups. Cattle were randomized according to the following procedure. Cattle were alternated through the chute in a 1 × 1 × 1 × 1 × 1 fashion into the five groups as cattle were processed, then placed in lots with respective treatments as lots were filled. Pen weights were collected across a platform scale following lot completion, and a standard 3% pencil shrink was applied when determining initial BW.

Once cattle were weighed and placed in pens, the acclimation period began. All cattle had a minimum 21 d acclimation period, and all cattle fed RAC (12-hRAC, 2-dRAC, 4-dRAC, and 7-dRAC) received RAC for the same length of time (33 d), although withdrawal times varied based on treatment. Table 2 depicts the precise day of the 62-d feeding period that each treatment began RAC supplementation. For both Periods 1 and 2, final live BW was collected at the feedyard using a truck platform scale at the time of shipment to the packing plant. Each semi-trailer was weighed empty, loaded with cattle from a single treatment, and weighed with cattle. A standard 4% pencil shrink was applied for final live BW calculation. For Period 1, cattle were harvested October 3 to 4, 2017. For Period 2, cattle were harvested December 19 to 20, 2017. All cattle were harvested at the same packing plant in Greeley, CO.

Animal Health

All cattle enrolled in the experiment were observed daily for general health by pen riders who were blinded to treatment assignment. When possible, a single pen rider examined all pens within a block, and all pulled animals within a block were treated at the same hospital facility. Sick cattle were removed from their home pen and walked to a hospital facility.

Standard feedyard protocols were used for treatment of diseases and were consistent for all cattle enrolled in the study. Cattle were allowed to convalesce in hospital pens for a minimum of 24 h prior to returning to respective home pens. Upon treatment of sick animals, information pertaining to lot, home pen, individual animal identification, date of treatment, diagnosis, rectal temperature, BW, medication(s) administered (including dose), and pen moves were recorded into the animal management software.

Mortalities were subjected to postmortem examination by a licensed veterinarian or trained personnel. Information obtained at the time of postmortem examination included individual animal identification, date of mortality, cause of death, and secondary observations when applicable.

Feeding and Milling

Bunk management and ration composition were treated similarly for all cattle with the exception of RAC addition and removal, due to the variation in treatments. Cattle were fed on a regular schedule, and all pens were delivered feed twice per day. The following feed additives were targeted based on concentration (ppm). Monensin sodium (Elanco Animal Health) was fed to provide 38.5 ppm in the finishing diet (actual = 413 mg/d), and tylosin phosphate (Huvepharma, Peachtree City, GA) was fed to provide 9.7 ppm [dry matter (DM) basis; actual = 104 mg/d]. Treatment diets containing RAC (Actogain; Zoetis, Inc.) were formulated to contain 30.0 ppm RAC on a DM basis for an average of dose of 322 mg per steer per day. Metal barriers were placed inside bunks to ensure that treatment diets remained separated for each pen. A detailed description of daily feeding and flushing procedures are described subsequently.

Pens within a statistical block were provided similar area (75 m^2 per animal) and bunk space (38.4 cm per animal) and were oriented in the same direction, with pen floor slope in the same direction. All pens contained 50 animals per pen at trial initiation.

Withdrawal Feed Calling

All cattle within Periods 1 and 2 were slaughtered on two consecutive days. On the day prior to slaughter, the daily feed assignment was adjusted to target all feed being consumed by 1800 h for slaughter at 0600 h the next morning. This ensured that the cattle on the 12-h treatment had a minimum 12-h withdrawal and that all treatments were managed equally. All treatments had a target slick bunk time of 1800 h on the night prior to slaughter. If bunks were not slick by 1800 h, the remaining feed was removed from the bunk.

Flush Procedures

In the afternoon, immediately after feeding non-trial cattle in the feedyard and prior to feeding RAC, the mill produced a flush load consisting of at least 2,497 kg of silage. Once completed,

the batch operator documented completion time, the location of the completed flush load (north or south hopper), and the truck that removed the load from the hopper onto a "Feed Truck and Mill Flush Form" that was kept in the mill.

One of two designated feed trucks was responsible for removing the flush load of silage from the hopper and emptying it into a separate pile from the main silage pile to prevent cross contamination of the trial ration. That same feed truck was then loaded up with the CON ration and began feeding the CON cattle and cattle being withdrawn from RAC, when applicable. A member of management or other authorized individual accompanied the feed truck driver to verify that the pens were fed the correct ration, amount, and appropriate distribution across the bunk. As the driver was feeding, this authorized individual provided his initials next to the ration number on the bunk sheet.

Once the CON diet was fed to CON cattle and to cattle being withdrawn from RAC (when applicable), the same feed truck was loaded with the first load of ration containing RAC, which was then delivered to cattle on RAC treatments of the trial that were not yet in withdrawal period. The same authorized individual remained in the feed truck and followed the record-keeping procedures that were previously described. Following the feeding of all cattle on RAC rations, the mill was closed for the evening and the feed trucks used for the study were parked with empty feed receptacles. On the following morning, the RAC-containing ration was delivered first, in the same feed truck that fed the RAC-containing ration the prior evening. Then, several loads of the CON ration were milled and fed to non-trial cattle, to act as a mixer flush, prior to the CON ration being fed to CON cattle and cattle in the RAC withdrawal period.

Feed Sampling Procedure

Composite bunk samples of the RAC treatments and CON treatments were collected for RAC assay. Samples were collected at three different time points according to the following procedure. Samples were collected during round 1 of feeding, to ensure that no previously fed ration was in the bunk. Pens and treatments for sampling were identified, and bunks where the CON diet was being fed (CON cattle or cattle being withdrawn from RAC) were sampled first. The load was sampled and composited throughout the feed delivery. Samples were frozen and shipped overnight on ice to an analytical laboratory (Zoetis Customer Analytical Services, Chicago Heights, IL) to ensure a level of 0 ppm RAC concentration within the CON diet (minimum level of detection was 1 ppm). Dietary ingredients and chemical composition of the basal finishing ration are presented in Table 1.

Table 1. Dietary ingredients and chemical composition for the basal finishing diet used in Periods 1 and 2

Ingredient	% of diet DM
Steam-flaked corn	68.8
Corn silage	12.0
Dried distillers' grains	4.0
Steep	3.7
Whey	2.4
Tallow	4.9
Supplement[1]	4.2
Chemical composition	Mean ± SD
Crude protein, %	14.3 ± 0.58
NDF, %	14.0 ± 1.06
Ca, %	0.61 ± 0.048
P, %	0.47 ± 0.029

[1]Formulated to provide monensin (Rumensin; Elanco Animal Health, Greenfield, IN) at 38.5 ppm; tylosin (Tylovet 100; Huvepharma, St. Louis, MO) at 9.7 ppm, and RAC (Actogain; Zoetis, Parsippany, NJ) at 30.0 ppm.

Statistical Analyses

Performance and non-categorical carcass characteristics were analyzed using PROC MIXED in SAS (Version 9.4; SAS Institute, Cary, NC) as a randomized complete block design with pen as experimental unit. Treatment and period were included as fixed effects, and weight block nested within period was included as a random effect in the model.

Categorical data [e.g., morbidity, mortality, quality grade, and yield grade (YG)] were analyzed as a random complete block design using PROC GLIMMIX in SAS, with pen serving as experimental unit. Treatment and period were included as fixed effects, and weight block nested within period was included as a random effect. Tukey's statistical adjustment was implemented to account for multiple pairwise comparisons. Data were modeled with a binomial distribution of outcomes in an events/trials analysis with number of reactors (morbidity, mortality, carcass-grading categories, etc.) for each lot representing events and the original lot head count or lot slaughter count (population at-risk) representing trials.

Initial BW was included as a covariate in the model if $\alpha < 0.10$, as it was statistically different among treatments. Orthogonal contrasts were

conducted to compare the CON treatment vs. the average of the four RAC-containing treatments. Orthogonal trend analysis using coefficients to account for unequally spaced withdrawal periods was conducted via PROC IML to determine linear and quadratic treatment effects of RAC withdrawal period. Statistical differences were reported at $\alpha < 0.10$, and trends were described at $\alpha < 0.15$.

RESULTS AND DISCUSSION

Effects of RAC withdrawal on health and performance and their contrast to CON animals are presented in Table 2. Initial BW elicited a quadratic curve with the 2-dRAC and 4-dRAC withdrawal periods having the greatest numerical starting weights ($P = 0.005$). Dry matter intake (DMI) followed a similar pattern, with the greatest DMI occurring in the 2-dRAC and 4-dRAC treatments ($P = 0.034$). This outcome could be expected, as initial BW of cattle is related to average DMI during a feeding period (Koknaroglu et al., 2008; Zinn et al., 2008; NRC, 2016). Feed intake response to RAC is varied in the literature. In a meta-analysis of 31 published manuscripts with 68 sub-trials (Lean et al., 2014) where cattle were exposed to RAC for 30.8 ± d, RAC had close to zero effect on DMI with a marked variation around the mean; some studies observed significant increases in DMI due to RAC, whereas others observed significant decreases in DMI. Authors reported that none of the covariates were significant in explaining the effects on DMI. Several studies that are similar to the current experiment have reported no effect of RAC on DMI relative to controls, in the presence of increased average daily gain (ADG), generating subsequent improvements in BW gain efficiency (Bryant et al., 2010, Scramlin et al., 2010; Genther-Shroeder et al., 2016). Contrary to these findings, in the current experiment final BW, ADG, and gain-to-feed ratio (G:F) were not different on a live basis ($P \geq 0.181$) when initial BW was used as a covariate in the model.

Table 2. Effects of ractopamine withdrawal on health and performance

	Treatments[1]							Contrast[2] *P*-value		
Item	CON	12-h RAC	2-d RAC	4-d RAC	7-d RAC	SEM[3]	*P*-value	L	Q	CON vs. RAC
No. of pens	12	12	12	12	12	—	—	—	—	—
Cattle enrolled	600	600	600	600	600	—	—	—	—	—
Days on trial	62	62	62	62	62	—	—	—	—	—
Days on RAC[4]	0	33	33	33	33	—	—	—	—	—
Initial BW[5], kg	528^{xy}	525^{x}	529^{y}	528^{xy}	526^{xy}	2.4	0.046	0.850	0.005	0.722
Morbidity, %	0.82	2.14	1.48	1.81	0.99	0.617	0.581	0.174	0.738	0.190
Railers, %	0.32	0.81	0.32	0.65	0.00	0.365	0.741	0.976	0.977	0.980
Mortality, %	0.00	0.67	0.40	0.53	0.40	0.325	0.976	0.621	0.868	0.976
DMI, kg/d	10.7	10.4	10.9	10.8	10.7	0.33	0.244	0.571	0.034	0.955
RAC dosage, mg/d	0^{y}	314^{x}	328^{x}	325^{x}	321^{x}	6.2	<0.0001	0.571	0.034	<0.0001
Live basis										
Final BW[6], kg	643	646	647	646	645	3.41	0.669	0.767	0.496	0.181
ADG, kg/d	1.85	1.89	1.92	1.90	1.88	0.053	0.656	0.764	0.606	0.181
G:F	0.168	0.177	0.172	0.174	0.175	0.003	0.641	0.858	0.551	0.193
Carcass-adjusted basis[7]										
Final BW, kg	639^{y}	645^{x}	647^{x}	649^{x}	646^{x}	3.13	0.006	0.975	0.077	<0.001
ADG, kg/d	1.79^{y}	1.88^{x}	1.92^{x}	1.95^{x}	1.89^{x}	0.049	0.005	0.986	0.087	<0.001
G:F	0.165^{y}	0.180^{x}	0.174^{xy}	0.180^{x}	0.176^{x}	0.020	0.025	0.842	0.975	0.002

[1]CON = control treatment, fed no RAC; 12-h = fed RAC for 33 d with 12-h withdrawal period; 2-d = fed RAC for 33 d with 2-d withdrawal period; 4-d = fed RAC for 33 d with 4-d withdrawal period; 7-d = fed RAC for 33 d with a 7-d withdrawal period.

[2]Observed significance levels for orthogonal contrasts: L and Q = linear and quadratic; CON vs. RAC = contrast of control treatment vs. the average of the 12-h, 2-d, 4-d, and 7-d treatments.

[3]SE of the least square means.

[4]RAC = ractopamine hydrochloride (Actogain 45, 100 g/kg; Zoetis Inc., Parsippany, NJ). Cattle on RAC treatments received RAC supplementation corresponding to withdrawal period i.e., 12-h started RAC on day 29 of the feeding period; 2-d started RAC on day 27; 4-d started RAC on day 25; 7-d started on day 22.

[5]Platform scale BW with a standard 4% shrink applied.

[6]Initial BW used as a covariate in the model ($P < 0.10$); Truck scale BW with a standard 4% shrink applied.

[7]Carcass performance calculated using 64.27% dressing percentage for all treatments; deads-out basis.

[xyz]Treatments with unlike superscripts differ ($P \leq 0.10$).

Ractopamine treatments did exhibit increased BW, ADG, and improved efficiency of gain on a carcass-adjusted basis compared to CON animals, which was calculated using a common 64.27% dressing percentage (average of all treatments). Supplementation with RAC consistently increases BW, ADG, and G:F in beef steers when compared to non-supplemented controls (Scramlin et al., 2010; Lean et al., 2014; Genther-Schroeder et al., 2016). The performance differences in the current experiment between RAC and CON cattle on a carcass-adjusted basis suggest that gut fill and resulting variation in dressing percentage likely accounted for a greater portion of the live BW in the CON treatment and may have also diluted possible differences in ADG and G:F on a live-weight basis.

Neither live nor carcass-adjusted ADG and G:F differed ($P > 0.10$) between the RAC-containing treatments, despite their various withdrawal periods. Experiments conducted to examine the effects of different/extended withdrawal periods in β-agonists are limited, and the authors are not aware of any published manuscripts to date that have examined the performance effects of extended withdrawal periods of RAC, specifically. Hanrahan et al. (1987) fed cimaterol to finishing lambs for 49 d prior to withdrawal periods of 0, 7, 14, 21, or 28 d. ADG and gain efficiency were decreased in the cimaterol-fed lambs following withdrawal, relative to controls. Barash et al. (1994) observed similar diminished results in ADG and efficiency of growing dairy heifers following cimaterol supplementation for 4-mo and a subsequent 2-mo withdrawal. It is important to note that these studies vary substantially from the current experiment, with regard to animal, product, and feeding period. In a study more similar to the current experiment, Casey et al. (1997) fed steers (initial BW = 264 kg) zilpaterol for 49 d followed by withdrawal periods of either 0, 7, or 14 d alongside a negative control treatment. Zilpaterol improved ADG and G:F compared to control cattle, and no differences were detected between zilpaterol-withdrawal treatments. More recently, Holland et al. (2010) examined the effects of withdrawal period on performance and carcass traits in finishing beef steers fed zilpaterol. Cattle were fed zilpaterol for 20 d prior to slaughter, with corresponding withdrawal periods of 3, 10, 17, or 24 d. ADG and G:F decreased linearly as days after withdrawal of zilpaterol increased, though both variables were greater than controls up to the 10-d withdrawal period. This is similar to the current experiment, where RAC withdrawal up to 7 d exhibited greater ADG and G:F than CON. Health measures did not differ due to either RAC supplementation or RAC withdrawal period ($P \geq 0.581$). Morbidity averaged 1.3% across all treatments and was not different ($P = 0.581$).

Main effects of RAC withdrawal on carcass characteristics, and their contrast to CON, are presented in Table 3. The RAC treatments displayed 4.90 kg greater hot carcass weight (HCW) and 0.4 percentage unit greater yields than CON cattle, with no differences observed between RAC withdrawal treatments. Similar to these results, HCW has consistently increased in several other studies where RAC was compared to a negative control treatment (Bryant et al., 2010; Scramlin et al., 2010; Genther-Schroeder et al., 2016). In the current experiment, ADG based on initial HCW (kilograms), which was calculated as 0.2598 × initial $BW^{1.1378}$ (Tatum et al., 2012), was improved for RAC treatments over CON steers, with RAC cattle displaying 5.6% greater ADG than CON ($P < 0.001$). In addition, longissimus muscle (LM) area was greater for RAC cattle vs. CON animals ($P < 0.001$) and fat thickness did not differ between treatments. Similarly, researchers from previous studies have observed greater LM area (Gruber et al., 2007; Bryant et al., 2010; Genther-Shroeder et al., 2016) and no difference in fat thickness (Abney et al., 2007; Scramlin et al., 2010; Genther-Shroeder et al., 2016) when RAC was compared to control cattle.

Ractopamine withdrawal period did not affect HCW or dressing percentage ($P > 0.10$), with 12-hRAC, 2-dRAC, 4-dRAC, and 7-dRAC withdrawal treatments producing similar results. In the extended withdrawal study previously mentioned, Holland et al. (2010) also observed increased HCW and dressing percentage in cattle fed zilpaterol vs. controls, and those increases were maintained for each withdrawal treatment, from 3- to 24-d withdrawal. On the basis of the results in Holland et al. (2010), it may be beneficial to observe RAC withdrawals beyond 7 d, as that was the greatest withdrawal period in the current trial. Similar to initial BW and DMI, cutability responded quadratically to withdrawal period, with the 2-dRAC and 4-dRAC treatments generating more YG 4 and 5 in addition to fewer YG 1 and 2 carcasses produced in the 2-dRAC treatment. Despite the quadratic response, likely due to initial BW and corresponding DMI differences, RAC cattle overall produced leaner carcasses compared to CON cattle ($P \leq 0.016$) with regard to YG 1 and 2 (31.0% vs. 24.7% for RAC vs. CON, respectively) and YG 4 and 5 (16.05% vs. 21.2% for RAC vs. CON, respectively).

Table 3. Effects of ractopamine withdrawal on carcass characteristics

	Treatments[1]							Contrast[2] *P*-value		
Item	CON	12-h RAC	2-d RAC	4-d RAC	7-d RAC	SEM[3]	*P*-value	L	Q	CON vs. RAC
No. of pens	12	12	12	12	12	—	—	—	—	—
HCW[4], kg	411^{y}	415^{x}	416^{x}	417^{x}	415^{x}	1.99	0.006	0.975	0.077	<0.001
Dressing percentage	63.94^{y}	64.25^{xy}	64.28^{xy}	64.58^{x}	64.30^{xy}	0.209	0.069	0.650	0.210	0.017
HCW ADG[5], kg/d	1.38^{y}	1.44^{x}	1.46^{x}	1.48^{x}	1.44^{x}	.031	0.006	0.984	0.078	<0.001
Camera grading and measurements										
Choice or greater, %	75.9	73.9	71.8	73.6	71.1	3.77	0.500	0.461	0.873	0.173
Sub-select, %	0.41	0.36	0.26	0.18	0.55	0.36	0.842	0.932	0.582	0.927
Marbling score[6]	453	447	448	454	444	7.5	0.621	0.721	0.219	0.450
YG 1 and 2, %	24.7^{xy}	36.3^{z}	22.8^{x}	31.3^{yz}	33.4^{yz}	4.90	<0.001	0.551	0.005	0.016
YG 4 and 5, %	21.2^{z}	14.6^{xy}	20.5^{yz}	18.2^{yz}	10.9^{x}	3.51	<0.001	0.017	<0.001	0.007
LM[7] area, cm^2	33.8^{x}	35.1^{y}	34.3^{x}	34.8^{y}	35.3^{y}	0.56	0.002	0.142	0.209	<0.001
Fat thickness, cm	1.40	1.37	1.47	1.40	1.40	0.04	0.312	1.000	0.220	0.879

[1]CON = control treatment, fed no ractopamine hydrochloride (RAC; Actogain 45, 100g/kg; Zoetis Inc., Parsippany, NJ); 12-h = fed RAC for 33 d with 12-h withdrawal period; 2-d = fed RAC for 33 d with 2-d withdrawal period; 4-d = fed RAC for 33 d with 4-d withdrawal period; 7-d = fed RAC for 33 d with a 7-d withdrawal period. Cattle on RAC treatments received RAC supplementation corresponding to withdrawal period i.e., 12-h started RAC on day 29 of the feeding period; 2-d started RAC on day 27; 4-d started RAC on day 25; 7-d started on day 22.

[2]Observed significance levels for orthogonal contrasts: L and Q = linear and quadratic; CON vs. RAC = contrast of control treatment vs. the average of the 12-h, 2-d, 4-d, and 7-d treatments.

[3]SE of the least square means.

[4]Initial BW used as a covariate in the model.

[5]On the basis of initial HCW (kg), which was calculated as 0.2598·(initial BW$^{1.1378}$; Tatum et al., 2012).

[6]As determined by camera; 400 = Small^{00}.

[7]Longissimus muscle.

[abc]Treatments with unlike superscripts differ ($P \leq 0.10$).

No differences in carcass quality existed among treatments, with cattle on all treatments averaging 73.26% of carcasses grading Choice or better and an average marbling score of 449. Effects of RAC on carcass quality are somewhat varied. Similar to the current experiment, Abney et al. (2007), Scramlin et al. (2010), and Genther-Shroeder (2016) observed no differences in marbling score between RAC treatments and controls. However, Gruber et al. (2007) observed a tendency for RAC treatments to have lower marbling scores, and Genther-Shroeder et al. (2016) observed a decrease in quality grade of RAC treatments relative to controls. Other β-agonists, such as zilpaterol, have demonstrated consistent decreases in marbling and diminished carcass quality when compared to controls (Lean et al., 2014); however, in a meta-analysis of studies on RAC, negative effects on carcass quality are minimal (Lean et al., 2014), which is consistent with our results. In addition, day of withdrawal had no effect on marbling or quality grade of carcasses ($P \geq 0.500$). In the zilpaterol withdrawal study conducted by Holland et al. (2010), marbling score was increased after 10 and 17 d of withdrawal. This is likely due to greater fat deposition as DOF increased beyond supplementation with zilpaterol. It is important to note that zilpaterol, as previously mentioned, has a more marked negative effect on marbling than RAC, and it is possible that marbling may be more consistent if extended RAC withdrawal periods are tested in the future.

In summary, RAC improved performance and carcass characteristics over CON, consistent with the body of published literature to date. A withdrawal period of RAC, up to 7 d prior to slaughter, did not negatively affect performance, health, or carcass traits; this suggests that producers are afforded flexibility with regard to RAC withdrawal times when making marketing and/or management decisions, without sacrificing the performance benefits of RAC. Further research examining the effects of varying extended withdrawal periods on performance and carcass characteristics of finishing cattle is warranted to substantiate these findings.

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