Applied Animal Science 39:56–68
https://doi.org/10.15232/aas.2022-02351

NUTRITION: *Original Research*

Effects of dietary protein concentration and degradability on performance, carcass characteristics, net energy utilization, and metabolizable protein balance of finishing beef heifers receiving 0 or 400 mg of ractopamine hydrochloride

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ABSTRACT

Objective: This study evaluated the effects of feeding beef cattle finishing diets with greater than 14.0% dietary CP and with or without ractopamine hydrochloride (RH) on growth performance, carcass merit, net energy utilization, and metabolizable protein balance.

Materials and Methods: Heifers (n = 525) were assigned to 48 pens in a generalized complete block design, and pens of cattle were assigned randomly to 0 or 400 mg of RH/animal per day and 3 CP treatments in a 2 × 3 factorial arrangement (n = 8 pens/treatment) fed for 35 d before slaughter. Dietary protein treatments were steam-flaked corn-based diets containing 13.9% CP, 8.9% RDP, and 5.1% RUP (CON); 20.9% CP, 14.4% RDP, and 6.5% RUP (High RDP); or 20.9% CP, 9.7% RDP, and 11.2% RUP (High RUP) on a DM basis.

Results and Discussion: No RH × CP interactions were observed. Final BW, ADG, water disappearance, DMI, and G:F were not different among CP treatments. Dressing percentage was greater for cattle fed High RDP than for those fed High RUP, but other carcass outcomes did not differ. The MP balance was greatest for High RUP, intermediate for High RDP, and least for CON. Cattle receiving 400 mg of RH had greater final BW, ADG, G:F, and hot carcass weight. The LM area was greater and KPH was less for 400 versus 0 mg of RH. Carcass-adjusted final BW, ADG, and G:F were greater for cattle consuming 400 mg of RH. Cattle fed 400 mg of RH had greater performance-adjusted and observed:expected NE_m and NE_g. The MP balance was less for 400 versus 0 mg of RH. Dietary CP requirements were greater for cattle fed 400 compared with 0 mg of RH but did not exceed the CP supplied by CON, High RDP, or High RUP.

Implications and Applications: Feeding greater than 14.0% CP does not negatively affect performance or carcass characteristics of finishing cattle, and the absence of interactions between CP and RH suggests that RH does not increase CP requirements above those provided in a typical finishing cattle diet.

Key words: beta-adrenergic agonist, crude protein, feedlot, ruminally degradable protein, ruminally undegradable protein

INTRODUCTION

Little to no improvements in cattle performance are observed when CP concentrations of finishing diets exceed 13.0% of DM (Gleghorn et al., 2004). However, increased availability of byproducts from the grain-milling industry has altered the ingredient and nutrient composition of finishing cattle diets in the past 30 yr (Crawford et al., 2022). In particular, feeding high amounts of grain-milling byproducts increases dietary CP supply. Samuelson et al. (2016a) reported that the average and maximum CP concentrations recommended by consulting feedlot nutritionists in finishing diets were 13.4% and 20.0% of DM, respectively. Providing high concentrations of dietary CP increases ureagenesis, which influences nutrient metabolism and requirements (Lobley et al., 1995; Mutsvangwa et al., 1997; Jennings et al., 2018). In finishing cattle diets with excess CP, protein degradability may also play a role in animal performance because of potential differences in the metabolic costs associated with ammonia detoxification (Lobley et al., 1995). This concept is further complicated when combined with use of growth-promoting technologies that alter cattle growth and performance.

The authors have not declared any conflicts of interest.

*Corresponding author: ksamuelson@wtamu.edu β-Adrenergic agonists (**βAA**) such as ractopamine hydrochloride (**RH**) increase final BW, ADG, and muscle deposition (Avendaño-Reyes et al., 2006; Arp et al., 2014) when fed during the last 20 to 42 d of the feeding period. Furthermore, because βAA increase N retention, it is likely that these feed additives influence protein metabolism (Reeds and Mersmann, 1991; Brake et al., 2011). Although the interaction between dietary CP and βAA has been investigated (Walker et al., 2006; Samuelson et al., 2016b), these studies did not determine how cattle receiving βAA would respond to concentrations of dietary CP greater than those provided in most finishing diets, and how this interacts with protein degradability. We hypothesized that CP concentrations greater than 14.0% of DM would increase performance of cattle fed βAA and would either have no effect or would decrease performance of cattle not receiving βAA. Therefore, the objective of this study was to determine the effects of feeding beef cattle finishing diets with excess CP, provided primarily as either RDP or RUP, with or without RH, on growth performance, carcass characteristics, net energy utilization, and metabolizable protein balance.

MATERIALS AND METHODS

Receiving Cattle Management

All procedures involving the use of animals in this study were approved by the New Mexico State University Institutional Animal Care and Use Committee. Approximately 10 mo before initiation of the experiment, crossbred heifers from south Texas were received at the Clayton Livestock Research Center (Clayton, NM) and divided between two 56-d receiving studies (Oosthuysen et al., 2015, 2017). After arrival, heifers were individually weighed using a Daniels Bud Box System (AH-10; Daniels Mfg.), administered a unique animal identification tag, vaccinated according to the respective study protocols, and provided with oral parasiticide (Safeguard; Intervet Inc.). Heifers were not administered metaphylactic antimicrobial treatment at arrival. After completion of these studies, heifers were limit-fed once daily with approximately 11.4 kg of a commercially available starter diet (RAMP; Cargill) until initiation of the current study.

Experimental Design and Dietary Treatments

A total of 525 heifers were weighed individually (423 ± 1.8 kg BW) before feeding and ranked in a spreadsheet according to BW. Heifers were then separated into 4 blocks based on BW and assigned consecutively to pens so that the average BW and standard deviation were similar among pens. After BW were recorded, heifers were sorted into their respective blocks, and then sorted into the appropriate pen. At this time, heifers were given a unique pen tag, re-vaccinated (Vista 3; Merck Animal Health), and administered a commercial growth implant (Revalor-200, 200 mg of trenbolone acetate and 20 mg of estradiol; Merck Animal Health). After heifers were allocated to pens, they were transitioned from the commercial starter diet (RAMP, Cargill) to a common finishing diet (**CON**; Table 1).

The study was a generalized complete block design consisting of 48 soil-surfaced pens (12 × 35 m, with 11-m bunk line) and 4 blocks (12 pens per block with 9 to 11 heifers per pen). Heifers were blocked by BW, which determined the date for both initiation of RH treatments and harvest. Within each block, pens of cattle were randomly assigned to 1 of 6 dietary treatments in a 2 × 3 factorial arrangement. Treatments consisted of either 0 or 400 mg of RH (Actogain; Zoetis) supplied to cattle consuming 1 of 3 CP treatments. Protein treatments (Table 1) were steam-flaked corn-based diets containing 13.9% CP, 8.9% RDP, and 5.1% RUP (CON); 20.9% CP, 14.4% RDP, and 6.5% RUP (**High RDP**); or 20.9% CP, 9.7% RDP, and 11.2% RUP (**High RUP**) on a DM basis. The CON treatment was designed to be within the range of CP concentrations (minimum = 13.0% of DM and maximum = 14.3% of DM) recommended for finishing cattle diets by consulting feedlot nutritionists (Samuelson et al., 2016a). In contrast, the High RDP and High RUP diets were designed to supply greater than the maximum CP (20.0% of DM) recommended by consulting nutritionists (Samuelson et al., 2016a). All diets were formulated to contain 9.0% corn stalks (DM basis), and the composition of corn gluten meal, soybean meal, urea, Sweet Bran (Cargill Corn Milling), and steam-flaked corn was modified to adjust the concentrations of CP, RDP, and RUP in the High RDP and High RUP diets compared with CON. The High RDP diet was designed to provide greater RDP than CON (14.4 vs. 8.9% RDP for High RDP vs. CON, DM basis), whereas the High RUP diet was designed to provide greater RUP than CON (11.2 vs. 5.0% RUP for High RUP vs. CON, DM basis). Diets were also formulated to contain similar concentrations of dietary energy (NE_m and NE_g).

Approximately 100 d before harvest, heifers assigned to receive the High RDP and High RUP treatments were transitioned from the common finishing diet (CON) to their respective CP treatment diets. However, an ingredient mixing error was discovered for the High RUP diet during the first 25 d after cattle were transitioned to their dietary CP treatments; therefore, data collected before initiation of the RH treatments were removed from this study. Initiation of RH for each block of heifers was determined based on a projected shrunk final BW of 573 kg. On the day all pens of heifers within a block were designated to receive RH, the cattle within each pen were weighed as a group on a pen scale before the morning feeding. These weights then served as initial BW (498, 527, 551, and 575 ± 3.82 kg for block 1, 2, 3, and 4, respectively) to evaluate the 2 × 3 factorial arrangement of dietary CP treatments and RH. The RH treatments were initiated 35 d before harvest; therefore, the data presented only reflects the final 35 d of the feeding period when RH was fed.

Table 1. Ingredients and nutrient composition of diets fed to finishing heifers

	CP treatment[1]		
Item	CON	High RDP	High RUP
Ingredient, % of DM			
Steam-flaked corn	67.1	57.0	57.0
Sweet Bran[2]	18.0	18.0	14.5
Corn stalks, ground	9.00	9.00	9.00
Soybean meal	—	9.60	—
Corn gluten meal	—	—	14.5
Corn oil	0.90	1.40	—
Urea	1.01	1.49	—
Supplement[3]	3.99	3.51	5.00
Nutrient analysis[4]			
DM, %	77.7	79.5	76.6
CP, %	13.9	20.9	20.9
Crude fat, %	3.55	3.83	2.80
RDP,[5] %	8.85	14.4	9.70
RUP,[5] %	5.05	6.46	11.2
ADF, %	8.80	8.97	9.10
eNDF,[5] %	10.2	9.95	9.80
TDN,[6] %	84.4	84.3	84.2
ME,[7] Mcal/kg	3.05	3.05	3.04
NE_m,[8] Mcal/kg	2.08	2.07	2.07
NE_g,[9] Mcal/kg	1.41	1.41	1.40

[1] Treatments were in a 2 × 3 factorial arrangement with 2 levels of ractopamine hydrochloride and 3 CP treatments (CON = finishing diet containing 13.9% CP, 8.9% RDP, 5.1% RUP; High RDP = finishing diet containing 20.9% CP, 14.4% RDP, 6.5% RUP; High RUP = finishing diet containing 20.9% CP, 9.7% RDP, 11.2% RUP).

[2] Cargill.

[3] Contained dried distillers grains with solubles, limestone, salt, trace minerals (1.8% Cu, 9.0% Zn, and 360 mg/kg Se; Beefmax 0510; Cargill), vitamins (1,030 IU vitamin A, 500 IU vitamin D, and 5.62 IU vitamin E per kg of DM), and a custom supplement containing Rumensin (Elanco Animal Health; supplied 33 mg of monensin per kg of dietary DM) and Tylan (Elanco Animal Health; supplied 9.8 mg of tylosin per kg of dietary DM).

[4] Nutrient concentrations are based on laboratory analysis of each treatment diet (Servi-Tech Laboratories, Amarillo, TX) and expressed on a DM basis.

[5] Calculated based on tabular values (NASEM, 2000).

[6] TDN % = 93.53 − 1.03 × % ADF (Undersander et al., 1993).

[7] ME (Mcal/kg) = TDN × 4.409 × 0.82 (NASEM, 2000).

[8] NE_m (Mcal/kg) = $1.37 \times ME - 0.138 \times ME^2 + 0.0105 \times ME^3 - 1.12$ (NASEM, 2000).

[9] NE_g (Mcal/kg) = $1.42 \times ME - 0.174 \times ME^2 + 0.0122 \times ME^3 - 1.65$ (NASEM, 2000).

For the 35-d treatment period, cattle were fed twice daily at 0600 and 1300 h, and RH treatments were top-dressed directly onto the CP treatment diets in feed bunks once daily at the morning feeding. For pens receiving the RH treatment, the appropriate amount of RH for a pen of cattle was mixed with 150 g of Sweet Bran (Cargill Corn Milling), whereas pens receiving no RH were top-dressed with 150 g of Sweet Bran only, as a placebo. After top-dressing, RH treatments were thoroughly mixed with the diet in the bunk using a rake to evenly distribute the RH treatments within the CP treatment diets.

Feeding Management and Collections

The amount of feed to offer each pen was determined by visually evaluating feed bunks twice daily, with the bunk management protocol designed to leave little to no accumulation of feed the following morning. Each diet was mixed in an overhead ribbon mixer (Hayes & Stolz Industrial Mfg. Co.) immediately before feeding and delivered to cattle using a custom 6-compartment feed truck with individual dispensing augers. Before delivery, the amount of feed to be provided to each pen was weighed into one of the individual compartments, such that feed for 6 pens could be delivered per truckload. The feeding order was CON, High RUP, and High RDP. Diet samples were collected weekly for analysis of DM (100°C for 48 h in a forced-air oven) and nutrient composition (Servi-Tech Laboratories, Amarillo, TX). Analyses conducted at the commercial laboratory (Servi-Tech Laboratories) included ADF (Ankom ADF method 5.2017), CP (AOAC 990.03), and crude fat (AOAC 920.39; AOAC, 2019). Any refusals or feed remaining as a result of inclement weather were collected, weighed, and analyzed for DM to calculate daily DMI over the 35-d treatment application period. The water disappearance of each pen was recorded throughout the study by a flow meter attached to each water trough (Cattlemaster 480; Ritchie Inc.).

Once all cattle within a block had received the appropriate RH treatment for 35 d, each pen of heifers was weighed using a pen scale before the morning feeding and shipped to a commercial abattoir (Cargill Meat Solutions, Friona, TX). At the abattoir, heifers were harvested, and hot carcass weight (**HCW**) and liver scores were recorded on the same day. Following a 36-h chill, individual carcass measurements were recorded and yield grade values were calculated (USDA, 2017). All parameters reported for carcass characteristics were collected by personnel from the Beef Carcass Research Center (West Texas A&M University, Canyon, TX).

Calculations

Initial and final BW were adjusted with a 4% shrink, and DP was calculated by averaging the HCW of heifers in each pen and dividing by the average shrunk final BW of heifers in that pen. Carcass-adjusted final BW was determined by dividing the HCW by a common DP (64.0%). Carcass-adjusted ADG was then calculated by subtracting carcass-adjusted final BW from initial BW and dividing by 35 d, and carcass-adjusted G:F was calculated by dividing carcass-adjusted ADG by average daily DMI. Because of low incidence, treatment effects on cattle morbidity and mortality were not evaluated. However, during the 35-d treatment period, 1 animal from the CON treatment died from unknown causes. Therefore, all performance parameters were calculated on a deads-out basis.

Empty BW (**EBW**) was calculated using the equation EBW (kg) = [1.316 × HCW (kg)] + 32.29 (Garrett, 1968; Guiroy et al., 2001). The percentage empty body fat (**EBF**) was calculated from carcass characteristics using the equations described by Guiroy et al. (2001). Adjusted final BW (**AFBW**) was calculated from EBW and EBF using the equation developed by Guiroy et al. (2001), where AFBW (kg) = [EBW (kg) + (28 − % EBF) × 14.26]/0.891. Energy maintenance (**EM**; Mcal/d) and energy gain (**EG**; Mcal/d) were estimated using the following equations (Lofgreen and Garrett, 1968; Zinn and Shen, 1998; NASEM, 2000): EM = $0.077 \times \text{SBW}^{0.75}$, and EG = $0.0557 \times \text{EQSBW}^{0.75} \times \text{ADG}^{1.097}$, where shrunk BW (**SBW**; kg) = average BW (kg) × 0.96 and equivalent shrunk BW (**EQSBW**; kg) = SBW × (478/AFBW). Performance-adjusted NE (Mcal/kg) values were determined using the following equations:

$$\text{Dietary NE}_{\text{m}} = -b \pm \frac{\sqrt{b^2 - 4ac}}{2c}, \text{ and}$$

$$\text{Dietary NE}_{\text{g}} = 0.877 \times \text{NE}_{\text{m}} - 0.41,$$

where $a = -0.41 \times \text{EM}$; $b = 0.877 \times \text{EM} + 0.41 \times \text{DMI (kg)} + \text{EG}$; and $c = -0.877 \times \text{DMI}$ (kg; Zinn and Shen, 1998). Ratios of observed to expected NE were calculated by dividing the performance-adjusted NE by the NE_{m} and NE_{g} of each treatment diet from Table 1.

Microbial CP supply was calculated using the following equations (NASEM, 2000): microbial CP supply (g) = [DMI (g) × % TDN × 0.13] × [1 − (20 − % eNDF) × 0.022], and RDP supply (g) = DMI (g) × % RDP, where % TDN, % RDP, and effective NDF (eNDF) were from Table 1. Total MP supply (g) was calculated as the sum of MP supply from microbial CP and MP supply from RUP using the following equations: MP supply from microbial CP (g) = microbial CP supply × 0.64, or MP supply from microbial CP (g) = RDP supply × 0.64, whichever was less, and MP supply from RUP (g; NASEM, 2000) = [DMI (g) × % RUP × 0.80]. Total requirements for MP were calculated as the sum of MP required for maintenance and MP required for gain using the equations: MP required for maintenance (g) = $3.8 \times \text{SBW}^{0.75}$ and MP required for gain (g) = {ADG × [268 − (29.4 × RE/ADG)]}/0.49, where ADG (kg) was from Table 2 and retained energy (RE) = $0.0635 \times (0.891 \times \text{EQSBW})^{0.75} \times (0.956 \times \text{ADG})^{1.097}$ (NASEM, 2000). Total MP balance (g) was calculated as the difference between total MP requirements and total MP supply. Equations from NASEM (2000) were used for model estimates of MP balance because they represented the equations available at the time the study was conducted (July to October 2015). The dietary CP requirements were calculated using the equations described by Galyean (1996), where dietary CP % = dietary CP need/DMI, and dietary CP need = {[total MP requirement − (microbial CP supply × 0.64)]/0.8} + microbial CP supply. All calculations for body composition, net energy utilization, and MP balance were completed on a pen basis.

Statistical Analysis

Continuous variables such as cattle performance, carcass characteristics, body composition, performance-adjusted NE, and model estimates of MP balance were analyzed using the MIXED procedure of SAS (SAS Institute Inc.). Categorical data such as liver scores and QG were analyzed using the GLIMMIX procedure of SAS. For all variables measured, pen served as the experimental unit. Because initial BW differed ($P < 0.01$) among dietary treatments at RH application, initial BW was used as a covariate in the model for all other dependent variables evaluated. Therefore, for analysis of initial BW, the model included the effects of diet, RH, and the interaction between diet and RH, whereas the model for all other statistical analyses included the effects of diet, RH, the interaction between diet and RH, and initial BW. Body weight block was included as a random effect. Although treatments were replicated within each block, neither the 2-way nor the 3-way interaction between block and treatment was statistically significant ($P \geq 0.12$; data not shown). Treatment differences were considered significant when $P \leq 0.05$, and a tendency was considered when $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Interaction Between Dietary Protein and RH

Because βAA increase uptake of AA into peripheral tissues, N retention, and growth rate (Beerman, 1993; Byrem et al., 1998; Carmichael et al., 2018), feeding RH has the potential to alter cattle requirements for CP. Therefore, we hypothesized that dietary CP concentrations greater than 14.0% of DM would increase performance of cattle fed RH but would either have no effect or would decrease performance of cattle not fed RH. However, no dietary CP × RH interactions ($P \geq 0.11$) were observed for performance or carcass characteristics (Table 2). Similarly, no dietary CP × RH interactions ($P \geq 0.31$) were observed for body composition (Table 3) and performance-adjusted NE (Table 4) or model estimates of MP balance (Table 5).

The lack of interaction between dietary CP concentrations and RH administration indicates that the performance responses to CP concentrations exceeding 14% of DM were not altered by feeding RH. Our research results agree with previous research. In a study by Hales et al. (2016), performance of steers consuming 300 mg of RH

Table 2. Effects of ractopamine hydrochloride (RH) and dietary protein concentration and degradability on live and carcass-adjusted performance of finishing heifers

	CP treatment[1]				RH treatment[1]			*P*-value[4]		
Item	**CON**	**High RDP**	**High RUP**	**SEM[2]**	**0 mg**	**400 mg**	**SEM[3]**	**CP**	**RH**	**CP × RH**
Live animal performance										
Initial BW,[5] kg	541[a]	546[a]	526[b]	16.50	538	538	16.46	<0.01	0.95	0.97
Final BW, kg	576	577	579	1.78	572	583	1.63	0.12	<0.01	0.42
ADG, kg	1.08	1.11	1.17	0.05	0.96	1.28	0.05	0.12	<0.01	0.42
DMI, kg/d	9.06	9.25	9.14	0.08	9.17	9.12	0.07	0.28	0.58	0.47
G:F	0.120	0.121	0.126	0.006	0.104	0.140	0.006	0.28	<0.01	0.40
Water disappearance, L/d	31.3	31.3	34.1	1.84	31.7	32.8	1.65	0.19	0.37	0.59
Carcass-adjusted performance										
Final BW,[6] kg	575	578	574	1.82	569	583	1.61	0.07	<0.01	0.81
ADG,[7] kg	1.06	1.15	1.03	0.05	0.89	1.27	0.05	0.07	0.10	0.81
G:F[8]	0.117	0.125	0.111	0.006	0.096	0.140	0.006	0.12	<0.01	0.81

[1] Treatments were a 2 × 3 factorial arrangement with 2 levels of RH (0 versus 400 mg per animal) and 3 CP treatments (CON = finishing diet containing 13.9% CP, 8.9% RDP, 5.1% RUP; High RDP = finishing diet containing 20.9% CP, 14.4% RDP, 6.5% RUP; High RUP = finishing diet containing 20.9% CP, 9.7% RDP, 11.2% RUP). No interactions ($P \geq 0.40$) were observed between RH and CP; therefore, only the means for main effect comparisons are presented.

[2] SEM for the main effect of diet.

[3] SEM for the main effect of RH.

[4] CP = *P*-value for main effect of CP concentration and degradability; RH = *P*-value for the main effect of RH; CP × RH = *P*-value for the interaction of CP and RH.

[5] Because initial BW differed by dietary treatment, it was used a covariate in the statistical model for all other dependent variables.

[6] Hot carcass weight adjusted to a common dressing percentage of 64.0%.

[7] Carcass-adjusted final BW − initial BW/35 d.

[8] Carcass-adjusted ADG/DMI.

Table 3. Effects of ractopamine hydrochloride (RH) and dietary protein concentration and degradability on carcass characteristics and body composition of finishing heifers

	CP treatment[1]				RH treatment[1]			*P*-value[4]		
Item	**CON**	**High RDP**	**High RUP**	**SEM[2]**	**0 mg**	**400 mg**	**SEM[3]**	**CP**	**RH**	**CP × RH**
Carcass characteristics										
HCW,[5] kg	368	370	367	1.17	364	373	1.03	0.07	<0.01	0.81
DP, %	63.9^{ab}	64.1^{a}	63.5^{b}	0.13	63.7	64.0	0.11	<0.01	0.10	0.51
Marbling score[6]	43.2	44.0	43.2	1.04	44.0	43.0	0.94	0.62	0.12	0.16
12th rib fat, cm	1.56	1.65	1.51	0.07	1.62	1.53	0.06	0.16	0.09	0.23
LM area, cm^2	92.7	93.4	92.1	0.89	91.8	93.6	0.76	0.48	0.04	0.51
KPH, %	3.32	3.24	3.10	0.13	3.31	3.13	0.12	0.10	0.02	0.11
Yield grade	2.53	2.60	2.48	0.11	2.59	2.48	0.10	0.55	0.15	0.19
Select, %	34.2	27.8	35.8	4.62	29.2	36.0	3.97	0.32	0.11	0.35
≥Choice,[7] %	65.1	72.0	63.3	4.63	70.0	63.6	3.99	0.25	0.14	0.37
Liver abscesses, %	7.58	7.36	6.84	1.67	8.99	5.53	1.36	0.95	0.07	0.23
Body composition										
EBW,[8] kg	517	519	516	1.54	512	523	1.36	0.07	<0.01	0.81
EBF,[9] %	30.4	30.8	30.0	0.50	30.6	30.2	0.46	0.15	0.09	0.34
AFBW,[10] kg	542	538	545	5.97	532	553	5.37	0.50	<0.01	0.31

[1] Treatments were a 2 × 3 factorial arrangement with 2 levels of RH (0 versus 400 mg per animal) and 3 CP treatments (CON = finishing diet containing 13.9% CP, 8.9% RDP, 5.1% RUP; High RDP = finishing diet containing 20.9% CP, 14.4% RDP, 6.5% RUP; High RUP = finishing diet containing 20.9% CP, 9.7% RDP, 11.2% RUP). No interactions ($P \geq 0.11$) were observed between RH and diet; therefore, only the means for main effect comparisons are presented.

[2] SEM for the main effect of diet.

[3] SEM for the main effect of RH.

[4] CP = *P*-value for main effect of CP concentration and degradability; RH = *P*-value for the main effect of RH; CP × RH = *P*-value for the interaction of CP and RH. Initial BW was used as a covariate in the statistical model for all dependent variables.

[5] HCW = hot carcass weight.

[6] Leading digit indicates marbling score where 2 = trace, 3 = slight, 4 = small, 5 = modest, 6 = moderate, 7 = slightly abundant, 8 = moderately abundant, and 9 = abundant. Following digits represent the degree of marbling present within each score.

[7] The proportion of carcasses grading choice, premium choice, and prime were pooled because of the low incidence of each individual quality grade.

[8] EBW = empty body weight; EBW (kg) = [1.316 × HCW (kg)] + 32.29 (Garrett, 1968; Guiroy et al., 2001).

[9] EBF = empty body fat, calculated from carcass characteristics using the equations described by Guiroy et al. (2001).

[10] AFBW = adjusted final body weight; AFBW (kg) = [EBW (kg) + (28 − % EBF) × 14.26]/0.891 (Guiroy et al., 2001).

was not altered by adding soybean meal to the diet to increase the CP concentration from 13.5 to 17.6% of DM. Similarly, Samuelson et al. (2016b) observed no interactions between increasing dietary CP concentrations from 13.7 to 15.8% of DM and administering zilpaterol hydrochloride to finishing steers.

In addition to overall CP concentration, protein degradability does not appear to influence performance of cattle consuming a βAA. For example, in the study completed by Samuelson et al. (2016b), the dietary CP was increased by providing additional RDP as urea. Walker et al. (2006) also reported that cattle receiving RH and diets containing 13.7% CP did not benefit from replacing a portion of urea in the diet with soybean meal to supply additional MP from RUP. Therefore, the results of previous research and the present study indicate that, although final BW and ADG increase with βAA administration, the alterations in protein metabolism associated with improved growth performance were not large enough to increase CP requirements beyond the 13.0 to 14.3% of DM provided in typical finishing diets or to influence the need for degradable versus undegradable protein.

Effects of Dietary Protein

Dietary protein supplied in excess of animal requirements increases AA oxidation and ammonia detoxification (NASEM, 1985). Amino acid catabolism in the liver and detoxification of ammonia absorbed from the gastrointestinal tract may be associated with an energy and AA cost (Lobley et al., 1995). However, it is not known whether these changes in energy and protein metabolism translate

Table 4. Effects of ractopamine hydrochloride (RH) and dietary protein concentration and degradability on net energy utilization of finishing heifers

	CP treatment[1]				**RH treatment**[1]			***P*-value**[4]		
Item	**CON**	**High RDP**	**High RUP**	**SEM**[2]	**0 mg**	**400 mg**	**SEM**[3]	**CP**	**RH**	**CP × RH**
Performance-adjusted NE[5]										
NE_m, Mcal/kg	2.02	2.04	2.04	0.08	1.89	2.18	0.08	0.79	<0.01	0.38
NE_g, Mcal/kg	1.36	1.38	1.38	0.07	1.24	1.50	0.07	0.79	<0.01	0.38
Observed:expected NE[6]										
NE_m	0.971	0.984	0.985	0.04	0.910	1.05	0.04	0.58	<0.01	0.37
NE_g	0.965	0.976	0.984	0.05	0.885	1.06	0.05	0.67	<0.01	0.36

[1] Treatments were a 2 × 3 factorial arrangement with 2 levels of RH (0 versus 400 mg per animal) and 3 CP treatments (CON = finishing diet containing 13.9% CP, 8.9% RDP, 5.1% RUP; High RDP = finishing diet containing 20.9% CP, 14.4% RDP, 6.5% RUP; High RUP = finishing diet containing 20.9% CP, 9.7% RDP, 11.2% RUP). No interactions ($P \geq 0.36$) were observed between RH and diet; therefore, only the means for main effect comparisons are presented.

[2] SEM for the main effect of diet.

[3] SEM for the main effect of RH.

[4] CP = *P*-value for main effect of CP concentration and degradability; RH = *P*-value for the main effect of RH; CP × RH = *P*-value for the interaction of CP and RH. Initial BW was used as a covariate in the statistical model for all dependent variables.

[5] Performance-adjusted $NE_m = -b \pm \frac{\sqrt{b^2 - 4ac}}{2c}$, and performance-adjusted $NE_g = 0.877 \times NE_m - 0.41$, where $a = -0.41 \times \text{EM}$; $b = 0.877 \times \text{EM} + 0.41 \times \text{DMI (kg)} + \text{EG}$; and $c = -0.877 \times \text{DMI}$ (kg; Zinn and Shen, 1998). Energy maintenance (EM; Mcal/d) and energy gain (EG; Mcal/d) were estimated using the following equations: $\text{EM} = 0.077 \times \text{SBW}^{0.75}$, and $\text{EG} = 0.0557 \times \text{EQSBW}^{0.75} \times \text{ADG}^{1.097}$, where SBW (kg) = average BW (kg) × 0.96 and equivalent shrunk BW (EQSBW; kg) = BW × 478/adjusted final BW (Lofgreen and Garrett, 1968; NASEM, 2000; Guiroy et al., 2001).

[6] Observed:expected NE ratios were calculated by dividing the performance-adjusted NE by the energy concentration of each treatment diet for NE_m (2.08, 2.07, 2.07 Mcal/kg for CON, High RDP, and High RUP, respectively) and NE_g (1.41, 1.41, and 1.40 Mcal/kg for CON, High RDP, and High RUP, respectively), as presented in Table 1.

to meaningful differences in feedlot cattle production outcomes when high concentrations of CP are provided in finishing cattle diets. In a companion study, Jennings et al. (2018) reported that increasing the CP concentration of the finishing diet from 13.8 to 19.5% CP increased NE_m requirements of growing cattle. Therefore, we hypothesized that excess dietary CP would negatively affect growth performance and carcass merit. However, final BW, ADG, DMI, water disappearance, and G:F were not different ($P \geq 0.12$) among cattle fed the 3 CP treatments (Table 2). The lack of difference between dietary CP treatments in the current study suggests that the 4 to 6% increase in NE_m requirements reported by Jennings et al. (2018) may not have been large enough to influence live performance.

To the authors' knowledge, there is limited research evaluating performance of cattle consuming diets with CP concentrations greater than 15.5% of DM. Several studies (Depenbusch et al., 2008; May et al., 2010; Luebbe et al., 2012) have demonstrated that increasing the concentrations of distillers grains in steam-flaked corn-based diets decreases cattle performance. Although those authors attributed the decreases in performance to factors such as changes in DMI and energy dilution, it is also possible that increases in the dietary CP concentrations as a result of increasing distillers grains could be a contributing factor to lower performance. In those studies, CP concentrations were increased from 12.4 up to 23.0% CP. However, the results of the current study do not support the hypothesis that excess CP provided from grain-milling byproducts reduces cattle performance.

In addition to overall dietary CP concentration, protein degradability may play a role in performance of cattle consuming high-CP diets, as it influences MP supply (NASEM, 2000). In the present study, diets contained differing concentrations of RDP (8.9, 14.4, and 9.7% for CON, High RDP, and High RUP, respectively) and RUP (5.1, 6.5, and 11.2% for CON, High RDP, and High RUP, respectively). The lack of difference in cattle growth performance agrees with previous research completed at lower CP concentrations, whereby performance of cattle was not improved by providing greater than 8.2% RDP (Gleghorn et al., 2004) or 5.1% RUP (Wagner et al., 2010) in steam-flaked corn-based finishing diets.

In a 27-d feedlot finishing study by Samuelson et al. (2016b), DMI and ADG of steers linearly decreased as the concentration of urea in the diet increased from 0 to 1.0% (DM basis) to increase the supply of CP from 13.5 to 15.8% of DM and RDP from 7.3 to 9.7% of DM. Therefore, the absence of differences in DMI, ADG, and G:F between High RDP and CON in the present study is interesting,

Table 5. Effects of dietary protein concentration and degradability on MP balance of finishing heifers receiving either 0 or 400 mg ractopamine hydrochloride (RH)

	CP treatment[1]				RH treatment[1]			*P*-value[4]		
Item	CON	High RDP	High RUP	SEM[2]	0 mg	400 mg	SEM[3]	Diet	RH	Diet × RH
Microbial CP supply,[5] g/d	780	789	776	7.18	784	780	5.85	0.45	0.59	0.47
RDP supply,[6] g/d	801^{c}	1,335^{a}	888^{b}	9.67	1,012	1,004	7.88	<0.01	0.44	0.33
MP supply, g/d										
From microbial CP[7]	499	505	497	4.63	502	499	3.77	0.45	0.57	0.45
From RUP[8]	365^{c}	477^{b}	813^{a}	5.53	553	551	4.50	<0.01	0.80	0.53
Total	864^{c}	982^{b}	1310^{a}	9.78	1,054	1,050	7.97	<0.01	0.67	0.47
MP requirements,[9] g/d	671	680	710	19.41	617	757	17.45	0.11	<0.01	0.42
MP balance,[10] g/d	191^{c}	297^{b}	607^{a}	21.51	438	292	19.84	<0.01	<0.01	0.54
Dietary CP requirement,[11] %	11.0	11.0	11.3	0.28	10.2	12.1	0.31	0.25	<0.01	0.42

[1] Treatments were a 2 × 3 factorial arrangement with 2 levels of RH (0 versus 400 mg per animal) and 3 CP treatments (CON = finishing diet containing 13.9% CP, 8.9% RDP, 5.0% RUP; High RDP = finishing diet containing 20.9% CP, 14.4% RDP, 6.5% RUP; High RUP = finishing diet containing 20.9% CP, 9.7% RDP, 11.2% RUP). No interactions ($P \geq 0.33$) were observed between RH and diet; therefore, only the means for main effect comparisons are presented.

[2] SEM for the main effect of diet.

[3] SEM for the main effect of RH.

[4] CP = *P*-value for main effect of CP concentration and degradability; RH = *P*-value for the main effect of RH; CP × RH = *P*-value for the interaction of CP and RH.

[5] Microbial CP supply (g/d) = DMI (g) × % TDN × 0.13 × [1 − (20 − % eNDF) × 0.022] (NASEM, 2000), where TDN and effective NDF (eNDF) were from Table 1.

[6] RDP supply (g/d) = DMI (g) × % RDP (NASEM, 2000), where % RDP was from Table 1.

[7] MP supply from microbial CP (g/d) = microbial CP supply × 0.64, or RDP supply × 0.64, whichever was less (NASEM, 2000).

[8] MP supply from RUP (g/d) = DMI (g) × % RUP × 0.80 (NASEM, 2000), where % RUP was from Table 1.

[9] MP requirements (g/d) = MP required for maintenance (g/d) + MP required for gain (g/d). MP required for maintenance = ($3.8 \times \text{SBW}^{0.75}$), MP required for gain = {ADG × [268 − (29.4 × RE/ADG)]/0.49}, and retained energy (RE) = $0.0635 \times (0.891 \times \text{average BW} \times 478/\text{AFBW})^{0.75} \times (0.956 \times \text{ADG})^{1.097}$ (NASEM, 2000). All BW were adjusted using a 4% shrink (SBW = BW × 0.96). Average BW (kg) was calculated as the average between initial and final BW, and ADG was calculated using the equation ADG (kg) = final BW (kg) − initial BW (kg)/35 d. The adjusted final body weight (AFBW) was calculated using the equation AFBW (kg) = [EBW (kg) + (28 − % EBF) × 14.26]/0.891 (Guiroy et al., 2001), where EBW = empty BW, and EBF = empty body fat.

[10] MP balance (g/d) = MP supply − MP required.

[11] Dietary CP % = dietary CP need/DMI, and dietary CP need = [total MP requirement − (microbial CP supply × 0.64)/0.8] + microbial CP supply (Galyean, 1996).

given that the High RDP diet contained 1.49% urea on a DM basis. Ponce et al. (2019) also reported no difference in DMI, ADG, or G:F when additional RDP from urea was added to steam-flaked corn-based diets containing 15.0% wet distillers grains with solubles to increase the dietary CP above 13.7%. In contrast, Hales et al. (2016) observed that increasing the concentration of soybean meal in the diet to supply greater than 13.5% of CP reduced DMI but did not influence ADG of feedlot steers. Carcass-adjusted G:F was not different ($P = 0.12$) among cattle consuming High RDP, High RUP, and CON. The variation observed in performance outcomes among the previously discussed studies suggests that perhaps days on feed, the source of RDP (true CP versus NPN), or the balance between RDP and RUP when high concentrations of CP are fed may play a role in DMI and growth performance; this requires further investigation. When adjusted to a common DP of 64.0%, carcass-adjusted final BW and ADG for cattle receiving High RDP tended to be greater ($P = 0.07$) than those receiving High RUP or CON.

Hot carcass weights tended to be greater ($P = 0.07$) for cattle receiving High RDP compared with High RUP and CON (Table 3). Because final BW did not differ among cattle fed the 3 different CP treatments, the calculated DP was greater ($P < 0.01$) for cattle fed High RDP than for those fed High RUP. Greater DP for cattle fed High RDP than for those fed High RUP is consistent with the research by Gleghorn et al. (2004), who reported that DP increased linearly as urea (and therefore RDP) was added to the diet to increase the concentration of CP from 11.5

to 14.5% of DM. Bartle et al. (1987) explained that, as the concentration of ammonia ions released during metabolism of RDP sources (such as urea) increases in muscle tissue, this may lead to greater water retention and subsequently increase DP. In contrast, Wagner et al. (2010) reported that DP did not differ but HCW tended to increase linearly with increasing RDP concentrations.

Marbling score, 12th rib fat depth, LM area, and yield grade were not different ($P \geq 0.16$) among dietary CP treatments. Heifers receiving High RUP tended to have less ($P = 0.10$) KPH than heifers receiving CON, but did not differ from High RDP. The percentage of carcasses grading USDA Select or ≥Choice did not differ ($P \geq 0.25$) among cattle fed High RDP, High RUP, and CON. Burroughs et al. (1975) suggested that increasing RDP concentration facilitates growth of rumen microbes, thus improving ruminal starch digestion and positively influencing cattle performance and carcass characteristics. Milton et al. (1997) reported that 12th rib fat thickness increased linearly as the concentration of CP and urea were increased in the diet. However, the similar carcass fatness in the present study is supported by the lack of differences in DMI, ADG, and G:F among cattle consuming High RDP versus High RUP and CON and agrees with the results reported by Shain et al. (1998) and Hales et al. (2016). The incidence of liver abscesses was not different ($P = 0.95$) among cattle consuming High RDP, High RUP, and CON.

Empty BW tended to be greater ($P = 0.07$) for High RDP than for High RUP and CON, which reflects the differences observed in HCW (Table 3). However, EBF and AFBW did not differ ($P = 0.15$) between High RDP, High RUP, and CON. Neither performance-adjusted nor observed:expected NE_m and NE_g were different ($P \geq 0.50$) among cattle consuming the 3 different CP treatments (Table 4). The ratios of observed:expected NE_m (0.971, 0.984, and 0.985 for CON, High RDP, and High RUP) and NE_g (0.965, 0.976, and 0.984 for CON, High RDP, and High RUP) suggest that cattle performed slightly less than expected based on the dietary NE_m and NE_g concentrations. However, this discrepancy is likely a result of changes in both composition of gain and feed efficiency that occur at the end of the finishing period (Owens et al., 1995; Walter et al., 2016; Ohnoutka et al., 2021), as the data presented only represent performance over the final 35 d of feeding.

Because DMI and dietary TDN concentrations were similar among CP treatments, the calculated microbial CP supply did not differ ($P = 0.45$) among heifers consuming High RDP, High RUP, and CON (Table 5). In contrast, the calculated RDP supply was greatest for High RDP, intermediate for High RUP, and least for CON ($P < 0.01$). Because the microbial CP supply was not different among cattle consuming the 3 CP treatments, the calculated MP supply from microbial CP did not differ ($P = 0.45$). However, in response to the RUP supplied by the diet, the calculated MP supply from RUP and subsequently the total calculated MP supply were greatest for High RUP, intermediate for High RDP, and least for CON ($P < 0.01$). Although the total calculated MP supply differed by treatment, minimal effects of dietary CP concentration on cattle performance and carcass characteristics indicate that the additional MP supplied by High RUP and High RDP compared with CON was neither useful nor detrimental to the animal.

The MP requirements were not different ($P = 0.11$) among High RDP, High RUP, and CON (Table 5). Therefore, because of greater MP supply, total MP balance was greatest for heifers receiving High RUP, intermediate for High RDP, and least for CON ($P < 0.01$). The dietary CP requirements did not differ ($P = 0.25$) between heifers receiving High RDP, High RUP, and CON. Interestingly, the dietary CP requirements of heifers in the current study (11.3, 11.0, and 11.0% CP for High RUP, High RDP, and CON, respectively) are less than the concentrations provided by any of the dietary CP treatments (20.9, 20.9, and 13.9% CP for High RUP, High RDP, and CON, respectively). This suggests that all 3 of the CP treatments fed in the present study provided CP concentrations in excess of animal requirements. Feeding CP concentrations in excess of cattle nutrient requirements is common in feedlots, to offset variations in feed milling and delivery and to address potential within-pen variation in CP requirements (Galyean, 1996; Samuelson et al. 2016a). However, it is possible that treatment differences could have occurred if the CON diet were formulated either to meet CP requirements or to create a CP deficiency, as opposed to modeling industry standards for CP supply. Nevertheless, because feeding more than 14.0% of CP (provided either as RDP or RUP) did not negatively affect any of the performance or carcass variables measured in the present study, it seems that cattle were able to efficiently clear from the body any additional N-containing compounds supplied by the higher-CP diets without greatly increasing energy costs. However, increasing the CP concentration in feedlot cattle diets has been shown to increase N excretion and NH_3-N emissions, particularly when the greater CP is primarily provided by RDP (Klopfenstein and Erickson, 2002; Cole et al., 2005; Waldrip et al., 2015). Therefore, although feeding CP and MP in excess of requirements did not affect cattle performance in the present study, additional research is needed to determine the environmental impact of excess dietary CP, and could have important implications for feedlot cattle producers.

Effects of RH

Greater live performance is commonly associated with RH administration in finishing cattle (Avendaño-Reyes et al., 2006; Bryant et al., 2010). In the current study, final BW of heifers receiving 400 mg of RH were greater ($P < 0.01$) than those not receiving RH (Table 2). Additionally, cattle receiving 400 mg of RH had 33.3% greater ($P < 0.01$) ADG and similar ($P \geq 0.37$) DMI and water disappearance compared with cattle receiving 0 mg of RH. This resulted in 34.6% greater ($P < 0.01$) G:F for cattle fed 400 versus 0 mg of RH. Heifers consuming 400 mg of RH also had greater ($P < 0.01$) carcass-adjusted final BW (2.46% increase), ADG (42.7% increase), and G:F (45.8% increase) than heifers not receiving RH.

Bittner et al. (2017) reported that final BW of steers fed 400 mg of RH per day for 28 d tended be greater than those fed 300 mg, but did not differ between steers fed 300 and 400 mg per day for 42 d. The results observed for ADG in the present study are greater than the 16% increase reported by Abney et al. (2007) for cattle receiving 200 mg of RH daily. However, Abney et al. (2007) indicated that the ADG response linearly increased with RH dose, and therefore is consistent given that 400 mg of RH (roughly 2-fold greater) was used in the current study. Research by Quinn et al. (2008) and Avendaño-Reyes et al. (2006) suggests that providing greater concentrations of RH decreases DMI. Decreased DMI was not observed in the current study or in the study by Arp et al. (2014), who also fed 400 mg of RH per animal daily. These variations in performance outcomes could be a result of some combination of differences in cattle feeding and management practices, days on feed, RH dosage, and length of RH administration among studies. Compared with previous research feeding RH, the results of the present study suggest that perhaps increasing the dose of RH can be used as a management tool to maximize live weight gain; however, additional research evaluating performance of feedlot cattle fed RH in excess of 300 mg per day is needed to validate this hypothesis.

Hot carcass weights were greater ($P < 0.01$) for cattle consuming 400 than 0 mg of RH (Table 3). Increases in HCW from 5.3 to 13.6 kg have been reported for cattle consuming RH (Avendaño-Reyes et al., 2006; Scramlin et al., 2010), which is consistent with the 9.0-kg increase in HCW observed in the current study. In contrast to Gruber et al. (2007) and Quinn et al. (2008), DP of cattle receiving RH in our study tended ($P = 0.10$) to be greater than those receiving 0 mg of RH. However, this could again be a function of RH dosage, as Arp et al. (2014) reported that DP was greater for cattle receiving 300 and 400 mg of RH per day than for those receiving 200 mg.

Marbling score did not differ ($P = 0.12$) among cattle receiving diets with or without RH, which agrees with the findings of Bryant et al. (2010). Measurements for 12th rib fat depth tended to be less ($P = 0.09$), and KPH was less ($P = 0.02$) for cattle receiving 400 versus 0 mg of RH. The tendency for lower 12th rib fat depth and less KPH indicate that RH may have more directly affected body fat composition in the current study than in previously reported research (Walker et al., 2006; Abney et al., 2007). However, it is likely that measurements of carcass fatness are also influenced by some combination of RH dose, length of administration, and cattle sex. Additional research feeding RH concentrations over 300 mg per animal daily is needed in order to further evaluate the response of carcass composition to RH feeding in heifers. Cattle fed RH had 1.80 cm^2 greater ($P = 0.04$) LM area, which is indicative of the increased muscle deposition commonly associated with βAA administration (Beerman, 1993). No difference ($P \geq 0.11$) was observed in yield grade or the proportion of cattle grading USDA Select or ≥Choice for 400 compared with 0 mg of RH. Cattle consuming 400 mg of RH tended to have a lower incidence ($P = 0.07$) of liver abscesses compared with those fed 0 mg of RH, although the mechanism of action to support these findings is unknown.

Empty BW was greater ($P < 0.01$) and EBF tended to be less ($P = 0.09$) for cattle fed 400 versus 0 mg of RH (Table 3). When adjusted to a common EBF percentage, AFBW of heifers receiving 400 mg of RH was greater ($P < 0.01$) than those not receiving RH. Greater EBW and lower EBF further supports the decrease in carcass fatness and increase in HCW associated with feeding RH. Greater AFBW is frequently observed when cattle are administered growth-promoting technologies such as anabolic implants and βAA (NASEM, 2016). Shifting the composition of gain in favor of lean tissue growth, particularly at the end of the finishing period, allows cattle to achieve a level of fatness similar to that of their counterparts not receiving a βAA at a heavier BW. In the present study, the cattle within each block were marketed at the same days on feed, but the greater EBW and lower EBF of cattle receiving RH resulted in 21 kg greater AFBW compared with those consuming no RH. In a study by Leheska et al. (2009), steers receiving 8.3 mg/kg zilpaterol hydrochloride for 20 or 40 d before harvest had 26 and 12 kg greater AFBW compared with steers receiving 0 mg of zilpaterol hydrochloride, respectively. However, it should be noted that the equations developed by Guiroy et al. (2001) to predict AFBW do not consider the changes in body composition and nutrient utilization that occur when feeding βAA. For example, the NASEM (2016) reported that the EBW required to increase EBF by one percentage unit for heifers receiving RH is 15.9 kg, which is greater than the 14.26 kg assumed by Guiroy et al. (2001). As a result, these equations may overestimate the AFBW of cattle fed RH and could present additional challenges when AFBW is used in prediction equations.

Performance-adjusted NE_m and NE_g and the ratio of observed to expected NE_m and NE_g were greater ($P < 0.01$) for cattle fed 400 than 0 mg of RH (Table 4). In the present study, performance-adjusted NE_m and NE_g of cattle receiving 400 mg of RH were 2.18 and 1.50 Mcal/kg. In contrast, the dietary NE_m and NE_g concentrations were 2.08, 2.07, and 2.07 mcal/kg and 1.41, 1.41, and 1.40 mcal/kg for CON, High RDP, and High RUP, respectively. Because it is unlikely that feeding RH influences dietary NE values, the greater observed versus expected NE_m (1.05 and 0.910 for 400 and 0 mg of RH, respectively) and NE_g (1.06 and 0.885 for 400 and 0 mg of RH, respectively) suggest that the equations used to calculate performance-adjusted NE may not accurately describe energy utilization of steers receiving βAA. Provision of growth-promoting technologies such as βAA transitions tissue deposition away from fat by increasing protein synthesis and simultaneously decreasing protein turnover, thus enhancing energetic efficiency (Owens et al., 1995). Additionally, feeding a βAA can increase total-tract nutrient digestibility (Harsh et al., 2021) and decrease liver mass as a proportion of BW (Trotta et al., 2021), which influences nutrient requirements and metabolism and could improve NE utilization. Because AFBW is used in the calculation of performance-adjusted NE_m and NE_g, these values may also reflect the overestimation of AFBW that likely occurs when cattle receive a βAA (NASEM, 2016). Furthermore, the equations used to calculate performance-adjusted NE were designed to evaluate cattle over the entire feeding period, as opposed to short increments of time, and therefore caution should be taken when interpreting these results.

The calculated microbial CP and RDP supply were not different ($P \geq 0.44$; Table 5) among heifers receiving 400 compared 0 mg of RH, which reflects the lack of difference in DMI (Table 2). Similarly, calculated MP supply from microbial CP, MP supply from RUP, and total MP supply were not different ($P \geq 0.57$) between cattle receiving either RH treatment. Feeding RH has been shown to increase cattle live weight gain and N retention (Carmichael et al., 2018) and reduce N excretion (Walker et al., 2007). Because ADG increased with RH administration, cattle receiving 400 mg of RH had greater ($P < 0.01$) MP requirements, most likely a result of increased requirements for gain. Cattle receiving 400 mg of RH had a lower ($P < 0.01$) MP balance than cattle not receiving RH (292 versus 438 g/d for 400 compared with 0 mg of RH). However, both cattle receiving RH and those not receiving RH had a positive MP balance, indicating that the MP provided by the diet was adequate to meet the requirements of cattle receiving βAA. This finding is further supported by the dietary CP requirements calculated from MP requirements, microbial CP supply, and DMI (Galyean, 1996). Although the dietary CP requirement was greater ($P < 0.01$) for cattle consuming 400 mg of RH, each of the 3 CP treatments fed provided sufficient CP to meet the 12.1% CP requirement of heifers consuming 400 mg of RH.

APPLICATIONS

These results imply that, although RH increases overall MP requirements, it does not increase the requirements for dietary CP above that provided in typical feedlot diets. Additionally, providing greater than 14.0% CP as either primarily RDP or RUP did not negatively influence performance of finishing cattle, suggesting that the potential alterations in N and the energy metabolism associated with excess ammonia from feeding high-CP diets may not have been large enough to influence cattle energy requirements in the present study. The results observed for RH administration in the present study agree with previously reported research, but also suggest that dosage and length of administration may play an important role in the results observed for RH. In particular, providing higher doses of RH may result in greater improvements in performance and have greater effects on traits relative to carcass characteristics.

ACKNOWLEDGMENTS

The authors thank P. Guiroy (Cargill Animal Nutrition; Minneapolis, MN), the Texas Cattle Feeders Association (Amarillo, TX), Cargill Animal Nutrition (Minneapolis, MN), Merck Animal Health (Summit, NJ), Elanco Animal Health (Indianapolis, IN), and Zoetis (Florham Park, NJ) for their support, and the staff at the Clayton Livestock Research Center (Clayton, NM) for their assistance with cattle management and care.

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