

Effect of rumen-protected lysine on growth performance, carcass characteristics, and plasma amino acid profile in feedlot steers

Katie J. Heiderscheit[†] and Stephanie L. Hansen^{†,1}

[†]Department of Animal Science, Iowa State University, Ames, IA 50011

ABSTRACT: The objective of this study was to evaluate growth performance, carcass characteristics, and plasma amino acid profiles of feedlot steers fed rumen-protected Lys. Forty-two Angus-cross steers (304 ± 25 kg) were blocked by weight and fed treatment diets for 180 d (growing days 0 to 55; finishing days 56 to 180): 1) Lys-deficient diet (CON; $n = 12$ steers), 2) Lys-adequate diet containing soybean meal (POS; $n = 12$ steers), or 3) Lys-deficient diet plus supplemental rumen-protected Lys (RPL; AjiPro-L; Ajinomoto Animal Nutrition North America, Eddyville, IA; $n = 18$ steers). Consecutive day bodyweights (BW) were recorded to begin and end growing and finishing. Individual steer dry matter intake (DMI) was recorded. Blood was collected on days 0, 56, and 179 for analysis of physiological free amino acids. Steers were harvested on day 180 and carcass characteristics were recorded. Data were analyzed using Proc Mixed of SAS 9.4. Steer was the experimental unit and treatment was the fixed effect for all parameters. Block was a fixed effect for growth performance, feed intake, and carcass data. The day 0 value for each parameter of physiological

free amino acids was used as a covariate during analysis. The CON steers had greater BW, average daily gain (ADG), and gain to feed (G:F) at the end of growing (day 56; $P \leq 0.05$) vs. POS and RPL. The CON steers also had greater final BW ($P = 0.04$) and overall ADG ($P = 0.04$) than RPL, while POS was intermediate. Carcass characteristics were not different across treatments [hot carcass weight, dressing percent, ribeye area, back fat, kidney/pelvic/heart (KPH) percent, marbling, or calculated yield grade; $P \geq 0.13$]. Plasma urea N was greater in POS steers on days 56 and 179 ($P \leq 0.04$). Plasma Lys and Arg concentrations were greater in POS at day 56 ($P \leq 0.02$); however, there was no difference among treatments for these two variables at day 179 ($P \geq 0.44$). Steers in all treatments had greater DMI than predicted, causing a negative metabolizable Lys balance for all treatments during growing. Though the metabolizable Lys balance was positive for POS and RPL-fed steers during finishing, the increased metabolizable Lys in these treatments may have decreased performance if other amino acids were imbalanced due to increased intakes.

Key words: amino acid, beef cattle, feedlot, growth, rumen-protected lysine

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Transl. Anim. Sci. 2020.4:1-9

doi: 10.1093/tas/txaa128

INTRODUCTION

In the Midwestern United States, corn-based diets are commonly fed to finishing cattle, and Lys is typically the first limiting amino acid in corn-based diets (Abe et al., 1997; Williams et al., 1999).

¹Corresponding author: slhansen@iastate.edu

Received April 20, 2020.

Accepted July 13, 2020.

Utilizing an ingredient source with high rumen-bypass Lys or a rumen-protected Lys product may improve growth performance by providing more Lys for the ruminant animal at the site of absorption.

Dairy cows have exhibited increased milk production with greater milk fat, protein, and lactose when supplemented with 41 g Lys/cow per day (Robinson et al., 2011). Similarly, Polan et al. (1991) reported Holstein cows fed a corn gluten meal-based diet with supplemental Lys increased milk yield in early lactation vs. cows fed a corn gluten meal diet without Lys supplementation. Rumen-protected amino acids are also being utilized in beef cattle. Several studies have reported moderate supplementation of rumen-protected amino acids is key as too much supplemental rumen-protected Lys has decreased growth performance, potentially from antagonisms to other amino acids during a dietary amino acid imbalance (Harper et al., 1964). Steers supplemented with 3 or 4 g Lys/d had greater average daily gain (ADG) than the control (0 g Lys/d) or those supplemented with 12 g Lys/d during the first 56 d on trial (Klemesrud et al., 2000). Likewise, Holstein steers supplemented with 5 or 10 g rumen-protected Lys and Met per steer had greater final bodyweight (BW) and overall ADG than steers supplemented rumen-protected Lys and Met at 0 or 15 g per steer (Hussein and Berger, 1995).

The objective of this study was to evaluate the effects of rumen-protected Lys concentrations on growth performance, plasma amino acid profile, and carcass characteristics. It was hypothesized that feedlot steers fed a corn-based ration would have greater gains and increased feed efficiency when rumen-protected Lys was included in the diet.

MATERIALS AND METHODS

The Iowa State University Institutional Animal Care and Use Committee approved all experimental procedures and protocols (IACUC Log Number 18–177).

Animals and Experimental Design

Fifty single-sourced, Angus crossbred steers (294 ± 29 kg) were transported to the Iowa State University Beef Nutrition Research Unit (Ames, IA) in November 2018. Steers were offered hay top-dressed with a corn-silage-based total mixed ration (TMR) upon arrival (day –23). Hay was removed and only TMR was offered by the second day after arrival. Steers were weighed, vaccinated

with Vision 7 and Vista Once SQ (Merck Animal Health, Madison, NJ), given an injectable anthelmintic (Dectomax; Zoetis, Kalamazoo, MI), and received electronic and visual identification tags 13 d prior to study initiation.

Forty-two steers (304 ± 25 kg) were utilized for this trial; steers were selected based on uniformity in BW and health at processing. Steers were weighed on consecutive days (days –1 and 0), blocked by BW on day 0 into light or heavy blocks, and assigned to seven pens (six steers per pen) equipped with a Feed Intake Monitoring System (Dahlke et al., 2008) to measure individual animal feed disappearance. Pens were randomly assigned to one of three dietary treatments: negative control (CON): a corn-based TMR diet formulated to be deficient in Lys ($n = 2$ pens, 12 steers total), positive control (POS): corn-based TMR formulated to meet Lys requirements through ingredients other than rumen-protected Lys ($n = 2$ pens, 12 steers total), and supplemental rumen-protected Lys (RPL): a corn-based diet formulated to meet Lys requirements through the rumen-protected Lys product (AjiPro-L; Ajinomoto Animal Nutrition North America; $n = 3$ pens, 18 steers total). The AjiPro-L product contains 41% crude protein (all Lys) that is 20.3% ruminally soluble. On day 0, steers were implanted with Component TE-IS (80 mg trenbolone acetate + 16 mg estradiol; Elanco Animal Health, Greenfield, IN), and growing period dietary treatments were initiated (Table 1). Growing diets were fed through day 55, and on the morning of day 56 bunks were cleaned out and finishing diets (Table 2) were offered. Sweet Bran (Cargill Corn Milling, Blair, NE) and DDGS were the primary crude protein contributors in CON and RPL growing and finishing diets, while the crude protein in the POS diet was supplied by Sweet Bran and Amino Plus (trademarked soybean meal; Ag Processing Inc, Omaha, NE). Cattle were weighed prior to feeding on two consecutive days to start the trial (days –1, 0), start the finishing period (days 55, 56), and end the trial (days 179 and 180). Single-day interim BW were recorded every 28 d. On day 113, all steers were re-implanted with Component TE-200 (200 mg trenbolone acetate + 20 mg estradiol; Elanco Animal Health).

Sample Collection and Analysis

Ingredients and diets were sampled weekly and analyzed for dry matter (DM) content by placing samples in a 70 °C forced-air oven for 48 h until all moisture was evaporated. Composites were created

Table 1. Growing diet fed days 0 to 55

	CON	POS	RPL
DM, % as fed	62.6	62.9	63.4
Ingredient, %DM			
Dry-rolled corn	35.2	35.1	35.2
DDGS	11.8	2.6	11.2
Corn silage	28.0	28.0	28.0
Sweet Bran ^a	20.0	20.1	20.0
Amino Plus ^b	-	9.2	-
AjiPro L ^c	-	-	0.6
Microingredient pre-mix ^d	5.0	5.0	5.0
Analyzed composition ^e , % DM			
Crude protein	13.0	14.6	14.1
NDF	21.1	19.3	20.7
Ether extract	5.9	5.1	6.1
Ala	0.80	0.81	0.84
Asp	0.74	0.96	0.76
Cys	0.24	0.22	0.27
Glu	1.90	2.16	1.97
Gly	0.50	0.56	0.52
Ile	0.35	0.42	0.37
Leu	1.16	1.20	1.22
Lys	0.37	0.51	0.57
Met	0.22	0.20	0.21
Pro	0.94	0.94	0.96
Thr	0.43	0.49	0.45
Val	0.49	0.55	0.52
Calculated NE _g ^f , Mcal/kg	1.35	1.28	1.34

^aBranded wet corn gluten feed (Cargill Corn Milling, Blair, NE).

^bTrademarked soybean meal (Ag Processing Inc, Omaha, NE).

^cRumen protected Lys product (Ajinomoto Animal Nutrition North America, Eddyville, IA).

^dVitamin and mineral pre-mix provided per kilogram of diet DM: 0.15 mg Co (cobalt carbonate), 10 mg Cu (copper sulfate), 20 mg Mn (manganese sulfate), 0.1 mg Se (sodium selenite), 30 mg Zn (zinc sulfate), 0.5 mg I (calcium iodate), and 2,200 IU vitamin A and 25 IU vitamin E (DSM Nutritional Products, Ames, IA). Provided as a percentage of total diet DM: dried distillers grain (3.04%), limestone (1.50%), salt (0.31%), and Rumensin 90 (0.015%).

^eFrom Dairyland, Inc. (Arcadia, WI) TMR analysis.

^fCalculated using NE_g values of feedstuffs from Nutrient Requirements of Beef Cattle (NASEM, 2016).

and sent to Dairyland Laboratories (Arcadia, WI) for nutrient composition (methods 990.03 and 920.39; AOAC, 1996) and amino acid profiling (Gehrke et al., 1985; Elkin and Griffith, 1985). Ingredients were individually composited for the entirety of the trial. Total mixed rations were composited by diet for growing and finishing. All composites were made using frozen samples that had not been dried.

Individual feed intake was calculated by associating as fed feed disappearance with individual steers via electronic identification. Daily totals of as fed intakes were converted to dry matter intakes (DMI) using the weekly dry matter percentages for

Table 2. Finishing diet formulation fed days 56 to 180

	CON	POS	RPL
DM, % as fed	68.4	68.2	68.2
Ingredient, % DM			
Dry-rolled corn	50.0	50.0	50.0
DDGS	8.0	1.3	7.56
Corn silage	16.0	16.0	16.0
Sweet Bran ^a	21.0	21.0	21.0
Amino Plus ^b	-	6.7	-
AjiPro-L ^c	-	-	0.44
Microingredient pre-mix ^d	5.0	5.0	5.0
Analyzed composition ^e , % DM			
Crude protein	12.8	15.2	13.5
NDF	19.1	17.0	18.7
Ether extract	4.4	7.4	5.1
Ala	0.77	0.81	0.78
Asp	0.71	0.93	0.74
Cys	0.21	0.28	0.27
Glu	1.81	2.17	1.90
Gly	0.48	0.55	0.50
Ile	0.32	0.37	0.34
Leu	1.11	1.18	1.15
Lys	0.37	0.49	0.58
Met	0.18	0.24	0.21
Pro	0.91	0.97	0.99
Thr	0.42	0.48	0.45
Val	0.45	0.50	0.48
Calculated NE _g ^f , Mcal/kg	1.42	1.36	1.41

^aBranded wet corn gluten feed (Cargill Corn Milling, Blair, NE).

^bTrademarked soybean meal (Ag Processing Inc, Omaha, NE).

^cRumen-protected Lys product (Ajinomoto Animal Nutrition North America).

^dVitamin and mineral pre-mix provided per kilogram of diet DM: 0.15 mg Co (cobalt carbonate), 10 mg Cu (copper sulfate), 20 mg Mn (manganese sulfate), 0.1 mg Se (sodium selenite), 30 mg Zn (zinc sulfate), 0.5 mg I (calcium iodate), and 2,200 IU vitamin A and 25 IU vitamin E (DSM Nutritional Products, Ames, IA). Provided as a percentage of total diet DM: dried distillers grain (3.04%), limestone (1.50%), salt (0.31%), and Rumensin 90 (0.015%).

^eFrom Dairyland, Inc. (Arcadia, WI) TMR analysis.

^fCalculated using NE_g values of feedstuffs from Nutrient Requirements of Beef Cattle (NASEM, 2016).

each diet. Individual ADG was calculated by subtracting the initial BW for the period from the final BW for the period and dividing by the total number of days in the period. The gain to feed ratio (G:F) for each individual steer was calculated by dividing ADG by DMI for each period. Dietary metabolizable Lys supply and balance was determined post-hoc using the Beef Cattle Nutrient Requirements Model (NASEM, 2016); solution type was set at empirical calculations. Body weight and DMI values for each treatment within the period were used, so Lys balance represented in Table 3 consider the increased DMI exhibited during this study.

Table 3. Effect of dietary Lys concentrations on growth performance of beef steers

	Treatment			SEM [§]	P-value
	CON [*]	POS [†]	RPL [‡]		Trt
Body weight [¶] , kg					
Day 0	307	308	307	4.0	0.98
Day 56	412 ^a	391 ^b	396 ^b	6.3	0.05
Day 180	640 ^a	610 ^{ab}	602 ^b	11.7	0.04
ADG ^{**} , kg/d					
Days 0 to 28	1.78	1.73	1.66	0.14	0.80
Days 28 to 56	2.11 ^a	1.43 ^b	1.65 ^b	0.14	0.01
Days 0 to 56	1.95 ^x	1.58 ^y	1.66 ^{xy}	0.11	0.06
Days 56 to 180	1.81	1.77	1.66	0.08	0.27
Days 0 to 180	1.87 ^a	1.70 ^{ab}	1.66 ^b	0.06	0.04
DMI ^{††} , kg/d					
Days 0 to 56	8.9	8.1	8.5	0.36	0.39
Days 56 to 180	11.3	11.0	10.7	0.36	0.43
Daily NE _g ^{‡‡} , Mcal/d					
Days 0 to 56	12.0	10.4	11.4	-	-
Days 56 to 180	16.0	15.0	15.1	-	-
Metabolizable Lys supply ^{‡‡‡} , g/d					
Days 0 to 56	44.7	51.5	55.4	-	-
Days 56 to 180	57.0	66.1	65.7	-	-
Metabolizable Lys balance ^{‡‡‡} , g/d					
Days 0 to 56	-14.7	-2.0	-1.3	-	-
Days 56 to 180	-1.3	7.6	7.6	-	-
Gain:Feed					
Days 0 to 56	0.230 ^a	0.192 ^b	0.193 ^b	0.008	0.01
Days 56 to 180	0.160	0.161	0.155	0.006	0.76

*CON—diet formulated to be deficient in Lys.

†POS—diet formulated to meet Lys requirements through feedstuffs.

‡RPL—diet formulated to meet Lys requirements through AjiPro-L (Ajinomoto Animal Nutrition North America, Eddyville, IA).

§Standard error of the mean.

¶Days 0, 56, and 180 BW are averages of two consecutive day weights. A 4% pencil shrink has been applied to all weights.

**ADG—average daily gain.

††DMI—dry matter intake.

‡‡Daily NE_g is the product of calculated NE_g and DMI.

‡‡‡Daily metabolizable Lys supply and balance determined used the NASEM Beef Cattle Nutrient Requirements Model (2016).

^{a,b,c}Means with different superscripts in the same row differ ($P \leq 0.05$).

^{x,y,z}Means with different superscripts in the same row tend to differ ($0.05 < P \leq 0.10$).

Blood was collected prior to feeding from steers on days 0, 56, and 179 via jugular venipuncture into 10 mL vacutainer blood collection tubes containing sodium heparin (BD Vacutainer). Blood was centrifuged at $1,000 \times g$ for 20 min at 4 °C, and plasma was stored at -80 °C. Samples from four steers per pen (28 total) were selected post hoc by determining the steers with the four most similar overall ADG in each pen. Samples from all three collection dates were analyzed by the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO) for physiological free amino acid profiling (Deyl et al., 1986; Fekkes, 1996; Le Boucher et al., 1997).

Steers were harvested at National Beef (Tama, IA). Hot carcass weight (HCW) was recorded on day of harvest. After a 48 h chill, ribeye area (REA), back fat (BF), and kidney, pelvic, and heart fat (KPH) percentage were measured and marbling scores as called by the USDA grader were recorded. Dressing percent was calculated by dividing HCW by final live BW (with a 4% pencil shrink) and multiplying by 100. Yield grade (YG) was calculated using the USDA yield grade equation.

Statistical Analysis

Data were analyzed in Proc Mixed of SAS 9.4 (SAS Institute, Cary, NC). Individual steer

was the experimental unit as feed disappearance was recorded for each individual steer for the entirety of the trial, similarly to [Genther-Schroeder et al. \(2016\)](#). The fixed effects of treatment and block were included in the model for the analysis of feed intake, growth performance, carcass data. Treatment was included in the model as a fixed effect for plasma amino acid analysis with day 0 values used as a covariate. Steers were designated as outliers based on Cook's D values of 0.5 or greater. One CON steer was removed from the study on day 68 due to illness unrelated to treatment; this steer's data were included in the growing period analysis but removed from all finishing period analysis. Data shown are least square means plus the standard error of the mean. Significance was declared at $P \leq 0.05$, and tendencies were declared at $0.05 < P \leq 0.10$.

RESULTS

Growth Performance and Dry Matter Intake

Growth performance and DMI data are reported in [Table 3](#). There were no differences among treatments for BW on day 0 ($P = 0.98$). Body weight was greater for CON compared to POS and RPL on day 56 ($P \leq 0.05$). Steers fed CON had greater BW on day 180 vs. RPL steers ($P = 0.04$), while POS was intermediate. Average daily gain for the growing period (days 0 to 56) tended to be greater for CON compared to POS while RPL was intermediate ($P < 0.06$). However, finishing period (days 56 to 180) ADG was similar across treatments ($P = 0.27$). Overall, ADG across the entire trial (days 0 to 180) was greater in CON vs. RPL ($P = 0.04$) while ADG for POS was intermediate. No differences were found

among treatments in either the growing or the finishing period for DMI ($P \geq 0.39$). The CON-fed steers were more feed efficient than POS or RPL-fed steers during the growing period ($P = 0.01$), while no differences in G:F were noted during the finishing period ($P = 0.76$).

Carcass Characteristics

There were no differences among treatments for any carcass characteristic, including hot carcass weight, dressing percent, ribeye area, back fat, kidney, pelvic, heart fat, marbling, or calculated yield grade ($P \geq 0.13$; [Table 4](#)).

Plasma Amino Acid Profile

Physiological free essential amino acids and plasma urea N are displayed in [Tables 5](#) and [6](#) for days 56 and 179, respectively. Non-essential plasma amino acids for days 56 and 179 are displayed in [Supplementary Tables 1](#) and [2](#), respectively. Steers fed CON and RPL diets had lesser concentrations of Arg, Lys, Ile, Asn, and 1-methyl histidine than POS-fed steers on day 56 ($P \leq 0.02$). Plasma urea N was greater in POS-fed steers ($P = 0.01$) at day 56 than RPL-fed steers, while CON steers were intermediate. The metabolites 3-methyl histidine and ethanolamine were both lesser in POS-fed steers vs. RPL-fed steers ($P \leq 0.05$), while CON-fed steers were intermediate. The POS-fed steers tended to have greater plasma concentrations of Val at day 56 than the RPL-fed steers ($P = 0.09$) with steers fed CON remaining intermediate. Glycine tended to be lesser at day 56 in steers fed CON than RPL-fed steers ($P = 0.08$). Steers fed CON tended to have lesser Thr blood plasma concentrations than POS-fed steers ($P = 0.06$). All other plasma metabolites

Table 4. Effect of dietary Lys concentrations on carcass characteristics of beef steers

	Treatment			SEM ^d	P-value
	CON ^a	POS ^b	RPL ^c		Trt
HCW, kg	411	393	390	8.5	0.13
Dressing percent, %	63.8	63.9	64.2	0.43	0.67
Ribeye area, cm ²	87.1	90.3	88.4	2.45	0.64
Back fat, cm	1.3	1.5	1.4	0.12	0.60
KPH, %	2.79	2.83	3.09	0.19	0.38
Marbling ^e	477	448	440	28	0.81
Yield grade	3.51	3.34	3.38	0.20	0.87

^aCON—diet formulated to be deficient in Lys.

^bPOS—diet formulated to meet Lys requirements through feedstuffs.

^cRPL—diet formulated to meet Lys requirements through AjiPro-L (Ajinomoto Animal Nutrition North America, Eddyville, IA).

^dStandard error of the mean.

^eMarbling scores: small = 400, modest = 500.

Table 5. Effect of dietary Lys concentrations on end of growing (day 56) physiological free essential amino acid profile and urea N in plasma of beef steers

	Treatment			SEM [§]	P-value
	CON [†]	POS [‡]	RPL		Trt
Plasma urea N, mg/dL	9.8 ^{ab}	11.0 ^a	8.5 ^b	0.53	0.01
Essential AA, µg/mL					
Arginine	16.0 ^b	19.1 ^a	16.1 ^b	0.70	0.01
Histidine	10.8	11.4	11.5	0.48	0.51
Isoleucine	14.2 ^b	16.8 ^a	13.4 ^b	0.70	0.01
Leucine	27.6	27.6	26.1	1.51	0.66
Lysine	14.4 ^b	17.9 ^a	15.4 ^b	0.86	0.02
Methionine	4.0	4.1	4.1	0.17	0.87
Phenylalanine	9.8	10.1	10.1	0.32	0.80
Threonine	7.9 ^z	9.9 ^y	9.0 ^{yz}	0.57	0.06
Tryptophan	7.9	8.6	8.7	0.49	0.44
Valine	32.7 ^{yz}	37.6 ^y	31.9 ^z	2.06	0.09

[†]CON—diet formulated to be deficient in Lys.

[‡]POS—diet formulated to meet Lys requirements through feedstuffs.

^{||}RPL—diet formulated to meet Lys requirements through AjiPro-L (Ajinomoto Animal Nutrition North America, Eddyville, IA).

[§]Standard error of the mean.

^{ab}Means with different superscripts in the same row differ ($P \leq 0.05$).

^{yz}Means with different superscripts in the same row tend to differ ($0.05 < P \leq 0.10$).

Table 6. Effect of dietary Lys concentrations on end of finishing (day 179) physiological free essential amino acid profile and urea N in plasma of beef steers

	Treatment			SEM [§]	P-value
	CON [†]	POS [‡]	RPL		Trt
Plasma urea N, mg/dL	10.7 ^b	12.5 ^a	11.0 ^b	0.53	0.04
Essential AA, µg/mL					
Arginine	16.5	15.5	17.1	0.98	0.44
Histidine	12.7	11.7	12.0	0.49	0.37
Isoleucine	14.5	15.6	14.0	0.95	0.41
Leucine	26.8	26.9	26.7	1.79	0.99
Lysine	17.8	16.5	16.8	1.11	0.66
Methionine	4.9	4.2	4.8	0.30	0.22
Phenylalanine	10.3	9.7	10.2	0.40	0.46
Threonine	8.5	9.1	9.0	0.63	0.72
Tryptophan	8.7	8.7	8.5	0.41	0.90
Valine	31.8	36.8	33.5	2.16	0.26

[†]CON—diet formulated to be deficient in Lys.

[‡]POS—diet formulated to meet Lys requirements through feedstuffs.

^{||}RPL—diet formulated to meet Lys requirements through AjiPro-L (Ajinomoto Animal Nutrition North America, Eddyville, IA).

[§]Standard error of the mean.

^{ab}Means with different superscripts in the same row differ ($P \leq 0.05$).

^{yz}Means with different superscripts in the same row tend to differ ($0.05 < P \leq 0.10$).

were not different among dietary treatments ($P \geq 0.16$) at day 56.

At the end of finishing (day 179), steers fed POS had greater plasma urea N than either CON or RPL ($P = 0.04$). Taurine was found in lesser concentrations in the plasma of CON-fed steers than steers fed RPL ($P = 0.04$) with POS-fed steers having intermediate plasma taurine concentrations.

Plasma concentrations at day 179 of 1-methyl histidine were greater ($P = 0.02$), while 3-methyl histidine was lesser ($P = 0.03$) for POS-fed steers than RPL-fed steers. Steers fed CON had greater phosphoserine on day 179 than POS-fed steers ($P = 0.05$). There was a tendency for CON-fed steers to have greater concentrations of cystathionine/allocystathionine on day 179 than POS-fed

steers ($P = 0.10$). Ethanolamine tended to be lesser in POS-fed steers than steers fed RPL ($P = 0.08$). All other plasma metabolites were not different among treatments on day 179 ($P \geq 0.13$).

DISCUSSION

The objective of this study was to evaluate the effects of supplemental rumen-protected Lys (AjiPro-L, Ajinomoto Animal Nutrition North America) on growth performance and carcass characteristics vs. the performance of steers fed a typical Midwestern corn-based, Lys-deficient diet. The hypothesis was that steers fed diets formulated to meet Lys requirements would have improved feed efficiency and greater gains than steers fed a Lys deficient diet.

The present study consisted of a 56-d growing phase (days 0 to 55) with corn silage-based diets followed by finishing (days 56 to 180) on a dry-rolled corn-based diet. For the growing period, metabolizable Lys balance of the CON, POS, and RPL diets was -14.7 , -2.0 , and -1.3 g/d, respectively. The metabolizable Lys balance of the diets for the finishing period was -1.3 , 7.6 , and 7.6 g/d, respectively. Over the entire feeding period, Lys content of the NEG, POS, and RPL diets analyzed to contain 0.37, 0.50, and 0.57% (DM basis), respectively. The CON diet was comparable to other corn silage-based diets not supplemented with Lys as [Xue et al. \(2011\)](#) reported corn silage-based diets to contain 0.39% Lys. Across treatments, cattle performance was greater than predicted. As such, the Lys requirement may have increased to support protein accretion, leading to negative metabolizable Lys balances during growing.

Growth performance responses for RPL-fed steers may have been negatively affected by over-consuming rumen-bypass Lys during finishing. [Klemesrud et al. \(1997\)](#) supplemented feedlot cattle with nine different concentrations of a rumen-protected Lys and Met product. The authors reported a predicted Lys flow of 55.4 g for the control diet; Lys dietary treatments were supplemented between 0 and 12 g Lys/d. A quadratic effect of Lys was reported by these authors, where steers supplemented with 3 or 4 g Lys/d over basal diet concentrations of Lys had greater ADG during the first 56 d, as well as over the length of the entire trial (161 d). Similarly, a quadratic effect of Lys on DMI was noted where steers fed 4 g Lys/d had greater intakes than steers in other treatments ([Klemesrud et al., 1997](#)). The authors concluded that supplementing the basal diet with 3 or 4 g Lys/d

provided similar amounts of Lys (58.4 g Lys/d) as the calculated NRC requirement (60.3 g Lys/d). In a study where rumen-protected Lys and Met was fed to Holstein steers at four different concentrations, steers fed 5 g rumen-protected Lys and Met per day had greater final BW and ADG than steers fed either 0, 10, or 15 g rumen-protected Lys and Met per day ([Hussein and Berger, 1995](#)). However, [Hussein and Berger \(1995\)](#) also reported a cubic response where steers fed 0 or 10 g rumen-protected Lys and Met per day had lesser DMI and greater G:F ratios.

Since the steers fed RPL in the current study consumed more feed than expected and had a more positive Lys balance during finishing, the results from this study may be similar to those seen in other studies where steers have lesser performance responses at greater supplementation of Lys. As Lys is increased in the diet, there may be a greater need for Arg as well to support the increased protein accretion capacity. Chicks fed dietary L-Lys HCl at either 1.19 or 2.44% had linearly increased gains due to graded increases of L-Arg HCl ([Allen and Baker, 1972](#)). However, in a study where no supplemental Lys and Arg, Arg supplemented, Lys supplemented, and Lys and Arg supplemented diets were fed to beef steers, there was no difference among treatments for BW at days 0, 87, or 170 ([Teixeira et al., 2019](#)). Regardless, it may be important to consider Lys and Arg balances together when formulating diets.

By day 56 of the current study, CON-fed steers were approximately 18 kg heavier than both POS- and RPL-fed steers. The CON-fed steers gained this weight advantage between days 28 to 56, as seen in the increased ADG during that time. Samples of TMR were analyzed for nutrient content, including Lys, for days 0 to 27 and days 28 to 56 but were nearly identical for both periods, so averages for the period are reported in [Table 1](#). During growing, the steers fed the CON, POS, and RPL diets consumed 12.0, 10.4, and 11.4 Mcal/d, respectively. This difference in energy consumption is due to the greater DMI in the CON-fed steers and may have caused the greater BW during this period.

Steers fed CON were heavier than RPL-fed steers at the end of the experiment, while POS-fed steers had intermediate final BW. This result is similar to a study which reported steers fed a diet supplementing rumen-protected Lys at 100% of the predicted Lys requirement tended to have greater final BW than the diet supplemented with rumen-protected Lys at 150% of the requirement ([Prestegard and Kerley, 2017](#)). Average daily gain

was not different among treatments during finishing; however, overall ADG assessed across the entire trial was greater in CON-fed steers than RPL. This is driven mostly by growth differences between treatments during the growing period. The G:F ratio during finishing was not different among treatments. Prestegaard and Kerley (2017) also found no differences in feed efficiency; however, the steers fed supplemental rumen-protected Lys at 100% of the requirement had lesser DMI as a percent of BW than other treatments. In a study where bypass Lys was fed to steers at four concentrations (0, 20, 40, or 60 g/d), there was no effect of Lys on any performance statistics, including G:F (de Aguiar Veloso et al., 2018).

Plasma urea N was greater in the POS-fed steers than the CON- and RPL-fed steers at sampling points at the end of growing and finishing (days 56 and 179). Batista et al. (2016) found more N was retained in growing steers when Lys supplementation was increased from 0 to 15 g/d of L-Lys through daily abomasum infusions. Though past studies have reported increased plasma Lys with increasing Lys supplementation (Xue et al., 2011; Batista et al., 2016), the current study found an increase in plasma Lys at day 56 in steers fed POS but plasma Lys did not increase in RPL steers, and no differences in plasma Lys due to treatment were noted at day 179. Similarly, Arg was found in greater concentrations in the plasma in POS-fed steers on day 56, though plasma Arg was not different among treatments on day 179. Wether lambs that were supplemented with 0.75 g Arg HCl/d had increased serum Arg concentrations but decreased ADG compared to lambs supplemented with 0.5 g Arg HCl/d (Davenport et al., 1995). This is similar to the current study, where POS steers had the greatest Arg plasma concentrations, but the lowest ADG during the growing period. This result may be further support that Lys and Arg supplementation may need to be considered together, as mentioned above.

No differences were found in carcass characteristics for steers fed CON, POS, or RPL. This result is different than that seen by Teixeira et al. (2019), where authors reported the diet containing only Lys (40 g bypass Lys/d) resulted in decreased back fat and yield grade and greater Longissimus area when compared to a diet containing no supplemental Lys. However, similar to the present trial, de Aguiar Veloso et al. (2019) noted that Lys had no effect on carcass characteristics when steers were supplemented with 0 or 40 g Lys daily.

To conclude, CON-fed steers had greater final BW and overall ADG than RPL-fed steers, while

POS-fed steers remained intermediate, though there were no differences among treatments for HCW or other carcass characteristics. Due to greater DMI than predicted, the metabolizable Lys balance for all treatments was negative during growing. Both POS and RPL diets had positive metabolizable Lys balances during finishing, and the increased metabolizable Lys balance may have decreased performance if other amino acids were imbalanced, such as Arg.

SUPPLEMENTARY DATA

Supplementary data are available at *Translational Animal Science* online.

ACKNOWLEDGMENTS

We would like to acknowledge partial financial support from Ajinomoto Animal Nutrition North America (Eddyville, IA). We are grateful to Dr. Monty Kerley for his advice and assistance with diet formulations.

Conflict of interest statement. None declared.

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