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Influence of supplemental flavomycin on growth performance, carcass characteristics, and nutrient digestibility in calf-fed Holstein steers

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ABSTRACT

The objective of this study was to evaluate the influence of supplemental flavomycin on cattle growth performance, carcass characteristics, diet digestibility, and ruminal fermentation characteristics of calf-fed Holstein steers. One hundred Holstein steers (123 ± 7 kg) were balanced by weight and assigned to 20 pens. Dietary treatments consisted of a steam flaked corn-based diet supplemented with (dry matter basis): 1) control, no feed additive; 2) 6.6 mg/kg flavomycin; 3) 13.2 mg/kg flavomycin, and 4) 30 mg/kg monensin (MON). There were no treatment effects ($P \geq 0.17$) on live weight, average daily gain (ADG), and gain efficiency. Flavomycin did not affect dry matter intake (DMI; $P \geq 0.24$). Flavomycin supplementation did not affect ($P \geq 0.37$) the ratio of observed vs. expected DMI. However, MON decreased ($P = 0.02$) observed vs. expected DMI by 3.7%. There were no treatment effects ($P \geq 0.44$) on ruminal pH or temperature. Flavomycin did not affect ($P \geq 0.13$) carcass characteristics and liver abscess among steers. Four Holstein steers (463 ± 20 kg) with ruminal cannulas were used in 4 × 4 Latin square experiment to study treatment effects on site and extent of digestion, ruminal pH, and volatile fatty acid (VFA) molar proportions. Dietary treatments were the same as experiment 1. Flavomycin tended to increase (linear effect, $P = 0.07$) ruminal organic matter (OM) digestion, associated with increased (linear effect, $P < 0.01$) ruminal starch digestion. Supplementing flavomycin at 13.2 mg/kg decreased net microbial N synthesis (quadratic effect, $P = 0.03$). Compared with control, MON tended to increase ($P = 0.10$) ruminal neutral detergent fiber (NDF) digestion and increased ($P < 0.01$) ruminal starch digestion. Monensin did not affect ($P = 0.39$) net microbial N synthesis, but decreased ($P = 0.01$) ruminal degradation of feed nitrogen (N). There were no treatment effects ($P > 0.10$) on total tract apparent digestion of DM, OM, NDF, and starch. Flavomycin decreased ruminal pH (quadratic effect, $P < 0.01$) measured 4 h postprandial. Compared with control, MON increased ruminal pH ($P = 0.03$). Flavomycin increased (linear effect, $P = 0.03$) ruminal propionate molar proportion and decreased (linear effect, $P \leq 0.04$) ruminal molar proportions of acetate and butyrate, and decreased (linear effect, $P = 0.02$) acetate:propionate molar ratio and estimated methane production. We conclude that supplementing flavomycin at 6.6 or 13.2 mg/kg had no major effects on cattle growth performance, carcass characteristics, diet digestibility, and ruminal fermentation characteristics.

Key words: flavomycin, feedlot, Holstein, performance

INTRODUCTION

Monensin (MON) is among the ionophores most commonly used in growing-finishing diets for feedlot cattle (Samuelson et al., 2016), having potentially beneficial effects on gain efficiency and digestive function (Goodrich et al., 1984). These effects are partially attributable to selective action on the gram-positive bacteria in the rumen, potentially decreasing ruminal acetate:propionate molar ratio and methane energy losses (Russell and Strobel, 1988; Zinn et al., 1994), and reducing maintenance energy requirements (Zinn, 1987).

Flavomycin is a fermentation product of *Streptomyces* spp. that inhibits bacterial cell wall peptidoglycan synthesis (Volke et al., 1997). Very little research has been reported evaluating the influence of flavomycin supplementation on feedlot cattle growth performance, and optimal levels of supplementation have not been established. De Schrijver et al. (1991) observed increased average daily gain (ADG) and gain efficiency with flavomycin supplementation (10 mg/kg) of a moderate energy diet (corn silage- or beet pulp-based) feed to feedlot bulls. Lemos et al. (2016) observed that ADG and gain efficiency were not appreciably different in bull fed a no-roughage whole corn diet supplemented with monensin (30 mg/kg) vs. flavomycin (4.4 mg/kg). Smith et al. (2019) observed increased dry matter intake (DMI) and a tendency for increased ADG in steers fed a corn-based finishing diet supplemented with flavomycin (1.6 mg/kg) vs. monensin (30 mg/kg). However, differences in gain efficiency were not appreciable. The influence of flavomycin supplementation on growing finishing diets for calf-fed Holstein steers has not been previously evaluated.

Therefore, the objective of this study was to evaluate the influence of supplemental flavomycin on site and extent of digestion, growth performance, energetic efficiency, ruminal pH, ruminal temperature, and carcass characteristics in calf-fed Holstein steers fed a conventional growing-finishing diet. A supplemental monensin treatment was included as a positive test of the control diet.

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MATERIALS AND METHODS

All procedures involving animal care and management were in accordance with and approved by the University of California, Davis, Animal Use and Care Committee (protocol # 18811 and 18812).

Experiment 1

Cattle management and treatments. One hundred Holstein steers (initial body weight (BW) = 123 ± 7 kg) originating from Tulare, California, were received at the University of California Desert Research Center, Holtville, CA on 2 February 2021. Upon arrival, steers were vaccinated subcutaneously (SC) for infectious bovine rhinotracheitis, bovine viral diarrhea, parainfluenza 3, and bovine respiratory syncytial virus (Bovi-shield Gold 4, Zoetis Animal Health, New York, NY), clostridial (UltraChoice 8, Zoetis Animal Health, New York, NY), gram-negative septicemic diseases (Endovac-Beef; IMMVAC, Inc. Columbia, MO), treated for parasites (Dectomax Injectable, Zoetis Animal Health, New York, NY) and injected (SC) with 400 mg Tulathromycin (Draxxin, Zoetis, Kalamazoo, MI). On day 28, steers were weighed and injected SC with three separate injections: Endovac-Beef vaccination, Ultra Choice 8 booster vaccination, and 1,000,000 IU vitamin A (Vitamin AD, Huvepharma, Inc., St. Joseph, MO). Pens were 43 m^2 with 22 m^2 overhead shade, automatic waterers, and 2.4 m fence-line feed bunks. The trial was initiated on 5 May 2021, following a 111-d initial growing period. Steers were balanced by individual off-truck weight (initial shrunk weight, Hostetler Scales UMC555AAAAA, 2267 kg × 0.45 kg, Imperial, CA) into five weight groups and assigned within weight groups to 20 pens, 5 steers/pen. On days 1 and 112 of the study, steers were implanted (Revalor S, Intervet, Millsboro, DE) and injected to meet vitamin A requirement with a product containing vitamins E, A, and D (Vital E-A + D, Stuart Products, Bedford, TX).

The health status of cattle was monitored daily by trained personnel for signs of illness or pinkeye. Cattle with signs of illness were pulled out, classified as morbid, and treated with an antimicrobial if the rectal temperature was ≥39.5 °C. Antimicrobial treatments were conducted following a veterinarian's recommendation. A post-treatment interval of 3 d was implemented after the first and second treatments. If cattle remained morbid after the third treatment and the prognosis of a full recovery was unlikely, cattle were removed from the study.

On 25 June, 56 days after initiation of the project, 20 steers (1 steer per pen) were orally administered a SmaX-tec intraruminal bolus. SmaX-tec animal care technology enables the continuous (every 10 min) real-time measurement of ruminal temperature. The data were measured remotely with the help of antennas (smaX-tec animal care technology, Graz, Austria) located in close proximity to cattle pens.

Dietary treatments are shown in Table 1, consisting of a steam-flaked corn-based diet supplemented with (DM basis): 1) control, no additive; 2) 6.6 mg/kg flavomycin (Gainpro, Huevapharma, Peachtree City, GA); 3) 13.2 mg/kg flavomycin, and 4) 30 mg/kg monensin (MON; Rumensin 90, Elanco, Greenfield, IN). The non-supplemented basal diet and MON served as negative and positive controls, respectively. Steers were allowed ad libitum access to dietary treatments and water through automatic waterers. Fresh feed was provided in a singular, daily feeding allowing for a daily feed residual of ≈5%. Steam-flaked corn was purchased from a local feedlot. The steam-flaked corn was allowed to air dry (5 d) before use in diet preparation. Forages (sudangrass hay and alfalfa hay) were ground in a hammer mill (Bear Cat #1A-S, Westerns Land and Roller Co., Hastings, NE) with a 2.6-cm (sudangrass hay) or 5.0-cm (alfalfa hay) screen before incorporation into the complete mixed diets. Once all the ingredients were included in the mixer, the diets were mixed for 5–7 min. Diets were prepared at weekly intervals and stored in plywood boxes located in front of each pen. Feed samples were collected from each batch and composited weekly for DM analysis (oven-drying at 105 °C until no further weight loss; method 930.15, Association of Official Analytical Chemists [AOAC], 2000) for determination of DMI. On the same day of cattle weighing, refusals from feed

Table 1. Composition of experimental diets (DM basis)

Item	Dietary treatments[2]			
		Flavomycin, mg/kg		MON, mg/kg
	CON	6.6	13.2	30
Ingredient composition, % DM[1]				
Sudangrass hay	8.00	8.00	8.00	8.00
Alfalfa hay	4.00	4.00	4.00	4.00
Tallow	2.50	2.50	2.50	2.50
Molasses, cane	4.00	4.00	4.00	4.00
Distillers grains w/solubles	17.50	17.50	17.50	17.50
Steam flaked corn	61.07	61.05	61.07	61.07
Urea	0.80	0.80	0.80	0.80
Dicalcium phosphate	0.15	0.15	0.15	0.15
Limestone	1.56	1.56	1.56	1.56
Magnesium oxide	0.12	0.12	0.12	0.12
TM[1] salt[3]	0.30	0.30	0.30	0.30
Nutrient composition[4]				
Dry matter, %	89.2	89.2	89.2	89.2
NEm[1], Mcal/kg	2.20	2.20	2.20	2.20
NEg[1], Mcal/kg	1.53	1.53	1.53	1.53
Crude protein, %	14.9	14.9	14.9	14.9
Rumen DIP[1], %	60.0	60.0	60.0	60.0
Rumen UIP[1], %	40.0	40.0	40.0	40.0
Ether extract, %	7.17	7.17	7.17	7.17
Ash, %	5.89	5.91	5.91	5.91
Nonstructural CHO[1], %	53.9	53.9	53.9	53.9
NDF[1], %	20.5	20.5	20.5	20.5
Calcium, %	0.80	0.80	0.80	0.80
Phosphorus, %	0.40	0.40	0.40	0.40
Potassium, %	0.83	0.83	0.83	0.83
Magnesium, %	0.28	0.28	0.28	0.28
Sulfur, %	0.20	0.20	0.20	0.20

[1]DM, dry matter; NDF, neutral detergent fiber; NE_g, net energy for gain; NE_m, net energy for maintenance; DIP, degradable intake protein; UIP, undegradable intake protein; CHO, carbohydrates.
[2]Treatments: CON: control no antibiotic; flavomycin (Gainpro, Huevapharma, Peachtree City, GA); MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN).
[3]Trace mineral salt contained: CoSO4, 0.068%; CuSO4, 1.04%; FeSO4, 3.57%; ZnO, 0.75%; MnSO4, 1.07%; KI, 0.052%; and NaCl, 93.4%.
[4]Based on tabular values for individual feed ingredients (NASEM, 2000).

bunks were shoveled back into the plywood boxes and boxes were weighed for remaining feed for determination of feed intake. Steers were weighed every 28 days and feed was not withheld before weighing.

Observed vs. expected DMI. The expected DMI of implanted calf-fed Holstein steers was determined as (Torrentera et al., 2017): DMI, kg/d = ((0.085 $LW^{0.66}$)/NEm)) + (0.175 ((478/550) $LW)^{0.66}$ $ADG^{0.234}$)/NEg), where NEm and NEg are 2.20 and 1.53, respectively (Table 1).

Carcass measurements. Before processing carcasses, a final live weight was recorded similar to previous live weights. Steers were transported approximately 18 miles to One World Beef (Brawley, CA) for slaughter. Hot carcass weights were obtained from all steers at slaughter (203 days on trial). Liver abscess was evaluated at the slaughter facility. Livers with abscesses or scars were visually identified and marked. After carcasses were chilled for 48 h, the following measurements were obtained: 1) longissimus muscle area (ribeye area), taken by direct grid reading of the muscle at the twelfth rib; 2) subcutaneous fat over the ribeye muscle at the twelfth rib taken at a location 3/4 the lateral length from the chine bone end; 3) kidney, pelvic and heart fat (KPH) as a percentage of hot carcass weight, and 4) marbling score (USDA, 1997).

Statistical design and analysis. The experimental data were analyzed as a completely random design experiment considering pen as experimental unit, according to the following statistical model: $Yi = \mu + Ti + \varepsilon i$, where μ is the common experimental effect, Tj represents dietary treatment effect, and εi represents the residual error (Statistix 10, Analytical Software, Tallahassee, FL). Treatments effects were tested using the following contrasts: 1) linear effect of flavomycin level; 2) quadratic effect of flavomycin level; and 3) control vs. monensin. Coefficients for polynomial contrasts (linear, quadratic effects of flavomycin) with unequal spacing (0, 6.6, and 13.2 mg/kg of virginiamycin). In determination of ADG, interim and final shrunk weights were reduced by 4% to account for digestive tract fill. Treatment main effects and interactions were tested by means of orthogonal contrasts.

Experiment 2

Animals and sampling. Four Holstein steers (initial BW = 463 ± 20 kg) with ruminal and proximal duodenal cannulas (3.8 cm internal diameter; Zinn and Plascencia, 1993) were used in 4 × 4 Latin square experiment to study treatment effects on site and extent of digestion, ruminal pH, and VFA molar proportions. Steers were housed (indoor facilities) in individual pens (4 m^2) with concrete floor covered by neoprene carpet, and equipped with automatic waterers and individual feed bunks. Diets were fed at 08:00 and 20:00 h daily. Treatments were the same as those used in experiment 1 with the incorporation of 0.4% chromic oxide as an inert digesta marker (Table 1). All steers were fed the same basal diet. Chromic oxide was added to the mineral premix and then added to the basal diet during feed mixing. Dietary treatments (flavomycin and monensin) were top-dressed on the individual steer's feed allotment at time of feeding (half dose in each feeding). To avoid the complications of feed refusals, DMI was restricted to 9.65 kg/d. Experimental periods consisted of 17-d diet adjustment period followed by a 4-d collection period. During collection, duodenal and fecal samples were taken twice daily as follows: day 1, 07:50 and 13:50 h; day 2, 09:00 and 15:00 h; day 3, 10:50 and 16:50 h; and day 4, 12:00 and 18:00 h. Individual samples consisted of approximately 700 mL of duodenal chyme and 200 g (wet basis) of fecal material. Samples of each steer within each collection period were composited for analysis. During the final day of each collection period, ruminal samples were obtained from each steer via the ruminal cannula at 4 h after feeding. Ruminal fluid pH was determined on freshly collected samples. Samples were then strained through four layers of cheesecloth. Two milliliters of freshly prepared metaphosphoric acid (250 g/L) was added to 8 mL of strained ruminal fluid. Samples were then centrifuged (17,000 × *g* for 10 min), and supernatant fluid was stored at −20 °C until volatile fatty acid (VFA) analysis (gas chromatography; Zinn, 1988). Upon completion of the experiment, ruminal fluid was obtained via the ruminal cannula from all steers and composited for isolation of ruminal bacteria via differential centrifugation (Bergen et al., 1968).

Feed and fecal samples were subjected to the following analysis: DM (oven drying at 105 °C until no further weight loss); ash (method 942.05, AOAC, 1987), Kjeldahl N (method 984.13, AOAC, 2000); aNDFom [Van Soest et al., 1991, corrected for NDF-ash, incorporating heat stable α-amylase (Ankom FAA, Ankom Technology, Macedon, NY) at 1 mL per 100 mL of NDF solution]; chromic oxide (Hill and Anderson, 1958); and starch (Zinn, 1990). Duodenal samples were subjected the following analysis: DM (oven drying at 105 °C until no further weight loss); ash (method 942.05, AOAC, 1987), Kjeldahl N (method 984.13, AOAC, 2000), ammonia N (method 941.04, AOAC, 2000); aNDFom [Van Soest et al., 1991, corrected for NDF-ash, incorporating heat stable α-amylase (Ankom FAA, Ankom Technology, Macedon, NY)] at 1 mL per 100 mL of NDF solution); purines (Zinn and Owens, 1986); chromic oxide (Hill and Anderson, 1958); and starch (Zinn, 1990). Duodenal flow and fecal excretion of DM were calculated based on marker ratio, using chromic oxide. Microbial organic matter (MOM) and N (MN) leaving the abomasum were calculated using purines as a microbial marker (Zinn and Owens, 1986).

Organic matter (OM) fermented in the rumen was considered equal to OM intake minus the difference between the amount of total OM reaching the duodenum and MOM reaching the duodenum. Feed N escape to the small intestine was considered equal to total N leaving the abomasum minus ammonia-N, MN, and endogenous N (0.195 × $BW^{0.75}$; Ørskov et al., 1986). Methane production (mol/mol glucose equivalent fermented) was estimated based on the theoretical fermentation balance for observed molar distribution of VFA (Wolin, 1960).

Statistical design and analysis. Treatment effects on characteristics of digestion, ruminal pH, and VFA molar proportions were analyzed as a 4 × 4 Latin square design (Stastix 10, Analytical Software, Tallahassee, FL). The statistical model for the trial was as follows: Yijk =μ+ Ai + Pj + Tk + Eijk, where: Yijk is the response variable, μ is the common experimental effect, Ai is the animal effect (df = 3), Pj is the period effect (df = 3), Tk is the treatment effect (df = 3), and Eijk is the residual error (df = 6). Treatments effects were tested using the following contrasts: 1) linear effect of flavomycin level; 2) quadratic effect of flavomycin level; and 3) control vs. monensin. Coefficients for polynomial contrasts (linear, quadratic effects of flavomycin) with unequal spacing (0, 6.6, and 13.2 mg/kg of virginiamycin).

RESULTS AND DISCUSSION

Treatment effects on growth performance are shown in Table 2. There were no treatment effects ($P \geq 0.12$) on morbidity or mortality; both averaging 3%. There were no treatment effects ($P \geq 0.17$) on live weight and ADG. Across treatments, overall (203 d) ADG was 1.53 kg/d, 93% of projected ADG based on the generalized equation for implanted calf-fed Holstein steers (1.65 kg/d; Torrentera et al., 2017). The slightly lower than expected ADG is likely because of the characteristically extreme ambient summer conditions during the course of this study (Table 3). Torrentera et al. (2017) observed ADG of calf-fed Holstein steers approaches maximal ADG at a live weight of 370 kg. In the present study steers would have approached that weight around mid-July, a period when extreme ambient conditions (THI > 80) can depress DMI and corresponding ADG.

Across treatments, observed DMI was consistent with expected (observed/expected DMI = 1.00), supporting the consideration that differences in observed vs. expected ADG are consistent with DMI (Table 2). Flavomycin did not affect DMI ($P \geq 0.24$). However, compared with control, MON tended ($P = 0.08$) to reduce DMI. Decreased DMI has been a characteristic response to MON supplementation (Duffield et al., 2012). Gain efficiency was not affected ($P \geq 0.39$) by dietary treatments. Along with the decrease in DMI it was anticipated that MON would increase gain efficiency (Duffield et al., 2012). Failure to detect and appreciable difference in gain efficiency with the MON treatment was due, in part, to a numerically decreased ADG. Evaluating treatment effects based on observed vs. expected DMI removes bias associated with differences in ADG. Thus, whereas flavomycin supplementation did not affect ($P \geq 0.12$) the ratio of observed vs. expected DMI, MON decreased ($P = 0.02$) the ratio by 3.7%. This result, where MON decreases DMI, is consistent with generalized improvement in efficiency of energy utilization due to MON supplementation (Duffield et al., 2012).

Very little research has been reported evaluating the influence of flavomycin supplementation on feedlot cattle growth performance. Moreover, there are no prior studies evaluating flavomycin supplementation of calf-fed Holstein steers. De Schrijver et al. (1991) observed increased ADG and gain efficiency with flavomycin supplementation (10 mg/kg) of a

Table 2. Influence of flavomycin or monensin on growth-performance of calf-fed Holstein steers

	Dietary treatments[2]					*P*-value		
		Flavomycin, mg/kg		MON, mg/kg		Flavomycin		
	CON	6.6	13.2	30	SEM	Linear	Quadratic	Control vs. MON
Body weight, kg								
Initial	295.7	296.8	293.9	295.7	1.1	0.31	0.17	0.99
112 d	461.8	468.1	459.3	462.4	6.2	0.78	0.34	0.98
203 d	607.1	611.1	604.2	600.8	7.1	0.78	0.55	0.80
ADG[1]								
1–112 d	1.48	1.53	1.48	1.49	0.052	0.92	0.46	0.98
112–203 d	1.59	1.57	1.59	1.52	0.048	0.95	0.70	0.29
1–203 d	1.53	1.55	1.53	1.51	0.033	0.89	0.68	0.51
DMI[1]								
1–112 d	7.59	7.77	7.54	7.27	0.134	0.82	0.24	0.12
112–203 d	10.32	10.34	10.15	9.85	0.180	0.54	0.65	0.09
1–203 d	8.82	8.93	8.72	8.44	0.139	0.64	0.37	0.08
G/F[1]								
1–112 d	0.195	0.197	0.195	0.205	0.005	0.99	0.81	0.24
112–203 d	0.155	0.152	0.157	0.154	0.004	0.70	0.39	0.88
1–203 d	0.174	0.173	0.175	0.178	0.002	0.65	0.67	0.21
EXP DMI[1]								
1–112 d	7.73	7.83	7.69	7.74	0.092	0.80	0.35	0.93
112–203 d	9.84	9.87	9.79	9.72	0.102	0.79	0.68	0.42
1–203 d	8.73	8.78	8.70	8.66	0.082	0.77	0.53	0.54
OBS/EXP DMI[1]								
1–112 d	0.982	0.993	0.980	0.939	0.012	0.93	0.44	0.03
112–203 d	1.050	1.049	1.038	1.015	0.011	0.46	0.71	0.05
1–203 d	1.009	1.017	1.002	0.973	0.009	0.60	0.37	0.02
Morbidity, %	8.0	0.0	0.0	4.0	3.4	0.12	0.35	0.42
Mortality, %	4.0	4.0	4.0	0.0	3.2	0.99	0.99	0.40

[1]ADG, average daily gain; DMI, dry matter intake; G/F, gain efficiency; EXP DMI, expected dry matter intake; OBS/EXP DMI, observed versus expected dry matter intake ratio.
[2]Treatments: CON: control no antibiotic; flavomycin (Gainpro, Huevapharma, Peachtree City, GA); MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN).

moderate energy diet (corn silage- or beet pulp-based) fed to bulls in the feedlot. In addition, Smith et al. (2019) observed an increased in DMI and a tendency for an increase in ADG in steers fed a corn-based finishing diet supplemented with flavomycin (1.6 mg/kg) vs. monensin (30 mg/kg). However, differences in gain efficiency were not appreciable (Smith et al., 2019). Lemos et al. (2016) observed that ADG and gain efficiency were not appreciably different in bulls fed a no-roughage whole corn diet supplemented with flavomycin (4.4 mg/kg) vs. monensin (30 mg/kg). It should be noted that the level of flavomycin supplementation in these three feedlot studies was quite variable. Indeed, level of supplementation to achieve optimal response has not been established.

There were no treatment effects ($P \geq 0.44$) on ruminal pH or ruminal temperature during three 7-wk periods of the study representing high, moderate, and cooler ambient conditions (Table 3). Treatment effects on carcass characteristics are shown in Table 4. There were no effects of flavomycin or monensin supplementation on carcass characteristics in the current study. This is consistent with Lemos et al. (2016) where flavomycin (4.4 mg/kg) did not affect ($P \geq 0.13$) carcass measures. In contrast, Smith et al. (2019) observed increased fat thickness and marbling score in steers fed a corn-based finishing diet supplemented with flavomycin (1.6 mg/kg) vs. monensin (30 mg/kg). Consistent with previous studies (Meyer et al., 2009; Salinas et al., 2009; Montano et al., 2014), differences in carcass characteristics between MON and control were not appreciable, although MON tended ($P = 0.06$) to have smaller LM area. Marbling score averaged 5.41 (modest), and all carcass were graded choice or greater (94% choice, 6% prime; data not shown). There were no incidences of liver abscess among steers in the study, and no effect ($P \geq 0.21$) of dietary treatment on liver scars.

Treatment effects on characteristics of digestion are shown in Table 5. Flavomycin tended to increase (linear effect, $P = 0.07$) ruminal OM digestion and increased ruminal starch digestion (linear effect, $P < 0.01$). Flavomycin supplementation decreased (linear effect, $P = 0.01$)

Table 3. Influence of flavomycin or monensin supplementation on ruminal pH and ruminal temperature during 7-week periods representing high moderate and cool ambient temperatures

Item	Dietary treatments[1]					*P*-value		
		Flavomycin, mg/kg		MON, mg/kg		Flavomycin		
	CON	6.6	13.2	30	SEM	Linear	Quadratic	Control vs. MON
30 June–August 18[2]								
Ruminal pH								
Maximum	6.52	6.52	6.61	6.64	0.16	0.98	0.99	0.96
Minimum	5.33	5.16	5.36	5.35	0.10	0.99	0.53	0.99
Average	5.92	5.86	6.07	6.08	0.12	0.90	0.86	0.86
Ruminal temperature, C								
Maximum	41.4	41.3	41.5	41.1	0.1	0.87	0.76	0.63
Minimum	39.3	39.2	39.4	39.1	0.1	0.66	0.62	0.86
Average	40.5	40.4	40.6	40.3	0.1	0.90	0.69	0.66
19 August–6 October[3]								
Ruminal pH								
Maximum	6.31	6.40	6.33	6.56	0.16	0.99	0.98	0.75
Minimum	5.49	5.22	5.65	5.48	0.14	0.89	0.28	0.99
Average	5.88	5.76	5.98	6.02	0.12	0.95	0.75	0.88
Ruminal temperature, C								
Maximum	41.1	41.1	41.2	40.9	0.1	0.91	0.98	0.78
Minimum	38.9	38.9	39.1	38.9	0.1	0.44	0.92	1.00
Average	39.9	39.9	40.2	39.9	0.1	0.70	0.92	0.92
October 7–November 24[4]								
Ruminal pH								
Maximum	6.36	6.32	6.29	6.56	0.18	0.99	1.00	0.88
Minimum	5.33	5.21	5.56	5.45	0.15	0.77	0.67	0.95
Average	5.86	5.76	5.96	6.02	0.12	0.94	0.79	0.84
Ruminal temperature, C								
Maximum	40.2	40.3	40.3	40.3	0.1	0.89	0.99	0.98
Minimum	38.7	38.7	38.8	38.7	0.1	0.54	0.99	0.96
Average	39.5	39.5	39.6	39.5	0.1	0.70	1.00	0.96

[1]Treatments: CON: control no antibiotic; flavomycin (Gainpro, Huevapharma, Peachtree City, GA); MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN).
[2]Minimum temperature 23.0 °C; maximum temperature 47.0 °C; average temperature 33.9 °C.
[3]Minimum temperature 14.2 °C; maximum temperature 44.7 °C; average temperature 30.5 °C.
[4]Minimum temperature 9.2 °C; Maximum temperature 32.6 °C; Average temperature 20.6 °C.

Table 4. Influence of flavomycin or monensin on carcass characteristics of calf-fed Holstein steers

	Dietary treatments[2]					*P*-value		
		Flavomycin, mg/kg		MON, mg/kg		Flavomycin		
	CON	6.6	13.2	30	SEM	Linear	Quadratic	Control vs. MON
HCW[1], kg	377.8	376.9	371.5	369.7	4.98	0.39	0.71	0.27
Dressing percentage	62.2	61.7	61.5	61.5	0.3	0.13	0.68	0.15
KPH, [1,3] %	3.45	3.49	3.51	3.44	0.07	0.54	0.93	0.96
Fat thickness, cm	0.73	0.78	0.71	0.77	0.06	0.78	0.44	0.67
LM[1] area, cm^2	85.3	81.7	81.8	81.0	1.49	0.13	0.32	0.06
Marbling score[4]	5.79	5.23	5.31	5.30	0.25	0.19	0.31	0.18
Calculated yield grade	2.82	3.06	2.93	3.06	0.11	0.50	0.18	0.14
Liver abscess,%	0	0	0	0				
Liver abscess scars, %	21.0	9.0	16.0	4.0	5.8	0.56	0.21	0.06

[1]HCW, hot carcass weight; KPH, kidney, pelvis, and heart fat; LM, longissimus muscle.
[2]Treatments: CON: control no antibiotic; flavomycin (Gainpro, Huevapharma, Peachtree City, GA); MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN).
[3]KPH fat as a percentage of carcass weight.
[4]Coded: minimum slight = 3.0, minimum small = 4.0, minimum modest = 5.0, minimum moderate = 6.0, and so on.

postruminal starch digestion andruminal net microbial N synthesis (quadratic effect, P = 0.03). However, there was a compensating increase in ruminal escape of feed N (quadratic effect, P = 0.04). Very little has been previously reported evaluating the effects of flavomycin on characteristics of ruminal and total tract digestion of finishing diets for feedlot cattle. Consistent with the present study, Lemos et al. (2016) did not observe an effect of flavomycin supplementation (4.4 mg/kg) of a whole-corn finishing diet on measures of total tract digestion.

Compared with control, MON tended to increase (P = 0.10) ruminal NDF digestion and increased (P < 0.01) ruminal starch digestion. However, MON did not affect (P = 0.39) net microbial N synthesis but decreased (P = 0.01) ruminal degradation of feed N. Neither flavomycin nor MON appreciably affected (P ≥ 0.16) ruminal N efficiency (nonammonia N entering the small intestine/N intake).

There were no treatment effects (P ≥ 0.18) on total tract apparent digestion of DM, OM, NDF, and starch (Table 5). However, compared with control, MON tended (P = 0.08) to increase apparent N digestion. The influence of supplemental monensin on characteristics of ruminal and total tract digestion has been variable. As with the present study, Zinn (1987) did not observe an effect of monensin supplementation on ruminal OM digestion. However, decreased ruminal OM digestion has been the more consistent response to monensin supplementation (Zinn and Borques, 1993; Zinn et al., 1994; Surber and Bowman, 1998; Salinas-Chavira et al., 2009; Montano et al., 2014). Decreased ruminal degradation of dietary crude protein, as observed in the present study, has also been a consistent response to monensin supplementation (Poos et al., 1979; Zinn and Borques 1993; Zinn et al., 1994; Surber and Bowman, 1998). This effect is apparently due to a marked reduction in monensin sensitive amino acid fermenting bacteria (Yang and Russell, 1993). As with the present study, effects of supplemental monensin on net flow of microbial N to the small intestine have been small or nonappreciable (Zinn and Borques, 1993; Surber and Bowman, 1998). Whereas in other studies (Poos et al., 1979; Zinn et al., 1994; Montano et al., 2014), supplemental monensin reduced net ruminal microbial N synthesis. Although monensin supplementation has been reported to depress total tract OM digestion (Simpson, 1978; Poos et al., 1979; Salinas et al., 2009), the more consistent response to supplemental monensin on measures of total tract digestion has been small or non-appreciable in feedlot cattle fed growing-finishing diets (Zinn and Borquez, 1993; Zinn, 1994; Suber and Bowman, 1998).

Treatment effects on ruminal pH and VFA molar proportions are shown in Table 6. The influence of supplemental flavomycin on ruminal pH and VFA molar ratios in cattle fed steam-flaked corn-based finishing diets has not been previously reported. In the current experiment, supplementing flavomycin decreased ruminal pH (quadratic effect, P < 0.01) measured 4 h postprandial. Consistent with Montano et al. (2014), MON increased (P = 0.03) ruminal pH compared with control. Flavomycin increased (linear effect, P = 0.03) ruminal propionate molar proportion and decreased (linear effect, P ≤ 0.04) ruminal molar proportions of acetate, butyrate, and acetate:propionate molar ratio and estimated methane production. Compared with control, MON tended to decrease ruminal butyrate molar proportion (P = 0.08) and acetate:propionate molar ratio (P = 0.09).

The effects of MON supplementation on ruminal VFA concentration have been inconsistent. Whereas, in some studies MON decreased acetate:propionate ratio (Rogers, 1991; Zinn and Borques, 1993; Guan et al., 2006), others have reported no effect of MON supplementation on this ratio (Zinn, 1987; Zinn et al., 1994; Salinas-Chavira et al., 2009; Felix and Loerch, 2011).

CONCLUSIONS

Supplementing calf-fed Holstein steers fed a steam-flaked corn-based diet with flavomycin at 6.6 or 13.2 mg/kg or 30 mg/kg of monensin had similar effects on cattle growth performance, carcass characteristics, diet digestibility, and ruminal fermentation characteristics.

Table 5. Influence of flavomycin or monensin supplementation on apparent ruminal and total tract digestion in Holstein steers

Item	Dietary treatments[2]					*P*-value		
		Flavomycin, mg/kg		MON, mg/kg		Flavomycin		
	CON	6.6	13.2	30	SEM	Linear	Quadratic	Control vs. MON
Steer replicates	4	4	4	4				
Intake, g/d								
DM[1]	9,625	9,627	9,673	9,675				
OM[1]	9,077	9,078	9,125	9,126				
NDF[1]	1,840	1,840	1,840	1,840				
N[1]	221	221	221	221				
Starch	3,727	3,727	3,727	3,727				
Flow to duodenum, g/d								
OM	5,078^{a}	5,109^{a}	4,636^{b}	4,777^{ab}	119	0.04	0.14	0.12
NDF	1,167	1,138	1,046	1,040	49	0.14	0.62	0.10
Starch	819^{a}	795^{a}	612^{b}	593^{b}	34	<0.01	0.11	<0.01
N	224^{ab}	225^{ab}	214^{a}	231^{b}	4.6	0.16	0.35	0.36
Ammonia N	10.07	9.66	9.73	10.33	0.34	0.52	0.58	0.60
Nonammonia N	214^{ab}	215^{ab}	204^{a}	221^{b}	4.4	0.16	0.31	0.36
Microbial N	97.6^{a}	103.3^{a}	83.6^{b}	92.9^{ab}	3.5	0.03	0.03	0.39
Feed N	97.3^{ab}	92.6^{a}	101.4^{b}	108.1^{c}	2.1	0.22	0.04	0.01
Ruminal digestion, %								
OM	54.8	55.1	58.3	57.8	1.2	0.07	0.34	0.11
NDF	36.6	38.1	43.2	44.0	2.7	0.14	0.62	0.10
Starch	78.0^{a}	78.7^{a}	83.6^{b}	84.1^{b}	0.9	<0.01	0.11	<0.01
Feed N	56.0^{ab}	58.1^{a}	54.2^{b}	51.1^{c}	0.9	0.22	0.04	0.01
MN efficiency[3]	19.9^{a}	20.9^{a}	15.9^{b}	18.2^{ab}	0.9	0.02	0.04	0.23
N efficiency[4]	0.97^{ab}	0.97^{ab}	0.92^{a}	0.99^{b}	0.02	0.16	0.31	0.36
Postruminal digestion, % leaving abomasum								
OM	63.9^{ab}	66.7^{a}	63.3^{ab}	62.0^{b}	1.4	0.77	0.14	0.41
NDF	25.6^{ab}	31.7^{a}	22.8^{ab}	24.0^{a}	7.8	0.81	0.47	0.09
Starch	94.9^{ab}	95.1^{b}	92.1^{c}	93.4^{ac}	5.5	0.01	0.04	0.09
N	75.0^{a}	76.1^{ab}	76.1^{ab}	78.2^{b}	0.9	0.43	0.65	0.05
Fecal excretion, g/d								
DM	2,134	1,977	1,980	2,072	79	0.22	0.44	0.60
OM	1,833	1,700	1,690	1,754	72	0.21	0.51	0.47
NDF	858^{ab}	777^{a}	802^{ab}	892^{b}	34	0.29	0.26	0.51
Starch	41.8	40.7	45.9	56.4	3.7	0.47	0.51	0.34
N	56.1	53.8	51.2	49.3	2.3	0.18	0.96	0.08
Total-tract digestion, %								
DM	77.8	79.5	79.5	78.6	0.8	0.19	0.47	0.54
OM	79.8	81.3	81.5	80.8	0.7	0.19	0.54	0.42
NDF	54.3^{ab}	57.8^{a}	56.4^{ab}	51.5^{b}	1.8	0.29	0.26	0.51
Starch	98.9	98.9	98.8	99.0	0.09	0.46	0.49	0.32
N	74.6	75.7	76.8	77.7	1.0	0.18	0.96	0.08

[1]DM, dry matter; OM, organic matter; NDF, neutral detergent fiber; N, nitrogen; MN, microbial nitrogen.
[2]Treatments: CON: control no antibiotic; flavomycin (Gainpro, Huevapharma, Peachtree City, GA); MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN).
[3]Duodenal microbial N, g/kg OM fermented in the rumen.
[4]Duodenal nonammonia N, g/g N intake.
[a]–
[b]Means in a row with different superscripts differ (P ≤ 0.05).

Supplementary Data

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

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Table 6. Influence of flavomycin or monensin supplementation on ruminal VFA concentration in Holstein steers

Item	Dietary treatments[2]					*P*-value		
		Flavomycin, mg/kg		MON, mg/kg		Flavomycin		
	CON	6.6	13.2	30	SEM	Linear	Quadratic	Control vs. MON
Ruminal pH	5.76[a]	6.00[b]	5.67[a]	5.99[b]	0.06	0.29	<0.01	0.03
Ruminal VFA[1], mol/100 mol								
Acetate	58.0	59.6	53.9	57.3	1.0	0.03	0.03	0.65
Propionate	27.7	27.4	34.4	30.5	1.4	0.02	0.08	0.21
Butyrate	14.3	12.9	11.6	12.1	0.7	0.04	0.96	0.08
Acetate/propionate	2.29[a]	2.26[a]	1.70[b]	1.89[ab]	0.14	0.03	0.19	0.09
Methane/mol glucose	0.51[a]	0.52[a]	0.43[b]	0.48[ab]	0.02	0.02	0.05	0.28

[1]VFA, volatile fatty acids.
[2]Treatments: CON: control no antibiotic; flavomycin (Gainpro, Huevapharma, Peachtree City, GA); MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN).
[a]–
[b]Means in a row with different superscripts differ (P ≤ 0.05).

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Conflict of interest statement

The authors declare no conflict of interest.

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