Title

Influence of supplemental condensed tannins on initial 112-d feedlot growth-performance and characteristics of digestion of calf-fed Holstein steers

Journal

Translational Animal Science, 6(1)

ISSN

2573-2102

Authors

Montano, Martin F
Carvalho, Pedro HV
Chirino-Romero, Juan O
et al.

Publication Date

2022

DOI

10.1093/tas/txac024

Peer reviewed

Translational Animal Science, 2022, **6**, 1–7
https://doi.org/10.1093/tas/txac024
Advance access publication 9 February 2022
Ruminant Nutrition

Influence of supplemental condensed tannins on initial 112-d feedlot growth-performance and characteristics of digestion of calf-fed Holstein steers

Martin F. Montano,[†] Pedro H. V. Carvalho,[‡] Juan O.Chirino-Romero ,[†] Brooke C. Latack,[ǁ] Jaime Salinas-Chavira,[$] and Richard Avery Zinn[‡,1]

[†]Department of Nutrition and Biotechnology of Ruminants, Instituto de Investigaciones en Ciencias Veterinarias-UABC, Mexicali, Baja California 21100, México
[‡]Department of Animal Science, University of California, Davis, CA 95616, USA
[ǁ]Cooperative Extension, Division of Agriculture and Natural Resources, University of California, Holtville, CA 92250, USA
[$]Department of Animal Nutrition, Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Tamaulipas, Cd. Victoria, Tamaulipas, 87000, México

[1]Corresponding author: razinn@ucdavis.edu

ABSTRACT

In experiment 1, 150 calf-fed Holstein steers (119 ± 6 kg) were used to evaluate the effects of level of supplemental condensed tannin (0, 14, and 28 g/kg diet DM) in a conventional steam-flaked corn-based growing-finishing diet on feedlot growth performance. There were no treatment effects on growth performance during the initial 56-d period. However, during the subsequent 56-d period, supplemental condensed tannin tended to increase average daily gain (ADG; linear effect, $P = 0.09$). The increase in ADG was consistent with the tendency for increased dry matter intake (DMI; linear effect, $P = 0.08$). Hence, differences in gain efficiency during the second 56-d period were not appreciably affected ($P = 0.80$). Supplemental condensed tannin did not affect overall (112-d) ADG, DMI, gain efficiency, or dietary NE. In a second experiment, six Holstein steers (179.4 ± 7.9 kg) with cannulas in the rumen and proximal duodenum were used in a replicated 3 × 3 Latin square design to evaluate treatment effects on characteristics of ruminal and total tract digestion. Treatments were the same as in Trial 1. Tannin supplementation decreased (linear effect, $P = 0.03$) ruminal OM digestion and tended to decrease (linear effect, $P = 0.06$) ruminal feed N degradation. Tannin supplementation decreased (linear effect, $P = 0.03$) ruminal pH, but did not affect ($P > 0.20$) ruminal molar proportions of volatile fatty acids and estimated methane production. In current study, supplemental tannin had marginal effects on overall growth performance of calf-fed Holstein steers, but reduced ruminal, postruminal, and total tract nitrogen digestion.

Key words: digestion, feedlot, Holstein steers, tannin

INTRODUCTION

Calf-fed Holstein steers comprise the majority of cattle fed in the desert southwest. Conventionally, calves are fed a steam-flaked corn-based diets growing-finishing diet containing 12% to 13% of crude protein (Zinn et al., 2005; Vasconcelos and Galyean, 2007). Although these corn-based diets often meet average metabolizable protein requirements for the entire (over 300 d) feedlot growing-finishing period (NASEM, 2000), it may not meet the metabolizable protein requirements of calf-fed Holstein steers during the first 112 d that cattle are on feed (Zinn and Shen, 1998; Zinn et al., 2007).

Tannins are a complex group of polyphenolic compounds found in a wide range of plant species commonly consumed by ruminants. They are conventionally classified into two major groups: hydrolyzable and condensed tannins. When fed in greater concentrations, tannins may be toxic to cattle, reducing voluntary feed intake and nutrient digestibility of the diet. However, when fed at moderate concentrations, tannin supplementation may shift the site of protein degradation, potentially increasing metabolizable amino acid flow to the small intestine of cattle (Min et al., 2003). The effect on ruminal protein degradation is due to the capacity of tannins to bind protein through hydrogen bonds forming tannin-protein complex which is stable in the rumen (pH 5.0–7.0), resistant to microbial degradation, and is dissociated in the abomasum due to the difference in pH (Mezzomo et al., 2011). Therefore, the shift in site of protein degradation promoted by tannin supplementation may explain improvements observed in the performance of feedlot calves during the initial growing phase where limitations in metabolizable protein supply are particularly manifested (Barajas et al., 2010; Zinn et al., 2007). Therefore, the objective of the present study was to further evaluate the effects of supplemental condensed tannin on feedlot cattle growth performance, energetics, and digestive function in light-weight calf-fed Holstein steers during the initial 112-d growing phase.

MATERIALS AND METHODS

Animal care and handling techniques were approved by the University of California Animal Care and Use Committee (#22271, 22362).

Received October 19, 2021 Accepted February 5, 2022.

Experiment 1. Effect of condensed tannin supplementation on growth performance of feedlot calves

Cattle management and treatments. One hundred fifty Holstein steers (119 ± 6 kg) were used to evaluate the effects of the level of condensed tannin supplementation on feedlot growth performance during the initial 112 d of the feedlot growing phase of calf-fed Holstein steers. Cattle were vaccinated for IBR, BVD, PI_3, and BRSV (Bovishield Gold 5, Zoetis Animal Health, Florham Park, NJ), clostridials (Ultrabac 8, Zoetis Animal Health, Florham Park, NJ), treated for parasites (Dectomax Injectable, Zoetis Animal Health, Florham Park, NJ), injected with 5-mL SC Vital E-AD (300 IU vitamin E, 100,000 IU vitamin A and 10,000 IU vitamin D_3/mL, Stuart Products, Bedford, TX), and 3-mL SC tuluthromycin (Draxxin, Zoetis Animal Health, Florham Park, NJ), and grouped by weight and assigned within weight groupings to 30 pens (5 steers per pen). Pens were 50 m^2 with 26.7 m^2 overhead shade, equipped with automatic drinkers, and 4.3 m fence-line feed bunks. Treatments consisted of a steam-flaked corn-based diet supplemented with ByPRO (70% condensed tannin; Silvateam USA, Tontitown, AR) at the rate of 0, 20, or 40 g/kg diet DM (0, 14, or 28 g/kg condensed tannin). Composition of experimental diets is shown in Table 1. Diets were prepared weekly and stored in plywood boxes in front of each pen. Calves were provided ad libitum access to the diet. Fresh feed was added to the feed bunk twice daily.

Estimation of dietary NE. Daily energy gain (EG; Mcal/d) was calculated by the equation: $EG = ADG^{1.097} \times 0.0557W^{0.75}$, where W is the mean shrunk BW (kg; NASEM, 1984). Maintenance energy (EM) was calculated by the equation: $EM = 0.086W^{0.75}$ (this has a 10% increase adjustment used for Holstein steers). Dietary NE_g was derived from NE_m by the equation: $NE_g = 0.877\ NE_m - 0.41$ (Zinn, 1987). Dry matter intake is related to energy requirements and dietary NE_m according to the equation: $DMI = (EM/NE_m) + (EG/(0.877NE_m - 0.41)$. From this relationship, dietary NE can be resolved by means of the quadratic formula: $x = (-b - \sqrt{b^2 - 4ac})/ = 2c$, where $x = NE_m$, a = −0.42 EM, b = 0.887 EM + 0.41 DMI + EG, and c = −0.877 DMI (Zinn and Shen, 1998).

Statistical design and analysis. The trial was analyzed as a randomized complete block design, using pens as experimental units. Linear and quadratic effects of tannin level were separated by means orthogonal polynomials (Stastistix 10, Analytical Software, Tallahassee, FL).

Experiment 2. Influence of supplemental tannin on characteristics of ruminal and total tract digestion

Animals, sampling, and treatments. Six Holstein steers (179.4 ± 7.9 kg) with cannulas in the rumen and proximal duodenum were used in a replicated 3 × 3 Latin square design to evaluate treatment effects on characteristics of ruminal and total tract digestion. Treatments were the same as in Trial 1, with the incorporation of 0.4% chromic oxide as an inert digesta marker. Dry matter intake was restricted to 2.2% of live weight. Steers were housed in a temperature controlled facility (≈ 25 C) with continuous lighting, and maintained in individual pens (3.9 m^2 with neoprene flooring) equipped with feed bunks and automatic waterers. Diets were fed at 0800 and 2000 h daily. The three experimental periods consisted of a 10-d diet adjustment period followed by a 4-d collection period. During collection periods duodenal and fecal samples were taken from all steers, twice daily as follows: day 1, 0750 and 1350 h; day 2, 0900 and 1500 h; day 3, 1050 and 1650 h; and day 4, 1200 and 1800 h. Individual samples consisted of approximately 700-mL duodenal chyme and 200 g (wet basis) fecal material. On the final day of each collection period (day 4), ruminal fluid (100 mL) was obtained via the ruminal cannula from each steer 4 h after the morning feeding (1200 h). Ruminal pH was determined on freshly collected samples. Ruminal fluid was then strained through four layers of cheesecloth. Freshly prepared 25% (wt/vol) m-phosphoric acid (2 mL) was added to 8 mL of the strained ruminal fluid. Samples were centrifuged (17,000 × *g* for 10 min) and supernatant fluid stored at −20 °C for analysis of volatile fatty acids (VFA) concentrations (gas chromatography). Feed, duodenal, and fecal samples from each steer and within each collection period were composited for analysis. Upon completion of the trial, ruminal fluid was obtained from all steers and composited for isolation of ruminal bacteria via differential centrifugation (Bergen et al., 1968). Samples were subjected to the following analysis: DM (oven drying at 105 °C until no further weight loss); ash, Kjeldahl N, ammonia N (AOAC, 1975); aNDFom (Van Soest, 1991), corrected for NDF-ash, incorporating heat stable α-amylase (Ankom FAA, Ankom

Table 1. Composition of experimental diets (DM basis)

Item	Condensed tannin, g/kg DM		
	0	14	28
Ingredient composition, % DM			
Corn grain flaked	45.70	45.50	45.30
Distillers dried grains plus solubles	20.00	20.00	20.00
Soybean meal-49	10.00	10.00	10.00
Alfalfa hay early bloom	8.00	8.00	8.00
Cane molasses	8.00	8.00	8.00
Sorghum Sudan hay	4.00	4.00	4.00
Yellow grease	2.00	2.00	2.00
Limestone	1.90	1.90	1.90
Trace mineral salt[a]	0.30	0.30	0.30
Magnesium oxide	0.10	0.10	0.10
ByPRO (70% condensed tannin)[b]	0.00	0.20	0.40
Nutrient composition, (DM basis)			
Dry matter, %	87.8	87.8	87.8
NEm, Mcal/kg	2.15	2.14	2.14
NEg, Mcal/kg	1.48	1.48	1.48
Crude protein, %	18.1	18.1	18.1
Ether extract, %	6.50	6.49	6.49
Ash, %	6.98	6.99	7.01
NDF, %	20.0	20.2	20.3
Calcium, %	0.98	0.98	0.98
Phosphorus, %	0.41	0.41	0.41
Potassium, %	1.21	1.21	1.22
Magnesium, %	0.31	0.31	0.31
Sulfur, %	0.28	0.28	0.28

[a]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%.
[b]ByPRO, 70% condensed tannin; Silvateam USA, Tontitown, AR.

Technology, Macedon, NY) at 1 mL per 100 mL of NDF solution], chromic oxide (Hill and Anderson, 1958), and starch. Microbial organic matter (MOM) and N (MN) leaving the abomasum was calculated using purines as a microbial marker (Zinn and Owens, 1986). Organic matter fermented in the rumen (OMF) is considered equal to organic matter (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 ($0.195 \times BW^{0.75}$; Orskov et al., 1986). Methane production was calculated based on the theoretical fermentation balance for observed molar distribution of VFA and OM fermented in the rumen (Wolin, 1960).

Statistical design and analysis. The trial was analyzed as a replicated 3 × 3 Latin squares according to the model: $Y_{ijkl} = m + B_i + A_{j(i)} + P_k + T_l + e_{ijkl}$, where B_i is block, $A_{j(i)}$ is steer within block, P_k is period, T_l is condensed tannin level, and e_{ijkl} is residual error. Linear and quadratic effects of tannin level were separated by means orthogonal polynomials.

RESULTS AND DISCUSSION

Treatment effects on feedlot growth performance are presented in Table 2. There were no treatment effects ($P \geq 0.26$) on cattle growth performance during the initial 56-d period. However, during the subsequent 56-d period, cattle fed supplemental condensed tannin tended (linear effect, $P \leq 0.09$)

Table 2. Influence of supplemental tannin on 112-d feedlot growth performance of Holstein steers (Trial 1)

Item	Condensed tannin, g/kg DM			SEM	*P*-value	
	0	14	28		L	Q
Days on test	112	112	112			
Pen replicated	10	10	10			
Live weight (kg)[a]						
Initial	119.6	119.6	119.5	0.14	0.79	0.92
56 d	201.7	202.0	202.4	1.15	0.66	0.99
Final	280.3	282.8	284.3	1.97	0.17	0.84
ADG (kg)						
1–56 d	1.47	1.47	1.48	0.02	0.65	0.98
56–112 d	1.40	1.44	1.46	0.02	0.09	0.76
1–112 d	1.43	1.46	1.47	0.02	0.16	0.84
DMI (kg/d)						
1–56 d	5.01	4.98	5.09	0.07	0.42	0.38
56–112 d	6.22	6.37	6.45	0.09	0.08	0.80
1–112 d	5.62	5.67	5.77	0.07	0.12	0.79
ADG/DMI (kg/kg)						
1–56 d	0.293	0.296	0.291	0.003	0.68	0.31
56–112 d	0.226	0.227	0.227	0.004	0.85	0.89
1–112 d	0.256	0.257	0.255	0.002	0.81	0.44
Dietary ME (Mcal/kg)[b]						
Maintenance						
1–56 d	1.93	1.94	1.91	0.01	0.54	0.26
56–112 d	2.02	2.02	2.02	0.02	0.90	0.96
1–112 d	1.98	1.99	1.98	0.01	0.72	0.45
Gain						
1–56 d	1.28	1.29	1.27	0.01	0.54	0.26
56–112 d	1.37	1.36	1.36	0.02	0.90	0.96
1–112 d	1.33	1.34	1.32	0.01	0.72	0.45
Observed/ expected dietary NE						
Maintenance						
1–56 d	0.904	0.911	0.898	0.006	0.54	0.26
56–112 d	0.950	0.950	0.948	0.010	0.91	0.96
1–112 d	0.931	0.935	0.928	0.005	0.72	0.45
Gain						
1–56 d	0.876	0.884	0.868	0.009	0.54	0.26
56–112 d	0.935	0.935	0.933	0.01	0.90	0.96
1–112 d	0.911	0.916	0.907	0.007	0.72	0.45

[a]Live weight reduced 4% to account for gut fill.
[b]Calculated based cattle performance according to Zinn and Shen (1998).

to increase both average daily gain (ADG) and dry matter intake (DMI). Hence, differences in gain efficiency during the second 56-d period were not appreciably affected ($P = 0.80$). Supplementing condensed tannin did not affect overall (112 d) ADG, DMI, gain efficiency, or dietary NE. Daily weight gain during this period (112 d) averaged 1.45 kg/d, which is consistent with expected ADG (1.44 kg/d), based on previous studies evaluating feedlot performance of calf-fed Holstein steers during the initial 4 mo of the feedlot phase (Carrasco et al., 2013; Torrentera, 2016).

Evaluations of supplemental tannin on growth-performance of calf-fed Holstein steers are limited. Rivera-Mendez et al. (2017) observed an increased ADG and feed efficiency, but no effect in DMI when Holstein steers were fed a steam-flaked corn-based diet similar to that of the current experiment and supplemented with condensed tannin (0.2%, 0.4%, 0.6%, DM basis) during late finishing phase (last 84 d on feed). Barajas et al. (2012) reported that tannin supplementation (0.33%, DM basis) increased ADG and gain efficiency of yearling bulls fed a ground-corn-based diet. However, Krueger

Table 3. Influence of supplemental tannin on characteristics of ruminal and total tract digestion of Holstein steers (Trial 2)

Item	Condensed tannin, g/kg DM			SEM	*P*-value	
	0	14	28		L	Q
Steer replication	4	4	4			
Intake, g/d						
DM	3977	3986	3995			
OM	3602	3609	3617			
NDF	805.7	807.5	809.2			
N	106.5	106.7	106.9			
Starch	1299	1299	1299			
Flow to the duodenum, g/d						
OM	1754	1809	1797	29.1	0.34	0.38
NDF	349.7	369.2	367.1	15.40	0.45	0.58
N	103.6	101.6	104.5	1.91	0.76	0.34
Starch	148.0	166.4	159.7	10.99	0.47	0.38
Microbial N	58.1	51.1	53.9	1.6	0.12	0.04
Nonammonia N	97.7	95.8	99.1	1.96	0.62	0.30
Feed N	29.9	35.1	35.6	1.66	0.05	0.31
Ruminal, %						
OM	67.4	64.0	65.2	0.72	0.07	0.03
NDF	56.6	54.3	54.6	2.70	0.48	0.58
Starch	88.6	87.2	87.7	0.85	0.47	0.38
Feed N	71.8	67.0	66.8	1.66	0.06	0.31
Microbial efficiency[a]	23.8	22.2	22.9	0.73	0.39	0.21
Protein efficiency[b]	91.73	89.7	82.6	2.58	0.73	0.30
Fecal excretion, g/d						
DM	840.9	836.0	850.7	15.28	0.67	0.61
OM	639.5	654.2	645.4	8.72	0.65	0.30
NDF	288.9	300.7	270.4	7.93	0.14	0.06
Starch	10.4	10.7	12.8	1.43	0.28	0.61
N	21.2	22.0	23.5	0.51	0.01	0.60
Postruminal digestion, % of flow to duodenum						
OM	63.6	63.8	64.0	0.83	0.71	0.99
NDF	15.9	17.7	24.2	3.32	0.12	0.57
Starch	92.9	93.5	91.7	0.97	0.37	0.34
N	79.4	78.3	77.4	0.64	0.05	0.89
Total tract digestion, %						
DM	78.9	79.0	78.7	0.38	0.78	0.62
OM	82.2	81.9	82.2	0.01	0.81	0.30
NDF	64.1	62.7	66.5	0.01	0.12	0.06
Starch	99.2	99.2	99.0	0.01	0.29	0.62
N	80.1	79.4	77.9	0.01	0.02	0.60

[a]Duodenal microbial N (MN; g/kg of OM fermented in the rumen).
[b]Duodenal nonammonia N (g/g of N intake).

et al. (2010) did not observe an influence of tannin supplementation (1.5%, DM basis) on cattle ADG, feed efficiency, and DMI of crossbred beef steers fed a corn-based diet during 42-d finishing study. These authors noted that cattle receiving 10.5 g tannins/kg diet DM (approximately four-fold of the higher dosage level of the present study) had decreased carcass weight (Krueger et al., 2010). Ebert et al. (2017) did not observe effects of supplemental condensed tannin (0, 3.5, and 7.0 g/kg DM) on the growth performance of beef steers. In a meta-analysis performed by of Orzuna-Orzuna (2021), the authors observed that the influence of supplemental tannin on feedlot cattle growth performance was not appreciable. Variation in observed growth-performance responses to supplemental tannin may be attributable to initial weight, type of cattle, and level of dietary CP, which are all factors that can influence growth response in feedlot cattle. In the present study, we evaluated supplemental tannin response in calf-fed Holstein steers (119 kg on average) fed diets with a relatively high level of CP (18.1%).

Effects of supplemental condensed tannin on characteristics of digestion, ruminal pH, and molar proportions of VFA are presented in Tables 3 and 4. Diets fed to cattle supplemented with tannin had decreased (linear effect, P = 0.03) ruminal OM digestion and ruminal feed N degradation (linear effect, P = 0.06). Based on prior studies (Min et al., 2001; Jolazedeh et al., 2015), the observed decrease in dietary ruminal nitrogen degradation with tannin supplementation was expected due to supplemental tannin effects on protein solubilization, inhibiting ruminal proteolytic activity. According to our results, the magnitude of the response to tannin supplementation is dose-dependent. Beauchemin et al. (2007) observed that supplementation of a high-protein barley-based finishing diet with condensed tannins at the rate of 10 and 20 g/kg DM decreased ruminal feed N degradation by 5% and 15%, respectively.

As mentioned previously, one of the goals of supplementing tannin to cattle is to reduce protein solubilization and degradation in the rumen (Min et al., 2001; Jolazedeh et al., 2015). Within the rumen, the binding of tannin with protein affords protection from microbial fermentation. However, the tannin-protein binding affinity is pH dependent and largely dissociates under the acid conditions of the abomasum. Therefore, cattle-fed diets supplemented with tannin may enhance protein flow to the small intestine. However, tannins may reassociate with protein in the upper small intestine due to alkalizing effects of bile secretions, leading to a potential decrease in total tract nitrogen digestion, as observed in the present study (linear effect, P = 0.02; Table 3). The greater feed nitrogen flow to the small intestine (g/d) might potentially explain a tendency for greater ADG from cattle supplemented with tannin during the second 56-d period. However, tannin supplementation did not result in increased metabolizable protein supply as post-ruminal and total tract digestion of N decreased.

Tannin supplementation decreased (linear effect, P = 0.03) ruminal pH (Table 4). This result was unexpected. In previous studies (Krueger et al., 2010; Mezzomo et al., 2011; Jolazadeh et al., 2015), condensed tannin supplementation did not appreciably affect ruminal pH.

There were no treatment effects (P > 0.20) of tannin supplementation on ruminal VFA molar concentration and estimated methane production. Likewise, Krueger et al. (2010) did not observe any effect of supplemental condensed tannins on VFA molar proportions, methane production, or ruminal pH. Moreover, Beauchemin et al. (2007) did not observe the effect of tannin supplementation on methane production, but reported that with increasing level of tannin supplementation, the ruminal acetate:propionate molar ratio linearly decreased. In contrast, Min et al. (2006) observed that tannin supplementation decreased in vitro ruminal methane production. Likewise, Tavendale et al. (2005) also observed that tannin supplementation (12.5g/kg DM) decreased in vitro methane production. These authors proposed two possible mechanisms whereby condensed tannins can reduce methane emissions from ruminants: 1) inhibition of methanogen bacteria growth and 2) decrease of H_2 production due to a reduction in fiber digestion. Lack of response to tannin supplementation on ruminal VFA and estimated methane production in the present study may be due, in part, to the moderate level of condensed tannin supplementation and the high diet energy density and level of dietary fat.

Table 4. Influence of supplemental tannin on ruminal pH and VFA molar proportions of Holstein steers (Trial 2)[a]

Item	Condensed tannin, g/kg DM			SEM	*P*-value	
	0	14	28		L	Q
Ruminal pH[b]	6.06	5.99	5.83	0.06	0.03	0.51
Total VFA, mM	132.8	131.9	135.3	5.43	0.76	0.75
Ruminal VFA, mol/100 mol						
Acetate	52.7	53.2	49.7	1.34	0.15	0.25
Propionate	28.1	25.6	30.9	1.91	0.32	0.13
Isobutyrate	1.35	1.26	1.26	0.13	0.65	0.80
Butyrate	14.5	16.4	14.3	0.78	0.91	0.07
Isovalerate	1.43	1.56	1.56	0.13	0.48	0.71
Valerate	1.95	1.97	2.18	0.12	0.19	0.55
Acetate/propionate	1.91	2.09	1.68	0.14	0.27	0.12
Methane/mol glucose[c]	0.48	0.51	0.44	0.02	0.26	0.16

[a]DMI was restricted to 2.0% of BW.
[b]Ruminal pH was taken 4 h post-feeding.
[c]Methane, mol/mol glucose equivalent fermented.

CONCLUSIONS

Supplementation of condensed tannin (14 and 28 g/kg DM) to a steam-flaked corn-based growing-finishing diet fed to calf-fed Holstein steers during the initial 112 d on feed tended to increase ADG and DMI during the second half of the experiment (56–112 d). However, it did not affect overall cattle growth performance (1–112 d). Tannin supplementation increased protein flow to the small intestine, but this effect was minimized by decreased postruminal N digestion.

ACKNOWLEDGMENTS

This project was supported through the University of California Agricultural Experiment Station with Hatch funding from the USDA National Institute of Food and Agriculture (CA-D-ASC-6578-H).

Conflict of Interest Statement

None declared.

LITERATURE CITED

Barajas, R., B. J. Cervantes, A. Camacho, E. A. Velazquez, M. A. Espino, F. Juarez, L. R. Flores, and M. Verdugo. 2010. Condensed tannins supplementation on feedlot performance of growing bulls. *J. Anim. Sci*. 88(Suppl 2):711.

Barajas, R., B. J. Cervantes, M. A. Espino, A. Camacho, M. Verdugo, L. R. Flores, J. J. Loneli, and J. A. Romo. 2012. Effect of tannins extract supplementation on feedlot performance and plasma urea nitrogen of yearling bulls fed dry-ground corn-based diets containing corn-DDG and cane molasses. *J. Anim. Sci*. 90(Suppl 3):600.

Beauchemin, K. A., S. M. McGinn, T. F. Martinez, and T. A. McAllister. 2007. Use of condensed tannin extract from quebracho trees to reduce methane emissions from cattle. *J. Anim. Sci*. 85:1990–1996. doi:10.2527/jas.2006-686.

Bergen, W. G., D. B. Purser, and J. H. Cline. 1968. Effect of ration on the nutritive quality of rumen microbial protein. *J. Anim. Sci*. 27:1497–1501. doi:10.2527/jas1968.2751497x.

Carrasco, R., A. A. Arrizon, A. Plascencia, N. G. Torrentera, and R. A. Zinn. 2013. Comparative feeding value of distillers dried grains plus solubles as a partial replacement for steam-flaked corn in diets for calf-fed holstein steers: characteristics of digestion, growth performance, and dietary energetics. *J. Anim. Sci*. 91:1801–1810. doi:10.2527/jas.2012-5260.

Ebert, P. J., E. A. Bailey, A. L. Shreck, J. S. Jennings, and N. A. Cole. 2017. Effect of condensed tannin extract supplementation on growth performance, nitrogen balance, gas emissions, and energetic losses of beef steers. *J. Anim. Sci*. 95:1345–1355. doi:10.2527/jas.2016.0341.

Hill, F. W., and D. L. Anderson. 1958. Comparison of metabolizable energy and productive energy determinations with growing chicks. *J. Nutr*. 64:587–603. doi:10.1093/jn/64.4.587.

Jolazadeh, A. R., M. Dehghan-banadaky, and K. Rezayazdi. 2015. Effects of soybean meal treated with tannins extracted from pistachio hulls on performance, ruminal fermentation, blood metabolites and nutrient digestion of holstein bulls. *Anim. Feed Sci. Technol*. 203:33–40. doi:10.1016/j.anifeedsci.2015.02.005.

Krueger, W. K., H. Gutierrez-Bañuelos, G. E. Casterns, B. R. Min, W. E. Pinchak, R. R. Gomez, R. C. Anderson, N. A. Krueger, and T. D. A. Forbes. 2010. Effects of dietary tannin source on performance, feed efficiency, ruminal fermentation, and carcass and non-carcass traits in steers fed a high-grain diet. *Anim. Feed Sci. Tech*. 159:1–9. doi:10.1016/j.anifeedsci.2010.05.003.

Mezzomo, R., P. V. R. Paulino, E. Detmann, S. C. Valadares Filho, M. F. Paulino, J. P. I. S. Monnerat, M. S. Duarte, L. H. P. Silva, and L. S. Moura. 2011. Influence of condensed tannin on intake, digestibility, and efficiency of protein utilization in beef steers fed high concentrate diet. *Livest. Sci*. 141:1–11. doi:10.1016/j.livsci.2011.04.004.

Min, B. R., G. T. Attwood, W. C. McNabb, and T. N. Barry. 2001. Effect of condensed tannins on proteolytic bacterial populations in the rumen and on nitrogen (N) flow to the abomasum of sheep. *J. Anim. Sci*. 79:163.

Min, B. R., T. N. Barry, G. T. Attwood, and W. C. McNabb. 2003. The effect of condensed tannins on the nutrition and health of ruminants fed fresh temperate forages: a review. *Anim. Feed Sci. Technol*. 106:3–19. doi:10.1016/S0377-8401(03)00041-5.

Min, B. R., W. E. Pinchak, R. C. Anderson, J. D. Fulford, and R. Puchala. 2006. Effects of condensed tannins supplementation level on weight gain and in vitro and in vivo bloat precursors in steers grazing winter wheat. *J. Anim. Sci*. 84:2546–2554. doi:10.2527/jas.2005-590.

NASEM. 2000. *Nutrient requirements of beef cattle* 7th rev. ed. Washington, DC: Natl. Acad. Press.

NASEM (National Academies of Sciences, Engineering, and Medicine). 1984. *Nutrient requirements of beef cattle*. 6th Ed. Washington, DC: Natl. Acad. Press.

AOAC, 1975. *Official methods of analysis*. 12th Ed. Washington, DC: Association of Official Analytical Chemists.

Orzuna-Orzuna, J. F., G. Dorantes-Iturbide, A. Lara-Bueno, G. D. Mendoza-Martinez, L. A. Miranda-Romero, and P. A. Hernandez-Garcia. 2021. Effects of dietary tannins' supplementation on growth performance, rumen fermentation, and enteric methane emissions in beef cattle: a meta-analysis. *Sustainability*. 13(13): 7410. doi:10.3390/su13137410

Orskov, E. R., N. A. MacLeod, and D. J. Kyle. 1986. Flow of nitrogen from the rumen and abomasum in cattle and sheep given protein-free nutrients by intragastric infusion. *Br. J. Nutr*. 56:241–248. doi:10.1079/bjn19860103.

Rivera-Mendez, C., A. Plascencia, N. Torrentera, and R. A. Zinn. 2017. Effect of level and source of supplemental tannin on growth-performance of Holstein steers during the late finishing phase. *J. Applied Anim. Research*. 45:199–203. doi:10.1080/09712119.2016.1141.

Tavendale, M. H., L. P. Meagher, D. Pacheco, N. Walker, G. T. Attwood, and S. Sivakumaran. 2005. Methane production from in vitro rumen incubations with *Lotus pedunculatus* and *Medicago sativa*, and effects of extractable condensed tannin fractions on methanogenesis. *Anim. Feed Sci. Technol*. 123–124:403–419. doi:10.1016/j.anifeedsci.2005.04.037.

Torrentera, N., A. Barreras, V. Gonzales, A. Plascencia, J. Salinas, and R. A. Zinn. 2016. Delay implant strategy in calf-fed Holstein steers: growth performance, growth rate and carcass characteristics. *J. Appl. Anim. Res*. 45:454–459. doi:10.1080/09712119.2016.1210012.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci*. 74:3583–3597. doi:10.3168/jds.S0022-0302(91)78551-2.

Vasconcelos, J. T., and M. L. Galyean. 2007. Nutritional recommendations of feedlot consulting nutritionist: The 2007 Texas Tech University survey. *J. Anim. Sci*. 85:2772–2781. doi:10.2527/jas.2007-0261.

Wolin, M. J. 1960. A theoretical rumen fermentation balance. *J. Dairy Sci*. 43:1452–1459. doi:10.3168/jds.S0022-0302(60)90348-9.

Zinn, R. A., and F. N. Owens. 1986. A rapid procedure for purine measurement and its use for estimating net ruminal protein synthesis. *Can. J. Anim. Sci*. 66:157–166. doi:10.4141/cjas86-017.

Zinn, R. A. 1987. Influence of lasalocid and monensin plus tylosin on comparative feeding value of steam-flaked versus dry-rolled corn in diets for feedlot cattle. *J. Anim. Sci*. 65:256–266. doi:10.2527/jas1987.651256x.

Zinn, R. A., L. Corona, and A. Plascencia. 2005. Fat and protein supplementation of calf – fed Holstein steer. In: Proc. Managing and Marketing Quality Holstein Steers. Rochester, MN; pp. 89–93.

Zinn, R. A., and Y. Shen. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. *J. Anim. Sci*. 76:1280–1289. doi:10.2527/1998.7651280x.

Zinn, R. A., A. Barreras, L. Corona, F. N. Owens, and R. A. Ware. 2007. Starch digestion by feedlot cattle: predictions from analysis of feed and fecal starch and nitrogen. *J. Anim. Sci*. 85:1727–1730. doi:10.2527/jas.2006-556.