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Influence of low-level tannin supplementation on comparative growth performance of Holstein and Angus × Holstein cross calf-fed concentrate-based finishing diets for 328 d

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Abstract

The objective of the current study was to evaluate the effects of tannin and monensin supplementation in feedlot diets and breed (Holstein vs. Angus × Holstein) on growth performance, energetic efficiency, and carcass characteristics. Eighty purebred Holstein calves (**HOL**; initial body weight (**BW**) = 130 ± 5 kg) and 80 Angus × Holstein calves (**AXH**; initial BW = 129 ± 6 kg) were blocked by initial BW and randomly assigned to 40 pens. Dietary treatments consisted of a steam-flaked corn-based diet supplemented with (1) no feed additive (**CON)**; (2) 30 mg of monensin/kg of dry matter (**DM**; **MON**; Rumensin 90, Elanco, Greenfield, IN); (3) 1.5 g tannin)/kg of DM (**TAN**; ByPro, 70% condensed tannin, SilvaFeed, Indunor, S.A., Buenos Aires, Argentina); (4) **M +T**, the combination of MON plus TAN dietary treatments. Data were analyzed as a randomized complete block in a 2 × 4 factorial arrangement of treatments, using pens as experimental units. There were no interactions ($P > 0.05$) between feed additives and breed. Supplemental MON increased ($P \leq 0.04$) initial 112-d BW and gain efficiency. However, there were no dietary treatment effects ($P > 0.10$) on overall growth performance. Monensin supplementation decreased ($P = 0.04$) minimum daily ruminal temperature compared with other dietary treatments during July, but TAN did not affect ruminal temperature. Holstein steers had greater ($P = 0.04$) overall DM intake compared with AXH, with no difference ($P = 0.19$) in overall ADG, leading to increased ($P < 0.01$) gain efficiency for AXH compared with HOL. Dietary net energy for maintenance and gain, based on growth performance, were greater ($P \leq 0.01$) for AXH vs HOL. Compared with HOL, AXH steers had greater ($P \leq 0.01$) carcass weight, dressing percentage, kidney, pelvic, and heart fat, 12th rib fat thickness, longissimus area, and preliminary yield grade. Holstein steers had lower ($P \leq 0.04$) minimum average ruminal temperature during June compared with AXH, with no differences ($P \geq 0.14$) between breeds during July or August. Results indicate that feed additives did not appreciably affect steer growth performance and carcass characteristics, but crossbred AXH steers had greater growth performance, efficiency of dietary energy utilization, and carcass quality measures compared with HOL. This study observed a reduction (4.7%) in maintenance energy expenditure in AXH compared with HOL, implying in maintenance energy coefficient of 0.086 vs 0.082 for HOL and AXH, respectively.

Lay Summary

Effects of tannin and monensin supplementation on growth performance, energetic efficiency, and carcass characteristics were evaluated in Holstein and Angus × Holstein steers. The investigation used a factorial design to access the impacts of both feed additives and breed on the study's parameters. Tannin supplementation did not affect growth performance. There were no dietary treatment effects on overall steer growth performance. Calf Holstein steers were fed with grain diet based. Holstein steers had greater overall DM intake than Angus × Holstein steers, but breed did not affect average daily gain. Thus, gain efficiency was greater for Angus × Holstein vs Holstein steers. There was no effect of dietary treatment on carcass measures. Compared with Holsteins, Angus × Holstein steers had greater carcass weight, dressing percentage, internal and external fat, longissimus area, and marbling score than Holstein steers. The current study suggests that monensin and tannin supplementation did not affect overall steer growth performance and carcass characteristics. Compared with Holsteins, crossbred Angus × Holstein steers had increased growth performance and carcass quality measures.

Keywords: crossbred, energetic efficiency, growth performance, Holstein, tannin

Abbreviations: ADG: average daily gain; AXH: Angus × Holstein; BW: body weight; DM: dry matter; DMI: dry matter intake; EM: maintenance energy; HCW: hot carcass weights; HOL: Holstein; KPH: pelvic and heart fat; LM: longissimus muscle; MON: monensin; NEg: net energy for gain; NEm: net energy for maintenance; SBW: shrunk body weight; TAN: tannin

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Introduction

Samuelson et al. (2016) surveyed practicing consulting feedlot nutritionists throughout the United States and reported that 97.3% of feedlots in the survey used ionophores (exclusively monensin) in finishing cattle diets. Barreras et al. (2013) reported an increase in growth performance when crossbred beef heifers were supplemented with monensin during a period of heat stress. Recently, Carvalho et al. (2023) reported an improvement in the efficiency of energy utilization of the diet when Holstein steers were supplemented with monensin. However, the utilization of ionophores as feed additives in animal feeds has been restricted in the European Union because of concerns regarding its safety and potential implications for human health (OJEU, 2003), leading to the search for more "natural" alternatives.

Tannins are a complex group of polyphenolic compounds, conventionally classified as either hydrolysable or condensed, that are found in a wide range of plant species commonly consumed by ruminants (McLeod, 1974; Mueller-Harvey and McAllan 1992; Van Soest 1994). Rivera-Méndez et al. (2017) observed that supplementation of Holstein steers with 0.2% to 0.6% (DM basis) of condensed tannin enhanced both average daily gain (**ADG**) and gain efficiency compared with a non-supplemented control. Recently, Montano et al., (2022) reported that tannin supplementation during the growing phase (initial 112 d on feed) of Holstein steers tended to increase ADG and DMI during their early feedlot. However, same authors concluded that tannin supplementation did not affect overall cattle growth performance (Montano et al., 2022).

The use of beef semen on dairy cows has increased across the United States, particularly in California (Pereira et al., 2022). Moreover, Lauber et al. (2023) reported a 290% increase in the use of semen from beef cattle breeds for artificial insemination of cows from dairy herds from 2019 to 2021 in more than 8 million of inseminations in the United States, with 55% of the semen from Angus sires. This trend towards using semen from beef on dairy cows is driven by the greater market value of beef × dairy crossbred calves than purebred dairy calves, representing a new profit center for dairies (De Vries, 2017).

Although beef × dairy crosses have been studied in the past (Beanaman et al., 1962; Henderson, 1969) and recent review papers have been published in the literature about this topic (Basiel and Felix, 2022; Foraker et al., 2022), there is limited peer-reviewed information on the growth performance and carcass characteristics of beef × dairy cross calves compared with purebred Holstein calves in southwestern feedlots of the United States, where cattle are typically fed a single steam flaked corn-based diet for over 300 d (Latack et al., 2021; Carvalho et al., 2022).

It was hypothesized that the inclusion of tannins could increase growth parameters in both groups of steers. In addition, it was hypothesized that beef × dairy calves could have greater growth performance and favorable carcass characteristics compared to Holstein steers in the feedlot. Therefore, we aimed to evaluate the comparative effects of tannin and monensin supplementation and breed (Holstein vs. Angus × Holstein) on growth performance, energetic efficiency, and carcass characteristics of calf-fed concentrate-based finishing diets for 328 days.

Materials and Methods

All animal care and management procedures were approved by the University of California, Davis, Animal Use and Care Committee (protocol #22271).

Cattle management and treatments

Eighty Angus × Holstein crossbred steers (**AXH**; body weight (**BW**) 129, SEM = 6 kg) and 80 purebred Holstein steers (**HOL**; BW 130, SEM = 5 kg) originating from Tulare were received at the University of California Desert Research and Extension Center feedlot in Holtville, California in the evening of January 18, 2022. Calves were held in a holding pen overnight with ad libitum access to water and sudan-grass hay and were weighed and processed the following morning. Calves were individually weighed (Hostetler Scales UMC555AAAAA, CA). Processing included vaccination for clostridials (Ultra Choice 7, Zoetis, Kalamazoo, MI) and IBR (Bovi-Shield Gold One Shot, Zoetis, Kalamazoo, MI), and injected with 1,000,000 IU vitamin A (Vitamin AD, Huvepharma, Inc., St. Joseph, MO). Calves were treated for internal and external antiparasites (Dectomax, Zoetis, Kalamazoo, MI) and injected subcutaneously with 400 mg Tulathromycin (Draxxin, Zoetis, Kalamazoo, MI). Calves were grouped by initial BW and breed and randomly assigned within weight groupings to 40 pens (4 steers from the same breed per pen). On day 28, calves received Ultra Choice 7 booster vaccination. On days 112 and 224 of the study, steers were implanted (Revalor S, Intervet, Millsboro, DE) and injected with 1,000,000 IU vitamin A (Vitamin AD, Huvepharma, Inc., St. Joseph, MO). Calves were weighed in the morning before feeding every 28 d for the duration of the study.

The health status of steers was monitored daily by trained personnel for signs of illness or infectious bovine keratoconjunctivitis (pinkeye). Steers with signs of illness were brought to the chute for treatment, and if classified as morbid, treated with an antimicrobial if the rectal temperature was greater than 39.5 °C, and put back in their pen. Antimicrobial treatments used were oxytetracycline, enrofloxican, or florfenicol and were used following a veterinarian's recommendation of treatment. A post-treatment interval of 3 days was implemented after the first and second treatments.

On day 112 of the experiment, SmaX-tec intraruminal boluses (SmaX-tec animal care technology®, Graz, Austria) were orally inserted into the rumen (1 steer per pen) to monitor the ruminal temperature. Continuous real-time temperature data were retrieved using a SmaX-tec Base Station data receiver located near steer pens.

Dietary treatments consisted of a steam-flaked corn-based diet supplemented with 1) no feed additive (**CON**); 2) 30 mg of monensin (**MON**)/ kg of dry matter (**DM**) (Rumensin 90, Elanco, Greenfield, IN); 3) 1.5 g tannin/ kg of DM (**TAN**; ByPro, 70% condensed tannin, SilvaFeed, Indunor, S.A., Buenos Aires, Argentina); 4) **M + T**, the combination of MON plus TAN dietary treatments. Level of tannin supplementation was selected in accordance with manufacturer recommendation. Steers were allowed ad libitum access to dietary treatments and water (automatic waterers) from day 1 to the final day of the study. Steers were fed a similar diet before arrival at the feedlot, so no adaptation period was needed. Fresh feed was provided in a single, daily feeding, allowing for a daily feed residual of around 5%. Steam-flaked corn was purchased from a local feedlot. The steam-flaked corn was allowed to air dry (5 days) before diet preparation. Forages (sudan-grass hay and alfalfa hay) were ground separately in a hammer mill (Bear Cat #1A-S, Westerns Land and Roller Co., Hastings, NE) with a 2.6-cm (sudan-grass hay) or 5.0-cm (alfalfa hay) screen before incorporation into the complete mixed diets. Sudangrass and alfalfa were included in the final diet at 8% (DM) and 4% (DM), respectively. The mixer is a single batch mixer with a capacity of 1,000 kgs/batch. Once all the ingredients were included in the mixer, the diets were mixed for 5 to 7 min. Diets were prepared weekly and stored in plywood boxes in front of each pen. Feed was fed by hand using large feed shovels with feed delivery amounts adjusted daily using a slick-bunk management approach. Feed samples were collected from each mixed batch and composited weekly with other samples from the same treatment 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 DM intake (**DMI**). On the same day of steer weighing (28 d intervals), refusals from feed bunks were shoveled back into the plywood boxes, and boxes were weighed for determination of feed intake.

Carcass measurements

Steers were slaughtered following day 328 of feeding. Steers were sent to a cattle processing plant approximately 19 miles north of the UC Desert Research and Extension Center. Cattle were transported in the morning and harvested in the early afternoon of the same day. Hot carcass weights (**HCW**), liver abscess incidence (based on size and number, scaled as 0, A−, A, and A+; Brown et al., 1975), and liver scarring measures were obtained during harvest. After carcasses were chilled for 24 h, the following measurements were obtained: Longissimus muscle (**LM**) area (cm^2) by direct grid reading of the muscle at the 12th rib; subcutaneous fat (cm) over the LM at the 12th rib taken at a location 3/4 the lateral length from the chine bone end (adjusted by eye for unusual fat distribution); kidney, pelvic and heart fat (**KPH**) as a percentage of HCW; marbling score (USDA, 1997; using 3.0 as minimum slight, 4.0 as minimum small, 5.0 as minimum modest, 6.0 as minimum moderate, etc.), and estimated retail yield of boneless, closely trimmed retail cuts from the round, loin, rib, and chuck as a percentage of HCW (Yield, % = 52.56 − 1.95 × subcutaneous fat − 1.06 × KPH + 0.106 × LM area—0.018 × HCW; Murphey et al., 1960).

Estimation of dietary NE

Performance adjusted net energy values of the diet were calculated from estimates of energy gain (EG, Mcal/d) based on growth performance [NRC, 1984; $EG = (0.0557BW^{0.75}) ADG^{1.097}$, where BW is the mean shrunk BW (full weight × 0.96)], and maintenance energy (EM, Mcal/d) was calculated ($EM = 0.077BW^{0.75}$; NRC, 1984; with a 12% increase adjustment used for Holstein steers; Garrett, 1971; Fox and Black, 1984; NRC, 1988). Dietary NE_g was derived from NE_m by the equation: $NE_g = 0.877\ NE_m — 0.41$ (Zinn, 1987), was estimated using the quadratic formula: $x = (-b - \sqrt{b^2 - 4ac})/2c$, where x = dietary NEm (Mcal/kg), $a = -0.877DMI$ (kg/d), $b = 0.877EM + 0.41DMI + EG$, $c = -0.41EM$ (Zinn and Shen, 1998).

Statistical design and analysis

Data were analyzed as a randomized complete block in a 2 × 4 factorial arrangement of treatments, using pens as experimental units. Treatment effects were tested according to the following statistical model:

$$Yijk = \mu + Bi + BRj + DTk + BR * DTjk + Eijk,$$

where μ is the common experiment effect, Bi represents the initial weight group effect (df = 4), BR represents the breed effect (df = 1), DTk represents the dietary treatment effect (df = 3), BR*DTjk represents breed × dietary treatment interaction (df = 3), and Eijk is the residual error (df = 28). Dietary treatments were tested for the main effects and interactions of supplemental monensin and tannin (Statistix 10, Analytical Software, Tallahassee, FL). The likelihood of positive cases for liver abscess, liver abscess scars, and morbidity were analyzed as a binomial response variable using the binary logistic regression model. The model included, besides the intercept, the fixed categorical effects of block, breed, treatment, and the residual term. Contrasts were considered significant when the P-value was ≤ 0.05 in Wald Chi-square test. Tendency is discussed at $0.05 < P \geq 0.10$.

Results and Discussion

There were no interactions ($P > 0.10$) between dietary treatments and breed. Thus, the main effects of the dietary treatment and breed are reported and discussed.

Diet

Treatment effects on growth performance and estimated dietary NE are shown in Table 1. Supplemental MON increased ($P = 0.04$) live BW during the first 112 d on feed with no effect ($P \geq 0.15$) of feed additive supplementation on overall BW changes. Supplemental TAN did not affect ($P > 0.10$) steer growth performance. Monensin supplementation tended ($P = 0.09$) to increase ADG during the initial 112 d on feed, leading to an improved initial 112-d gain efficiency (gain-to-feed ratio; $P < 0.01$), but there were no overall (328-d) dietary treatment effects on measures of growth performance and estimated dietary NE.

Although growth performance responses to supplemental monensin have been variable, Duffield et al. (2012) concluded in a meta-analysis that monensin supplementation improves feed efficiency in feedlot cattle mainly by reducing dry matter intake (DMI). Consistent with the present study, Burrin et al. (1988) observed enhanced gain efficiency with monensin supplementation during the early feeding period, with no effect of monensin supplementation on overall cattle growth performance. Previous studies with calf-fed Holstein animals have also reported no effect of monensin supplementation on steer growth performance (Zinn and Borques, 2017; Salinas-Chavira et al., 2009).

Previous studies have linked condensed tannin supplementation to reductions in methane production and increased efficiency of nitrogen utilization (Makkar, 2003; Beauchemin et al., 2008), but the overall effects of tannin supplementation on cattle growth performance have not been consistent. Differences in responses may be attributable to factors, including tannin concentration and chemical structure, animal species, physiological state, and diet composition (Makkar, 2003; Orzuna-Orzuna et al., 2021). Rivera-Mendez et al. (2017) observed increased ADG and gain efficiency in Holstein steers in response to supplemental tannin, but tannin concentrations were greater than that used in the present

Table 1. Influence of monensin, tannin, and breed on growth performance of Holstein and Holstein × Angus steers

	Dietary treatments[1]				Breed			*P*-value[2]			
Item	CON	MON	TAN	M + T	Holstein	Holstein × Angus	SD	MON	TAN	MON + TAN interaction	Breed
Days on test	328	328	328	328	328	328					
Pen replicates	10	10	10	10	20	20					
Weight, kg											
Initial	129.5	130.3	128.7	130.9	130.3	129.3	3.1	0.15	0.97	0.94	0.32
112 d	286.2	288	285.8	297.8	285.2	293.7	10.6	0.04	0.32	0.77	0.01
224 d	467.6	465.5	470.6	480.9	469.9	472.5	17.2	0.46	0.49	0.99	0.64
328 d	607.1	612	614.6	629.1	611.6	619.8	22.9	0.19	0.16	0.69	0.26
DMI, kg/d											
1 to 112 d	5.75	5.62	5.76	5.89	5.83	5.68	0.33	0.97	0.33	0.67	0.14
112 to 224 d	8.02	8	8.24	8.37	8.33	7.99	0.42	0.68	0.36	0.61	0.01
224 to 328 d	9.88	10.05	10.03	10.09	10.17	9.85	0.79	0.65	0.59	0.54	0.21
1 to 328 d	7.83	7.84	7.96	8.07	8.06	7.79	0.39	0.65	0.34	0.65	0.04
ADG, kg/d											
1 to 112 d	1.39	1.41	1.4	1.49	1.38	1.47	0.09	0.09	0.28	0.77	<0.01
112 to 224 d	1.62	1.59	1.65	1.64	1.65	1.59	0.09	0.41	0.92	0.75	0.09
224 to 328 d	1.34	1.41	1.38	1.43	1.36	1.42	0.15	0.25	0.18	0.56	0.25
1 to 328 d	1.46	1.47	1.48	1.52	1.47	1.49	0.07	0.25	0.15	0.67	0.19
G/F											
1 to 112 d	0.244	0.251	0.244	0.253	0.237	0.259	0.01	<0.01	0.78	0.81	<0.01
112 to 224 d	0.202	0.198	0.201	0.195	0.198	0.2	0.01	0.08	0.32	0.82	0.52
224 to 328 d	0.135	0.14	0.138	0.142	0.134	0.144	0.01	0.25	0.18	0.84	0.01
1 to 328 d	0.186	0.188	0.186	0.188	0.182	0.192	0.01	0.33	0.49	0.96	<0.01
Overall NE_m	2.21	2.23	2.21	2.25	2.19	2.26	0.06	0.16	0.38	0.99	<0.01
Overall NE_g	1.53	1.54	1.53	1.56	1.51	1.57	0.06	0.16	0.38	0.99	<0.01
Overall obs/exp NE_m	0.99	1	1	1.01	0.98	1.01	0.03	0.16	0.38	0.99	<0.01
Overall obs/exp NE_g	0.99	1	0.99	1.01	0.98	1.01	0.04	0.16	0.38	0.99	<0.01

[1]Treatments: CON: control, no antibiotic; MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN); TAN: ByPro, 70% condensed tannin, SilvaFeed, Indunor, S.A., Buenos Aires, Argentina); M + T: consists of the MON plus the TAN dietary treatments.
DMI, dry matter intake; ADG, average daily gain; G/F, gain efficiency; NE_m, net energy for maintenance; NE_g, net energy for gain, obs/exp NE_m, observed versus expected net energy for maintenance; obs/exp NE_g, observed versus expected net energy for gain.

study. In their study, daily tannin intake averaged 23, 46, and 68 g/d considering the DMI over the course of the experiment (Rivera-Méndez et al., 2017). Whereas in the present study, supplemental tannin intake averaged 12 g/d considering the DMI along the experiment. The lower level of tannin supplementation in the current study may not have been adequate to evoke a growth performance response. Montano et al., (2022) observed that condensed tannin supplementation of a steam-flaked corn-based diet at dosage levels greater than that of the present study (~80 and 160 g/d) did not affect the growth performance of Holstein steers. Likewise, Krueger et al. (2010) did not observe an influence of tannin supplementation (~170 g/d) on measures of feedlot growth performance in crossbred beef steers fed a corn-based diet.

Dietary treatment effects on carcass characteristics and health are presented in Table 2. There were no dietary treatment effects ($P \geq 0.22$) on carcass characteristics. The absence of supplemental tannin effects on carcass measures is consistent with previously reported studies (Ebert et al., 2017; Rivera-Méndez et al., 2017; Tabke et al., 2017). Previous studies have also reported a similar lack of response on carcass characteristics in Holstein (Zinn, 1987; Salinas-Chavira et al., 2009; Carvalho et al., 2023) or beef cattle supplemented with monensin (Meyer, 2008; Montano et al., 2014).

The incidence of liver abscess and liver scaring was low (averaging 3.7% and 6.2%, respectively) and not affected ($P \geq 0.39$) by dietary treatments. Morbidity, although low (averaging 6.9%), was yet appreciably lower for monensin-supplemented steers (2.5% vs. 11.2%; $P < 0.01$). This decrease in morbidity of steers in the MON group may have contributed to the improvement in efficiency during the initial 112-d period.

Breed

Breed effects on growth performance and estimated dietary NE are shown in Table 1. During the initial 112-d period, AXH had greater ($P < 0.01$) ADG and live BW than HOL. Rezagholivand et al. (2021) reported that Angus × Holstein crosses had a 7% greater overall ADG compared with purebred Holstein; this is in close agreement with the growth performance observed during the initial 112 d of the current experiment, where AXH had a 6.5% greater ADG compared with HOL. However, this was not apparent in subsequent periods; from

Table 2. Influence of monensin, tannin, and breed on carcass characteristics and health of calf-fed Holstein and Holstein × Angus steers

	Dietary treatments[1]				Breed			*P*-value			
Item	CON	MON	TAN	M + T	Holstein	Holstein × Angus	SD	MON	TAN	MON + TAN Interaction	Breed
HCW, kg	377.8	376.5	379.9	388.6	375.2	386.3	14.7	0.43	0.27	0.59	0.02
Dressing percentage	62.2	61.5	61.8	61.8	61.4	62.3	1.05	0.25	0.56	0.72	<0.01
KPH[2], %	3.3	3.36	3.34	3.29	3.22	3.43	0.19	0.89	0.89	0.95	<0.01
Fat thickness, cm	0.72	0.66	0.78	0.74	0.55	0.89	0.12	0.22	0.38	0.79	<0.01
LM area, cm	83.4	83.3	82.9	82.4	79.1	86.9	4.83	0.84	0.99	0.47	<0.01
Marbling score[3]	4.89	4.95	4.85	5.05	4.49	5.38	0.48	0.39	0.44	0.69	<0.01
Calculated yield grade	2.89	2.84	2.99	3.04	2.89	2.99	0.24	0.98	0.34	0.58	0.26
Liver abscess, %	0	5	5	5	5	2.5	1.21	0.94	0.94	0.94	0.4
Liver abscess scars, %	2.5	10	7.5	5	8.75	3.75	1.54	0.81	0.5	0.21	0.2
Morbidity, %	7.5	2.5	15	2.5	6.3	7.5	7.5	0.62	0.05	0.66	0.73

[1]Treatments: CON: control, no antibiotic; MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN); TAN: ByPro, 70% condensed tannin, SilvaFeed, Indunor, S.A., Buenos Aires, Argentina); M + T: consists of the MON plus the TAN dietary treatments.
[2]Kidney, pelvic, and heart fat as a percentage of carcass weight.
[3]Coded: minimum slight = 3.0, minimum small = 4.0, minimum modest = 5.0, minimum moderate = 6.0, and so on.
HCW, hot carcass weight; KPH, kidney, pelvic, heart fat; LM area, longissimus area.

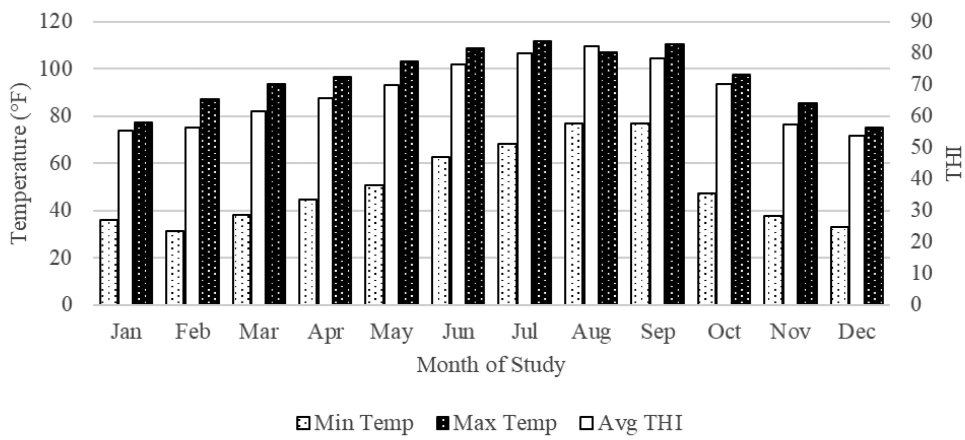

Figure 1. Temperature-humidity index (THI) during the 286-d feeding period: THI = (0.8 × Ta) + [(H/100) × (Ta − 14.4)] + 46.4, where Ta is air temperature (°C) and *H* is relative humidity (Thom, 1959; NOAA, 1976); Min = minimum; Max = maximum.

day 112 – 224, HOL steers tended ($P = 0.09$) to have greater ADG than AXH steers. The tendency for less ADG in AXH compared with HOL from days 112 to 224 matches the hottest months of the year (May to August; Figure 1) and a period (June) when AXH had a greater ($P = 0.04$) average ruminal temperature than HOL (Table 3). This increased ADG is consistent with a concomitantly greater DMI (4%, $P < 0.01$) for HOL vs AXH steers. Silva et al. (2003) observed a difference in radiation absorption between black and non-pigmented cattle coats. Black coats were found to absorb as much as 94% of short-wave radiation reaching the surface, emphasizing their high absorptive capacity. In contrast, non-pigmented areas exhibited significantly lower absorbance, accounting for only 43% of the short-wave radiation. This disparity underscores the unique thermal characteristics associated with different coat pigmentation in cattle. Accordingly, the black hided steers (AXH) in the current experiment faced greater challenges during the summer months than the black and white hided steers (HOL). Differences in ADG and steer live weight between breeds were not different ($P > 0.10$) during the subsequent periods and overall.

The tendency of greater ADG observed in HOL compared with AXH from days 112 to 224 also reflects a 4.2% greater ($P = 0.01$) DMI observed in HOL (Table 1). Moreover, the increase in DMI observed in purebred dairy animals compared with Angus × Holstein crosses in the current study is in close agreement with the DMI adjustments recommended by the NRC (1987). The NRC (1997) suggested that purebred dairy animals have an intake of 8% greater than traditional beef, and the beef × dairy crosses a 4% greater intake than traditional beef breeds (adjustments of 1.08 and 1.04, respectively, compared with traditional beef breeds). This is 3.7% greater DMI for purebred Holstein steers in the feedlot compared with beef × dairy crosses (NRC, 1987), which is in close agreement with the current experiment where HOL had a 3.5% greater ($P = 0.04$) overall DMI compared with AXH. The overall lesser DMI observed in the AXH resulted in a 5.5% greater ($P < 0.01$) overall feed efficiency ratio for AXH compared with purebred HOL. These results are similar to Rezagholivand et al. (2021), who reported that the Angus × Holstein cross had a 4.5% greater overall feed efficiency compared with purebred Holsteins.

Table 3. Influence of monensin, tannin, and breed on ruminal temperature in June, July, and August (2022)

Item	Dietary treatments[1]				Breed			P-value			
	CON	MON	TAN	M + T	Holstein	Holstein × Angus	SD	MON	TAN	MON + TAN Interaction	Breed
June ruminal temp, °C											
Min temp	39.5	39.4	39.4	39.5	39.3	39.5	0.13	0.21	0.95	0.25	<0.01
Ave temp	40.3	40.1	40.1	40.2	40.1	40.2	0.17	0.45	0.91	0.29	0.04
Max temp	40.9	40.8	40.7	40.9	40.8	40.9	0.23	0.71	0.76	0.25	0.21
July ruminal temp, °C											
Min temp	39.7	39.5	39.6	39.6	39.5	39.6	0.18	0.04	0.93	0.94	0.14
Ave temp	40.5	40.3	40.3	40.4	40.3	40.4	0.22	0.38	0.91	0.69	0.19
Max temp	41.2	41	41	41.2	41.1	41.2	0.28	0.95	0.67	0.47	0.31
August ruminal temp, °C											
Min temp	39.9	39.7	39.9	39.8	39.8	39.9	0.25	0.11	0.84	0.71	0.24
Ave temp	40.7	40.5	40.6	40.6	40.6	40.7	0.27	0.42	0.84	0.99	0.28
Max temp	41.4	41.2	41.2	41.4	41.3	41.4	0.3	0.95	0.68	0.65	0.34

[1]Treatments: CON: control, no antibiotic; MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN); TAN: ByPro, 70% condensed tannin, SilvaFeed, Indunor, S.A., Buenos Aires, Argentina); M + T: consists of the MON plus the TAN dietary treatments.

As stated previously, the maintenance requirement per unit metabolic weight of Holsteins is 8 percentage units greater than that of conventional beef breeds (maintenance coefficient of 0.086 vs 0.077). Thus, it may be expected that the maintenance coefficient of beef × Holstein cross would be midway between that of Holstein vs. beef breeds (i.e., 0.082). As shown in Table 1, the estimated dietary NE_m and NE_g for HOL were in agreement with expected based on diet formulation; the ratio of observed to expected NE was 1.0. However, applying the same maintenance coefficient used for HOL (0.086), estimated dietary NE values for AXH were greater than expected based on diet formulation ($P < 0.01$). Adjusting the maintenance coefficient for AXH by iteration so that observed dietary NE was consistent with diet formulation (Table 4), the resulting maintenance coefficient becomes 0.082, in agreement with the assumption that the maintenance coefficient might be midway between that of Holstein and beef breeds. Therefore, crossing Angus × Holstein animals (AXH) enhances dietary energy utilization through a reduction in maintenance energy expenditures compared with Holstein steers.

Steer breed effects on carcass characteristics and health are presented in Table 2. Hot carcass weight, dressing percentage, KPH, fat thickness, LM area, and marbling score were greater ($P \leq 0.02$) for AXH than HOL. As previously mentioned, Rezagholivand et al. (2021) reported that Holstein fat animals had greater internal organ size than Holstein × Angus cross steers, which is reflected by the greater dressing percentage and carcass weight of AXH compared with HOL in the current experiment. Foraker et al. (2022) suggested that the LM area might be similar between beef × dairy crosses and dairy-type steers, which is different from what was observed in the current study. Therefore, more research is needed to verify genetic differences in LM area when animals are finished with similar feeding management. Previous studies have reported that cattle breeds might affect fat deposition in the animal (Marshall, 1994; Albrecht et al., 2006), which was also consistent with Jaborek et al. (2019a, 2019b). In this study, AXH steers had 62% greater fat thickness and a 20% greater marbling score than HOL ($P < 0.01$). These results carry implications for markets where consumers prefer greater fat content in meat, possibly leading to product differentiation based on breed-specific qualities. Producers and stakeholders should factor in these findings when making decisions to ensure competitiveness in a market that places a growing emphasis on meat quality. As stated previously, the incidence of steer morbidity, liver abscess, and liver abscess scars was low and not affected by breed ($P \geq 0.23$; Table 2). A greater incidence of liver abscesses has been reported in dairy-type cattle compared with beef breeds, with incidences in beef × dairy crosses being similar to that of Holsteins (Amachawadi and Nagaraja, 2016; Foraker et al., 2022). Regardless of breed, liver abscesses and scaring averaged 3.7% and 6.2%, respectively, much less than what has been suggested but not different than previous research conducted by our research group, with liver abscess incidence averaging <10% (Carvalho et al., 2022, 2023; Latack et al., 2022).

Conclusion

The study provides insights into the effects of monensin and tannin on growth performance, carcass characteristics, and health of Holstein and crossbred steers. Overall, monensin and tannin did not affect growth performance and carcass characteristics. However, AXH steers were more efficient in growth performance and had heavier carcasses and more fat content than Holstein steers. These results have the potential to influence industry practices and strategies, prompting considerations for optimizing the use of beef breeds sires for dairy cows. Producers may reevaluate their breeding and management approaches to capitalize on the demonstrated advantages in growth efficiency and meat characteristics

Table 4. Composition of experimental diets (DM basis)

Item	Dietary treatments[1] CON	MON	TAN	M + T
Ingredient composition, % DM				
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	60.92	60.90
Urea	0.80	0.80	0.80	0.80
Limestone	1.56	1.56	1.56	1.56
Dicalcium phosphate	0.15	0.15	0.15	0.15
Magnesium oxide	0.12	0.12	0.12	0.12
TM salt[2]	0.30	0.30	0.30	0.30
Rumensin 90[3]	0.00	0.018	0.00	0.018
ByPro[4]	0.00	0.00	0.15	0.15
Nutrient composition, DM basis (NRC, 2000)				
Dry matter, %	89.2	89.2	89.2	89.2
NEm, Mcal/kg[5]	2.20	2.20	2.20	2.20
NEg, Mcal/kg[5]	1.53	1.53	1.53	1.53
Crude protein, %	14.9	14.9	14.9	14.9
Rumen DIP, %[5]	60.0	60.0	60.0	60.0
Rumen UIP, %[5]	40.0	40.0	40.0	40.0
Ether extract, %	7.16	7.16	7.16	7.16
Ash, %	5.91	5.91	6.04	6.05
Nonstructural CHO, %[5]	54.0	54.0	54.0	54.0
NDF, %[5]	20.50	20.50	20.50	20.50
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]Treatments: CON: control, no antibiotic; MON: monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN); TAN: ByPro, 70% condensed tannin, SilvaFeed, Indunor, S.A., Buenos Aires, Argentina); M + T: consists of the MON plus the TAN dietary treatments.
[2]Trace mineral salt contained: $CoSO_4$, 0.068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 0.75%; $MnSO_4$, 1.07%; KI, 0.052%; and NaCl, 93.4%.
[3]20% monensin (Elanco Animal Health, Greenfield, IN, USA).
[4]70% condensed tannin (ByPro, SilvaFeed, Indunor, S.A., Buenos Aires, Argentina).
[5]NE_m, net energy for maintenance; NE_g, net energy for gain; DIP, degradable intake protein; UIP, undegradable intake protein; CHO, carbohydrates; NDF, neutral detergent fiber.

associated with beef × dairy steers, ultimately increasing the value of calves from Holstein cows.

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Conflict of Interest Statement

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

All authors were involved in study design, data collection, data analysis, and manuscript preparation and approved the submitted version.

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