SEMINA
Ciências Agrárias

DOI: 10.5433/1679-0359.2026v47n2p483

Effects of different additive combinations and high-energy diets on the performance and carcass characteristics of finishing feedlot steers

Efeito de diferentes aditivos associados a dietas de alta densidade energética sobre o desempenho e as características de carcaça de novilhos confinados na fase de terminação

Mikael Neumann[1]; Fernando Braga Cristo[2]; Fernando de Souza Sidor[2]; Daniel Corrêa Plodoviski[2]; Luísa da Costa Venancio[2]; Maria Eduarda de Oliveira Poleto[2]; Paulo Victor Cesar Pinheiro[2]; Paulo Eduardo Piemontez de Oliveira[2]; André Martins de Souza[2]*

Highlights

Animal performance was superior with the use of monensin + virginiamycin.
The combination of enzymes and essential oils improved carcass finish.
Ingestive behavior (hours day^{-1}) was not influenced by the diets and additives.

Abstract

The study aimed to evaluate the combined effects of a carbohydrase enzyme complex and an essential oil blend, used as replacements for sodium monensin and virginiamycin, on the growth performance and carcass characteristics of feedlot-finished steers fed two high-energy diets. Thirty-two half-blood Angus steers were used. The experiment followed a randomized block design in a 2 × 2 factorial arrangement, consisting of two diet types and two additive combinations. The four treatments, with four replicates each, were as follows: T1, pelleted total diet supplemented with sodium monensin and virginiamycin; T2, pelleted total diet supplemented with an enzyme complex and essential oil blend; T3, diet consisting of 85% whole shelled corn and 15% protein-vitamin-mineral supplement, supplemented with sodium monensin and virginiamycin; and T4, diet consisting of 85% whole shelled corn and 15% protein-vitamin-mineral supplement, supplemented with an enzyme complex and essential oil blend.

[1] Prof. Dr., Graduate Program in Veterinary Sciences and Plant Production, Department of Veterinary Medicine and Agronomy, Universidade Estadual do Centro-Oeste, UNICENTRO, Guarapuava, PR, Brazil. E-mail: neumann.mikael@hotmail.com

[2] Collaborators from the NUPRAN research group, Department of Veterinary Medicine, Guarapuava, PR, Brazil. E-mail: fernandobragacristo@gmail.com; fernandosiddor@gmail.com; danielplodoviski@gmail.com; luisacosta23@outlook.com; maripoletoliver@gmail.com; paulo_victor147@hotmail.com; piemontez@gmail.com; andrems_92@hotmail.com

* Author for correspondence

Received: Dez. 07, 2025 Approved: Ago. 26, 2026

Steers fed the whole shelled corn diet had 11.30% greater weight gain than those fed the pelleted total diet. They also had greater carcass gain (140.3 vs. 120.7 kg), hot carcass weight (306.70 vs. 286.05 kg), and ribeye area (82.53 vs. 79.56 cm²). Supplementation with sodium monensin and virginiamycin resulted in greater average daily gain and better feed conversion over the periods from 0 to 112 days and from 0 to 140 days. This combination was also more effective than the essential oil blend combined with the enzyme complex in terms of carcass gain (135.15 vs. 126.05 kg) and hot carcass weight (302.05 vs. 290.70 kg). In contrast, supplementation with the essential oil blend and enzyme complex resulted in higher marbling scores and greater subcutaneous and picanha (rump cap) fat thickness than supplementation with sodium monensin and virginiamycin (3.00 vs. 2.72, 7.57 vs. 6.95 mm, and 9.98 vs. 9.17 mm, respectively). A diet consisting of 85% whole shelled corn and 15% protein-vitamin-mineral supplement improved growth performance and carcass characteristics compared with a fully pelleted diet. The combined use of essential oils and fibrolytic enzymes in high-energy diets improved carcass finish compared with the combined use of sodium monensin and virginiamycin.
Key words: Carcass characteristics. Essential oils. Ionophores. Non-starch polysaccharides. Total diet.

Resumo

O estudo teve por objetivo avaliar o efeito associativo de enzimas carboidrases e blend de óleos essenciais, em substituição à monensina sódica e virginiamicina, sobre desempenho produtivo e características de carcaça de novilhos terminados em confinamento recebendo dois diferentes tipos de dieta com alta densidade energética. Foram utilizados 32 novilhos ½ sangue Angus. O delineamento experimental foi o de blocos casualizados, num esquema fatorial 2 x 2, sendo dois tipos de dieta e duas combinações de aditivos, constituindo quatro tratamentos com quatro repetições: T1 – dieta total peletizada com monensina sódica + virginiamicina; T2 - dieta total peletizada com complexo enzimático + blend de óleos essenciais; T3 – dieta 85% de milho grão inteiro e 15% de núcleo proteico-vitamínico-mineral com monensina sódica + virginiamicina; e T4 - dieta 85% de milho grão inteiro e 15% de núcleo proteico-vitamínico-mineral com complexo enzimático + blend de óleos essenciais. Os animais alimentados com milho grão inteiro apresentaram ganho de peso 11,30% superior que os alimentados com dieta total peletizada, além de possuírem maior ganho de carcaça (140,3 versus 120,7 kg), maior peso de carcaça quente (306,70 versus 286,05 kg) e maior área de olho de lombo (82,53 versus 79,56 cm2). A suplementação com monensina sódica associada a virginiamicina proporcionou melhor ganho médio diário e melhor conversão alimentar quando avaliado os animais de 0 a 112 dias e de 0 a 140 dias, assim como se mostrou mais eficiente que a suplementação com óleo essencial associado ao complexo enzimático para ganho de caraça (135,15 versus 126,05 kg) e peso de carcaça quente (302,05 versus 290,70 kg). Já a suplementação com óleo essencial associado ao complexo enzimático fez com que os animais apresentassem melhores índices de marmoreio, maior espessura de gordura subcutânea e de picanha que a suplementação com monensina sódica associada a virginiamicina (3,00 versus 2,72; 7,57 mm versus 6,95 mm e 9,98 mm versus 9,17 mm, respectivamente). A dieta composta por 85% milho grão inteiro e 15% concentrado proporcionou melhorias no desempenho e nas características de carcaça dos animais em relação aos alimentados com dieta total peletizada. O uso combinado de óleos essenciais a enzimas fibrolíticas em dietas de alta densidade energética promoveram melhor acabamento das carcaças em relação a uso de monensina sódica associada a virginiamicina.
Palavras-chave: Caracterização da carcaça. Dieta total. Ionóforos. Óleos essenciais. Polissacarídeos não amiláceos.

Introduction

The use of high-energy diets is common in beef cattle nutrition, particularly during the finishing phase, because these diets can improve growth performance, feed efficiency, and carcass characteristics (Monteschio et al., 2017; Abreu et al., 2022). They are characterized by high proportions of concentrate, which may include whole corn grain at 80–90% of the total diet (Millen et al., 2009; Neumann et al., 2018) or may be supplied as commercially manufactured complete pelleted diets.

The physical form of the diet can contribute significantly to feed sorting at the bunk, a behavior in which animals selectively consume their preferred particles, typically the smaller ones (Barreta, 2020). Although feed sorting can result in nutritional imbalances, pelleting can prevent this behavior. Complete pelleted diets are already used in sheep, goat, and beef cattle production (Chen et al., 2018; Bonfante et al., 2016).

In addition to preventing feed sorting, complete pelleted diets are highly stable because of their low moisture content and are easy to handle, store, and transport. Moreover, the pelleted form allows diets to contain a higher energy concentration (Bonfante et al., 2016). Nutritional strategies that maximize nutrient utilization, improve feed efficiency and animal performance, and consequently increase the profitability of production systems are valuable tools in livestock production (Schären et al., 2017).

As livestock production systems face increasing pressure to achieve greater efficiency and profitability while shortening production cycles, diets formulated to improve performance must be accompanied by other technologies capable of maximizing production. Feed additives, including ionophores, nonionophore antibiotics, essential oils, and enzymes, are among these technologies. Of the additives used in ruminant nutrition, sodium monensin, an ionophore, is the most widely used, whereas virginiamycin is a prominent nonionophore antibiotic (Soares et al., 2015; Maciel et al., 2015). These additives can substantially alter ruminal fermentation by modulating the rumen microbiota. This activity increases propionic acid production, improves ruminal stability, and reduces the incidence of acidosis (Maciel et al., 2015; Tedeschi & Buenfil, 2018).

Similarly, essential oils can affect several groups of ruminal microorganisms, including Gram-positive and Gram-negative bacteria, thereby altering ruminal fermentation patterns (Estrada-Angulo et al., 2022). Exogenous enzymes can increase fatty acid production in the rumen, which may, in turn, affect fat synthesis and carcass characteristics (Vargas et al., 2013; Rossi et al., 2015). Although studies evaluating individual diets and feed additives have demonstrated several benefits for animal production, research on their combined use remains limited.

This study aimed to evaluate the effects of a carbohydrase enzyme complex combined with an essential oil blend and sodium monensin combined with virginiamycin on weight gain, dry matter intake, apparent dry matter digestibility, and carcass characteristics of finishing feedlot steers fed either a diet composed of 85% whole corn grain and 15% concentrate or a complete pelleted diet.

Material and Methods

Location, experimental animals, and facilities

The study was conducted at the Animal Production Center of the Agricultural and Environmental Sciences Sector, in collaboration with the Graduate Program in Veterinary Sciences at the State University of the Center-West (UNICENTRO), Guarapuava, Paraná, Brazil. All experimental procedures were submitted in advance to the UNICENTRO Ethics Committee on Animal Use (CEUA/UNICENTRO) and approved under protocol No. 032/2019.

The experimental animals consisted of 32 intact Angus-crossbred males from the same herd, with a mean initial live weight (LW) of 332 ± 5 kg and a mean age of 10 ± 2 months. The animals were assigned to the experimental units according to LW, ribeye area (REA), and subcutaneous fat thickness. REA and subcutaneous fat thickness were measured ultrasonographically using an Aloka® SSD-500 Vet ultrasound unit fitted with a 17-cm, 3.5-MHz probe.

The facilities consisted of 15 feedlot pens, each measuring 15 m² (2.5 × 6.0 m). Each pen was equipped with a concrete feed bunk measuring 2.30 m long, 0.60 m wide, and 0.35 m high and a metal water trough fitted with an automatic float valve.

Experimental design

The experiment followed a randomized complete block design in a 2 × 2 factorial arrangement, resulting in four treatments with four replicates per treatment: Treatment 1, complete pelleted diet supplemented with sodium monensin (240 mg animal day^{-1}) and virginiamycin (120 mg animal day^{-1}); Treatment 2, complete pelleted diet supplemented with an enzyme complex (5 g animal day^{-1}) and an essential oil blend (5 g animal day^{-1}); Treatment 3, diet composed of 85% whole corn grain and 15% protein-vitamin-mineral concentrate, supplemented with sodium monensin (240 mg animal day^{-1}) and virginiamycin (120 mg animal day^{-1}); and Treatment 4, diet composed of 85% whole corn grain and 15% protein-vitamin-mineral concentrate, supplemented with an enzyme complex (5 g animal day^{-1}) and an essential oil blend (5 g animal day^{-1}).

Description of feed additives and diets

The Potenzya® enzyme complex (ENZ; Safeeds, Cascavel, Paraná, Brazil), obtained through the fermentation of the fungi Aspergillus niger and Trichoderma reesei, was subjected to a preliminary enzyme activity analysis using the 3,5-dinitrosalicylic acid (DNS) assay adapted from Miller (1959). The complex exhibited xylanase, cellulase, β-glucanase, mannanase, α-galactosidase, and amylase activities of 3,117; 2,870; 2,210; 372; 11; and 21 U g^{-1}, respectively. The assay conditions were as follows: xylanase, pH 4.5 and 40 °C; cellulase, pH 4.8 and 50 °C; β-glucanase, mannanase, and amylase, pH 5.0 and 40 °C; and α-galactosidase, pH 5.5 and 37 °C. The essential oil blend (EO) was Ruminatos® (Safeeds, Cascavel, Paraná, Brazil), a product containing Eugenia caryophyllata, eugenol, Thymus zygis, thymol, anacardic acid, castor oil, and Vanilla pompona.

The sodium monensin product (MO) was Rumensin® 200, manufactured by Elanco Animal Health, containing 200 g kg⁻¹ sodium monensin and registered with MAPA under No. SP-59410 30002. The virginiamycin product (VM) was Eskalin®, containing 20 g kg⁻¹ virginiamycin and registered with MAPA by Phibro Animal Health International Ltda. under No. SP-09492 30012.

The complete pelleted diet contained 187.0 g kg⁻¹ wheat bran, 230.0 g kg⁻¹ malt sprouts, 220.0 g kg⁻¹ barley, 139.0 g kg⁻¹ corn, 170.0 g kg⁻¹ corn germ, 33.3 g kg⁻¹ calcitic limestone, 6.5 g kg⁻¹ feed-grade urea, 8.4 g kg⁻¹ vitamin-mineral premix, and 5.8 g kg⁻¹ sodium chloride. The diet was manufactured by Cooperativa Agrária, Guarapuava (Table 1).

Table 1
Bromatological composition of the experimental diets, based on total dry matter

Parameter	Experimental diet[1]	
	Corn kernels + concentrate	Complete pelleted diet
Dry matter, g kg⁻¹	900.60	897.80
Mineral matter, g kg⁻¹	30.90	44.70
Ether extract, g kg⁻¹	33.00	33.40
Crude protein, g kg⁻¹	138.40	140.00
Neutral detergent fiber, g kg⁻¹	182.50	226.20
Acid detergent fiber, g kg⁻¹	78.80	107.10
Starch, g kg⁻¹	552.40	378.00
Total digestible nutrients, g kg⁻¹	797.50	758.80
Ca, g kg⁻¹	100.10	85.60
P, g kg⁻¹	29.80	27.60

[1]Guaranteed levels of minerals and vitamins per kg of diet: vit. A: 11.500 IU; vit D3: 1.500 IU; vit. E: 55 IU; S: 0,51 g; Mg: 0,92 g; Na: 2,6 g; Co: 0,72 mg; Cu: 12,01 mg; Mn: 25,80 mg; Se: 0,34 mg; e Zn: 60,20 mg).

The diet composed of 85% whole corn grain and 15% pelleted concentrate was mixed at feeding to maintain the proper proportion of the two components. The pelleted concentrate contained 875.0 g kg⁻¹ dry matter (DM) and, on a DM basis, 240.1 g kg⁻¹ mineral matter (MM), 28.5 g kg⁻¹ ether extract (EE), 434.2 g kg⁻¹ crude protein (CP), 242.9 g kg⁻¹ neutral detergent fiber (NDF), 148.5 g kg⁻¹ acid detergent fiber (ADF), 15.0 g kg⁻¹ lignin, 117.8 g kg⁻¹ starch, 650.1 g kg⁻¹ total digestible nutrients (TDN), 43.6 g kg⁻¹ calcium (Ca), and 9.7 g kg⁻¹ phosphorus (P). The protein-vitamin-mineral concentrate contained 214.0 g kg⁻¹ wheat bran, 270.0 g kg⁻¹ malt sprouts, 289.0 g kg⁻¹ soybean meal, 100.0 g kg⁻¹ calcitic limestone, 58.0 g kg⁻¹ feed-grade urea, 46.5 g kg⁻¹ vitamin-mineral premix, 10.0 g kg⁻¹ sodium bicarbonate, 7.0 g kg⁻¹ monodicalcium phosphate, and 5.5 g kg⁻¹ sodium chloride. The concentrate was manufactured by Cooperativa Agrária, Guarapuava (Table 1).

Data collection

The experimental period lasted 148 days, including 8 days of adaptation to the diets and facilities and 140 days of evaluation, divided into five 28-day periods. During the first three days of adaptation, the animals received a concentrate mixture equivalent to 1.2% of their live weight (LW) and corn silage ad libitum. From the fourth through the seventh day, the concentrate mixture was increased to 1.6% of LW, while corn silage continued to be provided ad libitum. On the eighth day, roughage was withdrawn, and only the concentrate mixture was supplied in the feed bunk. Feed supply was adjusted daily to maintain refusals at approximately 5% of the dry matter (DM) offered.

Additives were added to the diets at feeding to ensure their complete consumption. The animals were fed twice daily, at 06h00 and 17h00. Feed intake was recorded daily, and the amount supplied was adjusted to maintain refusals at 5% of the total amount offered.

Fecal consistency was assessed visually for each pen every afternoon using a scale from 1 to 6: 1 = liquid feces with low consistency; 2 = liquid feces with low consistency, forming small piles up to 2.5 cm high; 3 = feces of intermediate consistency, with a concentric ring and a pile height of 3–4 cm; 4 = pasty feces with concentric rings and a pile height greater than 5 cm; 5 = drier feces without concentric rings and with a pile height greater than 5 cm; and 6 = hardened or desiccated feces. This scoring system was adapted from Ferreira et al. (2013). Scores of 2 and 3 are considered normal for cattle fed high-energy diets.

Composite samples of each treatment diet were collected weekly throughout the experimental period to determine their chemical composition. The samples were oven-dried at 55 °C for 72 h and subsequently ground in a Wiley-type mill fitted with a 1-mm screen. Dry matter (DM; method 930.15), crude protein (CP; method 990.03), ash (method 923.03), and ether extract (EE; method 920.39) were analyzed according to Association of Official Analytical Chemists [AOAC] (2000). Neutral detergent fiber (NDF) was determined according to Van Soest et al. (1991), using heat-stable α-amylase, and acid detergent fiber (ADF) was determined according to Goering and Van Soest (1970). Total digestible nutrients (TDN) were estimated according to Weiss et al. (1992), and starch concentration was determined using the enzymatic method proposed by Bach Knudsen et al. (1997).

The animals were weighed every 28 days on days 0, 28, 56, 84, 112, and 140 of the evaluation period to determine average daily gain (ADG). Weighing was performed before the morning feeding after a 10-h withdrawal of solid feed. Average daily gain was calculated from the initial and final LW and the number of days in each period, as follows: $\mathrm{ADG} = \left(\frac{\text{final LW} - \text{initial LW}}{\text{Number of days in the period}}\right)$. Feed offered and refusals were weighed daily to determine daily dry matter intake (DMI). Feed conversion (FC) was calculated from DMI and ADG as follows: $\mathrm{FC} = \left(\frac{\mathrm{DMI}}{\mathrm{ADG}}\right)$.

Two assessments of ingestive behavior were conducted during the experimental period, each consisting of 48 h of continuous observation. One animal from each pen was randomly selected and identified to ensure accurate observation and recording. The first assessment was conducted on days 29–31 and the second on days 85–87. Both began at 12h00 on the first day and ended at 12h00 on the third day. Observations were performed by six observers per shift, with shifts rotating every 6 h and behavior recorded at 3-min intervals. Artificial lighting was used during nighttime observations; the animals had been accustomed to this condition since their arrival at the experimental facility.

The time spent idle, ruminating, eating, drinking, and performing non-ingestive oral behaviors was expressed in hours per day. The frequencies of feeding, drinking, urination, and defecation were assessed using the same observation method and expressed as the number of occurrences per day.

At the end of each 6-h shift, total fecal output was collected from each experimental unit to determine the apparent digestibility of the diets. Before the assessment, the pens were washed to remove debris that could contaminate the fecal material. The feces were weighed, and 500-g samples were stored at −18 °C for subsequent analysis. At the end of the 24-h collection period, the feces collected from each pen were pooled and homogenized. A 300-g subsample was then placed in a forced-air oven at 55 °C. After reaching a constant weight, the sample was reweighed to determine fecal dry matter (DM) content. The samples were subsequently ground in a Wiley-type mill fitted with a 1-mm screen and subjected to laboratory analysis. These procedures were used to determine fecal output on an as-fed basis, fecal DM content, and fecal output on a DM basis, expressed as kg day^{-1}.

Apparent dry matter digestibility (DMD), expressed as g kg^{-1} DM, was calculated using the following equation:

$$\mathrm{DMD} = \left(\frac{\text{(DM intake} - \text{fecal DM output)}}{\text{total ingerido}}\right) \times 1{,}000.$$

Starch digestibility was calculated using the same equation, based on starch intake and fecal starch output. The DM and starch concentrations of feed refusals and feces from each experimental unit were determined using the same procedures applied to the diet samples.

Carcass ultrasonography was performed one day before slaughter using an Aloka® SSD-500 Vet ultrasound unit fitted with a 17-cm, 3.5-MHz probe. Measurements were obtained between the 12th and 13th ribs, with the probe positioned transversely over the *Longissimus thoracis* muscle (Herring et al., 1994). The parameters evaluated included ribeye area (REA), subcutaneous fat thickness, a ratio derived from REA, and marbling score. Marbling was assessed based on fat deposition between the muscle fibers of the *Longissimus thoracis* and scored on a scale from 1 (none) to 5 (excessive), adapted from Müller (1987).

On the following day, after a 10-h withdrawal of solid feed, the animals were weighed to determine their final body weight (BW) and then fed according to the same management procedures used throughout the experiment. After feeding, the animals were transported to the slaughter facility, where they were weighed again to determine pre-slaughter live weight. Slaughter was performed at a federally inspected facility.

Each carcass was evaluated according to Müller (1987). The measurements included hot carcass weight (HCW), carcass yield (CY), carcass length, arm length, arm circumference, round thickness, and subcutaneous fat thickness.

The following organs and gastrointestinal tract components were also weighed at slaughter: heart, kidneys, liver, lungs, spleen, empty rumen-reticulum, full rumen-reticulum, full abomasum, empty abomasum, and full intestines.

Total carcass gain (TCG), daily carcass gain (DCG), and carcass gain efficiency (CGE) were calculated from average daily gain (ADG), dry matter intake (DMI), and CY. Total carcass gain was calculated as the product of ADG, CY expressed as a decimal, and the number of days in the feedlot: TCG = [ADG × (CY / 100)] × 140 . Daily carcass gain was calculated over the 140-day feedlot period: DCG $=\left(\frac{TCG}{140}\right)$. Carcass gain efficiency (CGE), representing the efficiency with which ingested DM was converted into carcass gain, was calculated as follows: CGE = $\left(\frac{DCG}{DMI}\right)$. Hot carcass weight was used as the basis for the carcass-related calculations.

Statistical analysis

The UNIVARIATE procedure was used to identify potential outliers. Subsequently, data for each parameter were subjected to analysis of variance (ANOVA) using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC, USA). Statistical significance was declared at P ≤ 0.05. The following statistical model was used: $Y_{ijk} = \mu + B_i + D_j + A_k + (D*A)_{jk} + \varepsilon_{ijk}$; where: Y_{ijk} is the observed value of the dependent parameter; μ is the overall mean of all observations; B_i is the random effect of the i^{th} block (*i* = 1, 2, 3, or 4); D_j is the fixed effect of diet (1 = complete pelleted diet and 2 = diet composed of 85% whole corn grain and 15% protein-vitamin-mineral concentrate); A_k is the fixed effect of the k^{th} feed additive combination (k=1, sodium monensin + virginiamycin; or k=2, enzyme complex + essential oil blend); $D*A_{jk}$ is the interaction effect between the j^{th} diet type and the k^{th} feed additive combination; and ε_{ijk} is the random residual error.

Results and Discussion

No significant interaction between diet and feed additive combination was detected; however, significant main effects were observed for some parameters ($P < 0.05$).

Regardless of the evaluation period (Table 2), diet affected ADG and FCR. Compared with the complete pelleted diet, the whole corn grain diet resulted in 11.30% greater ADG and a 9.83% lower FCR. These superior results may be attributed to the higher starch and TDN concentrations of the whole corn grain diet, as shown in Table 1. According to Bento et al. (2019), diets with a higher energy content promote weight gain and improve the efficiency of dietary nutrient utilization.

Table 2
Average performance of feedlot-finished steers under the associative effect of different additives and high-energy-density diets

Period (days)	TD		CG			*P - value*		
	EO+ENZ	MO+VM	EO+ENZ	MO+VM	SEM	D	A	DxA
		ADG, kg dia^{-1}						
0 to 28	1.183	1.174	1.509	1.719	0.0705	*	ns	ns
0 to 56	1.270	1.379	1.406	1.603	0.0572	*	ns	ns
0 to 84	1.310	1.394	1.451	1.625	0.0455	*	ns	ns
0 to 112	1.239	1.427	1.475	1.662	0.0402	*	*	ns
0 to 140	1.275	1.518	1.520	1.628	0.0480	*	*	ns
		DMI, kg dia^{-1}						
0 to 28	6.90	7.48	7.46	7.77	0.0921	ns	ns	ns
0 to 56	7.39	7.95	7.77	7.89	0.1178	ns	ns	ns
0 to 84	7.67	8.07	8.14	8.07	0.1467	ns	ns	ns
0 to 112	7.75	8.08	8.39	8.17	0.1763	ns	ns	ns
0 to 140	7.84	8.18	8.60	8.32	0.1575	ns	ns	ns
		DMI, % body weight						
0 to 28	1.92	2.03	1.99	2.04	0.1009	ns	ns	ns
0 to 56	1.95	2.04	1.97	1.97	0.0804	ns	ns	ns
0 to 84	1.93	1.97	1.97	1.91	0.0613	ns	ns	ns
0 to 112	1.87	1.89	1.93	1.84	0.0521	ns	ns	ns
0 to 140	1.83	1.83	1.89	1.79	0.0594	ns	ns	ns
		FC						
0 to 28	5.91	6.60	5.55	4.65	0.0709	*	ns	ns
0 to 56	6.20	5.98	5.92	5.21	0.0879	*	ns	ns
0 to 84	6.25	6.03	5.95	5.17	0.1061	*	ns	ns
0 to 112	6.54	5.85	5.99	5.11	0.1223	*	*	ns
0 to 140	6.58	5.82	5.94	5.24	0.1101	*	*	ns

TD: Total diet; CG: Corn grais; ADG: Average daily gain; DMI: Dry matter intake; FC: Feed conversion; EO+ENZ: Essential oil + Enzyme complex; MO+VM: Monensin + Virginiamycin; SEM: Standard error mean; D = Diet; A = Additives; DxA = Diet x Additives; * = $P \leq 0.05$; ns = Not significant.

Regarding ADG and FCR, supplementation with MO + VM was, on average, more effective than supplementation with EO + ENZ during the periods from 0 to 112 days and from 0 to 140 days. In a study comparing the effects of monensin combined with virginiamycin and monensin combined with essential oils on the performance of feedlot steers, Heker et al. (2018) also reported greater ADG in animals supplemented with the monensin–virginiamycin combination.

The greater weight gain obtained with MO + VM may be associated with improved energy utilization. The combined use of these additives can reduce the acetate-to-propionate ratio, ruminal methane production, and ruminal protein degradation while increasing nitrogen retention and improving intestinal health, thereby enhancing nutrient absorption and utilization (Navarrete et al., 2017; Robinson et al., 2019; Estrada-Angulo et al., 2022).

Animals fed the whole corn grain diet produced less fecal matter than those fed the complete pelleted diet (1.47 vs. 1.84 kg DM day^{-1}). Mean fecal DM content and apparent dry matter digestibility (DMD) were also higher with the whole corn grain diet than with the complete pelleted diet (31.49% vs. 22.95% and 82.45% vs. 77.32%, respectively; Table 3).

Table 3
Excreta parameters and apparent digestibility of dry matter and starch in feedlot-finished steers under the associative effects of different additives and high-energy-density diet types

Parameters	TD		CG			*P - value*		
	EO+ENZ	MO+VM	EO+ENZ	MO+VM	SEM	D	A	DxA
FO, kg DM day^{-1}	1.75	1.93	1.55	1.40	0.0631	*	ns	ns
DM feces, %	23.49	22.41	33.00	29.98	0.2492	*	ns	ns
Score	2.89	2.63	2.52	2.68	0.0183	ns	ns	ns
pH	7.03	7.12	6.39	6.82	0.0455	*	ns	ns
DMD, %	77.52	77.12	81.55	83.35	0.4152	*	ns	ns
SD, %	94.28	96.93	92.36	96.62	0.3133	*	ns	ns

TD: Total diet; CG: Corn grais; EO+ENZ: Essential oil + Enzyme complex; MO+VM: Monensin + Virginiamycin; FO: Fecal output; MS: Dry matter; DMD: Dry matter digestibility; DA: Starch digestibility; SEM: Standard error mean; D = Diet; A = Additives; DxA = Diet x Additives; * = P≤ 0.05; ns = Not significant.

The lower fecal output was attributed to the greater DMD of the whole corn grain diet. The higher fecal DM content, in turn, may be associated with a slower digesta passage rate. According to Vigne et al. (2019) and Carvalho et al. (2015), passage rate affects intestinal luminal osmolarity and water absorption. A slower passage rate increases fecal DM content and may improve diet digestibility by extending digesta retention time in the gastrointestinal tract.

Conversely, apparent starch digestibility (ASD) and fecal pH were lower in animals fed the whole corn grain diet than in those fed the complete pelleted diet (94.49% vs. 95.60% and 6.60 vs. 7.07, respectively).

During the manufacture of the complete pelleted diet, the corn grain undergoes physical processing and exposure to elevated temperatures. Physical processing increases the contact surface area and causes starch gelatinization, respectively. These changes facilitate the action of bacterial enzymes on starch, thereby increasing starch digestibility and reducing fecal starch proportion (Moron et al., 2000; Hoffman et al., 2012).

The time spent performing the different ingestive behaviors, expressed as h day^{-1}, was not affected by diet or feed additive combination (Table 4). However, when behavior was expressed as events day^{-1}, a significant effect of diet was detected ($P < 0.05$). Animals fed the whole corn grain diet visited the water trough and defecated less frequently than those fed the complete pelleted diet (6.0 and 5.0 vs. 7.2 and 6.5 events day^{-1}, respectively). Conversely, non-ingestive oral behaviors occurred more frequently in animals fed the whole corn grain diet than in those fed the complete pelleted diet (13.5 vs. 10.2 events day^{-1}).

Table 4
Ingestive behavior of feedlot-finished steers under the associative effect of different additives and high-energy-density diets

Parameters	TD		CG			*P - value*		
	EO+ENZ	MO+VM	EO+ENZ	MO+VM	SEM	D	A	DxA
			Ingestive behavior (hours day^{-1})					
Feed intake	1.68	1.39	1.18	1.30	0.1181	ns	ns	ns
Water intake	0.31	0.31	0.25	0.25	0.0251	ns	ns	ns
Rumination	0.92	0.90	0.72	1.07	0.0729	ns	ns	ns
Idle	20.40	20.80	21.10	20.54	0.0897	ns	ns	ns
Niob	0.71	0.62	0.80	0.87	0.0417	ns	ns	ns
			Ingestive behavior (events day $^{-1}$)					
Feeding	19.9	17.8	18.6	16.4	0.4378	ns	ns	ns
Drinking	7.5	7.0	5.6	6.4	0.4735	*	ns	ns
Defecation	6.0	7.1	5.0	5.0	0.3404	*	ns	ns
Urination	5.9	5.6	5.4	4.2	0.3285	ns	ns	ns
Niob	10.6	9.9	13.7	13.4	0.6379	*	ns	ns

TD: Total diet; CG: Corn grais; EO+ENZ: Essential oil + Enzyme complex; MO+VM: Monensin + Virginiamycin; Niob: Non-ingestive oral behavior; SEM: Standard error mean; D = Diet; A = Additives; DxA = Diet x Additives; * = P≤ 0.05; ns = Not significant.

The lower fecal output reflects the greater digestibility of the whole corn grain diet, as shown in Table 3. The lower frequency of visits to the water trough may be associated with more frequent rumination, a behavior that stimulates saliva production and helps buffer ruminal pH (Santos et al., 2020).

Nevertheless, the potentially lower ruminal pH did not appear to adversely affect animal health or performance. Ruminal acidosis is commonly associated with decreased animal performance (Goularte et al., 2011), which was not observed in the present study (Table 2).

Regarding carcass-related parameters (Table 5), animals fed the whole corn grain diet generally had better outcomes than those fed the complete pelleted diet. The whole corn grain diet resulted in greater total carcass gain (140.3 vs. 120.7 kg), daily carcass gain (1.002 vs. 0.862 kg day^{-1}), final BW (552.85 vs. 516.70 kg), and HCW (306.70 vs. 286.05 kg), as well as a lower feed conversion ratio (8.48 vs. 9.30 kg DM kg^{-1} carcass gain).

Table 5
Carcass parameters of feedlot-finished steers under the associative effect of different additives and high-energy density diet types

Parameters	TD		CG			*P - value*		
	EO+ENZ	MO+VM	EO+ENZ	MO+VM	SEM	D	A	DxA
TCG, kg	114.0	127.4	137.7	142.9	2.5676	*	*	ns
DCG, kg day^{-1}	0.814	0.910	0.983	1.021	0.0183	*	ns	ns
CGE	9.71	8.98	8.77	8.19	0.1188	*	*	ns
DCG ADG^{-1}, %	66.15	62.91	64.70	62.39	0.6125	ns	*	ns
IW, kg	326.00	335.25	333.50	332.13	2.9262	ns	ns	ns
FW, kg	500.0	533.4	543.2	562.5	4.3392	*	*	ns
HCW, kg	277.0	295.1	304.4	309.0	2.2843	*	*	ns
CY, %	55.45	55.32	56.00	54.92	0.1185	ns	ns	ns
SFT, mm	5.63	5.13	5.80	5.00	0.0223	ns	*	ns
CL, m	1.32	1.32	1.33	1.35	0.0088	ns	ns	ns
RT, cm	23.88	23.38	22.88	22.75	0.6928	ns	ns	ns
AL, cm	38.13	39.13	38.63	38.75	0.2009	ns	ns	ns

TD: Total diet; CG: Corn grais; EO+ENZ: Essential oil + Enzyme complex; MO+VM: Monensin + Virginiamycin; kg: Quilograma; TCG: Total carcass gain; DCG: Daily carcass gain; CGE: Carcass gain efficiency; IW: Initial weight; FW: Final weight; HCW: Hot carcass weight; CY: Carcass yield; SFT: Subcutaneous fat thickness; CL: Carcass lenght; RT: Round thickness; AL: Arm length; mm: Millimeters; m: Meters; cm: Centimeters; SEM: Standard error mean; D = Diet; A = Additives; DxA = Diet x Additives; * = P≤ 0.05; ns = Not significant.

According to Monteschio et al. (2017), diets with a higher energy content improve carcass gain. This finding is consistent with the higher starch and TDN concentrations of the whole corn grain diet (Table 1), suggesting that the greater carcass gain may be associated with its higher digestibility.

The carcass gain ratio (CGR), defined as the ratio of daily carcass gain to average daily gain, and subcutaneous fat thickness were higher in animals supplemented with EO + ENZ than in those supplemented with MO + VM (65.42% vs. 62.65% and 5.71 vs. 5.06 mm, respectively).

When combined with microorganisms in the digestive tract, essential oils and exogenous enzymes can maximize dietary energy utilization and facilitate the release of sugars and other components from complex carbohydrates (Nogueira et al., 2013; Jafari et al., 2019). In the present study, these mechanisms may have increased ruminal propionate availability and its subsequent utilization, thereby promoting carcass gain and fat deposition.

Kholif et al. (2018) evaluated a capsicum–thyme essential oil blend combined with a fibrolytic enzyme cocktail containing pectinase and cellulase and reported an increase in ruminal propionate concentration. After absorption, propionate serves as a major precursor for hepatic gluconeogenesis. The resulting glucose can stimulate insulin secretion, and under a positive energy balance, insulin promotes lipogenesis (Kozloski, 2009; Gonçalves et al., 2012).

In contrast, supplementation with MO + VM was more effective than supplementation with EO + ENZ in terms of total carcass gain (135.15 vs. 126.05 kg), DM-to-carcass conversion ratio (8.58 vs. 9.24 kg DM kg^{-1} carcass gain), final live weight (547.95 vs. 521.60 kg), and hot carcass weight (302.05 vs. 290.70 kg). These results may be attributed to the improved utilization of dietary protein and energy promoted by this additive combination (Navarrete et al., 2017; Robinson et al., 2019; Estrada-Angulo et al., 2022), as well as the greater weight gain and better feed conversion observed during the periods from days 0 to 112 and 0 to 140 (Table 2).

Diet affected ribeye area (REA; $P < 0.05$; Table 6), which was greater in animals fed the whole corn grain diet than in those fed the complete pelleted diet (82.53 vs. 79.56 cm^2). According to Fernandes et al. (2008), REA is positively correlated with mean carcass weight, with heavier animals having larger REAs, as also observed in the present study. A larger REA is desirable because it reflects greater muscular development and is associated with a higher yield of commercially valuable cuts.

Table 6
Carcass ultrasound parameters of feedlot-finished steers at slaughter under the associative effect of different additives and a high-energy-density diet

Parameters	TD		CG			*P - value*		
	EO+ENZ	MO+VM	EO+ENZ	MO+VM	SEM	D	A	DxA
REA, cm^2	80.00	79.12	82.65	82.40	0.8209	*	ns	ns
Ratio	0.545	0.514	0.525	0.541	0.0040	ns	ns	ns
Marbling	3.02	2.83	2.97	2.62	0.0511	ns	*	ns
SFT, mm	7.51	6.94	7.63	6.95	0.2734	ns	*	ns
FTP, mm	9.82	9.11	10.15	9.23	0.2414	ns	*	ns

TD: Total diet; CG: Corn grais; EO+ENZ: Essential oil + Enzyme complex; MO+VM: Monensin + Virginiamycin; REA: Ribeye area; cm^2: Square centimeter; SFT: Subcutaneous fat thickness; FTP: Fat thickness of the picanha; mm: Millimeters; SEM: Standard error mean; D = Diet; A = Additives; DxA = Diet x Additives; * = P≤ 0.05; ns = Not significant.

Animals supplemented with EO + ENZ had higher mean marbling scores (3.00 vs. 2.72), subcutaneous fat thickness (7.57 vs. 6.95 mm), and picanha (rump cap) fat thickness (9.98 vs. 9.17 mm) than those supplemented with MO + VM. According to Silveira et al. (2021), improving glucose metabolism is one strategy for increasing marbling, fat deposition, and meat quality without increasing visceral fat. This effect may be promoted by supplementation with essential oils and exogenous enzymes (Kozloski, 2009; Kholif et al., 2018; Gonçalves et al., 2012).

Non-carcass components (Table 7) were affected only by diet. Animals fed the whole corn grain diet had lower full and empty rumen-reticulum weights than those fed the complete pelleted diet (full rumen-reticulum: 7.59% vs. 8.07% of live weight; empty rumen-reticulum: 2.39% vs. 2.79% of live weight). The size of the rumen and reticulum can change according to the diet. Animals fed whole corn grain may have consumed a smaller volume of feed than those fed the complete pelleted diet, resulting in less distension and development of these organs.

Table 7
Mean weights of non-carcass components, expressed as a percentage of live weight, of feedlot-finished steers subjected to the associative effects of different additives and high-energy-density diet types

Parameters	TD		CG			*P - value*		
	EO+ENZ	MO+VM	EO+ENZ	MO+VM	SEM	D	A	DxA
Heart	0.34	034	0.34	0.35	0.0043	ns	ns	ns
Lungs	0.99	0.91	0.97	0.92	0.0112	ns	ns	ns
Spleen	0.37	0.38	0.32	0.36	0.0144	ns	ns	ns
Kidneys,	0.20	0.19	0.19	0.21	0.0035	ns	ns	ns
Liver	1.04	1.08	1.14	1.12	0.0312	ns	ns	ns
Full rumen-reticulum	7.74	8.40	7.04	8.14	0.2369	*	ns	ns
Empty rumen-reticulum	2.90	2.68	2.45	2.33	0.1026	*	ns	ns
Full abomasum	0.38	0.42	0.44	0.44	0.0253	ns	ns	ns
Empty abomasum	0.34	0.32	0.37	0.36	0.0219	ns	ns	ns
Full intestines	3.69	3.53	3.59	3.52	0.1028	ns	ns	ns

TD: Total diet; CG: Corn grais; EO+ENZ: Essential oil + Enzyme complex; MO+VM: Monensin + Virginiamycin; SEM: Standard error mean; D = Diet; A = Additives; DxA = Diet x Additives; * = P≤ 0.05; ns = Not significant.

Conclusions

A diet containing 85% whole corn grain and 15% protein-vitamin-mineral concentrate improved animal performance, dry matter digestibility, and carcass characteristics compared with a complete pelleted diet.

Supplementation with essential oils combined with fibrolytic enzymes in high-energy diets did not improve finishing performance but enhanced carcass finish compared with sodium monensin combined with virginiamycin.

Acknowledgments

To everyone involved in the conception and conduct of this work, especially Eduardo Mateus Moresco (in memoriam).

References

Abreu, J. A. D. C., Neumann, M., Paris, W., Souza, A. M., Vigne, G. L. D., Almeida, E. R., Cristo, F. B., & Sidor, F. S. (2022). Combination of carbohydrases and essential oils improve dietary performance of feedlot steers on a high-energy diet. *Semina: Ciências Agrárias, 43*(2), 523-540. doi: 10.5433/1679-0359.2022v43n2p523

Association of Official Analytical Chemists (2000). *Official methods of analysis of the Association of the Analytical Chemists* (17nd ed.). AOAC.

Bach Knudsen, K. E., Johansen, H. N., & Glitso, V. (1997). Methods for analysis of dietary fibre - advantage and limitations. *Journal Animal Feed Science, 6*(1), 185-206.

Barreta, D. A. (2020). Average particle size of the diet determination, interpretation and effects for dairy cows. *Revista Acadêmica Ciência Animal, 18*(1), 1-9. doi: 10.7213/2596-2868.2020.18102

Bento, F. C., Rovani, E. A., Mesquita, G. F., Ruiz, L. R. B., Silva, M. I. L., Moreira, P. S. A., Polizel Neto, A., & Gomes, H. F. B. (2019). Efeito dos níveis de suplementação no desempenho de bovinos em sistema de semiconfinamento. *Nativa, 7*(6), 813–819, 2019. doi: 10.31413/nativa.v7i6.7090

Bonfante, E., Palmonari, A., Mammi, L., Canestrari, G., Fustini, M., & Formigoni, A. (2016). Effects of a completely pelleted diet on growth performance in Holstein heifers. *Journal Animal Science, 99*(12), 9724-9731. doi: 10.3168/jds.2016-11033

Carvalho, S., Bernardes, M. C., Pires, C. C., Bianchi, G., Pilleco, V. M., Venturini, R. S., Motta, J., & Teixeira, C. T. (2015). Efeito de dietas de alto grão sobre o comportamento ingestivo de cordeiros em confinamento. *Zootecnia Tropical, 33*(2), 145-152.

Chen, F., Wei, J. T., Yang, X. H., Zhao, N., Zhang, W., Huang, S. W., Yan, N. D., & Guo, W. Z. (2018). Effect of pelleted total mixed rations with different levels of intact rapeseed on performance, carcass traits, serum biochemical indices and meat quality of Boer goats. *Animal Production Science, 59*(1), 82-88. doi: 10.1071/AN17172

Estrada-Angulo, A., Mendoza-Cortez, D. A., Ramos-Méndez, J. L., Arteaga-Wences, Y. J., Urías-Estrada, J. D., Castro-Pérez, B. I., Ríos-Rincón, F. G., Rodríguez-Gaxiola, M. A., Barreras, A., Zinn, R. A., & Plascencia, A. (2022). Comparing blend of essential oils plus 25-Hydroxy-Vit-D3 versus monensin plus virginiamycin combination in finishing feedlot cattle: growth performance, dietary energetics, and carcass traits. *Animals, 12*(13), 1715. doi: 10.3390/ani12131715

Fernandes, A. R. M., Sampaio, A. A. M., Henrique, W., Oliveira, E. A., Tullio, R. R., & Perecin, D. (2008). Carcass and meat characteristic of cattle receiving differents diets in feedlot. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 60*(1), 139-147. doi: 10.1590/S0102-09352008000100020

Ferreira, S., Guimarães, T., Moeira, K., Alves, V., Lemos, B., & Souza, F. (2013). Caracterização fecal de bovinos. *Revista Científica Eletrônica de Medicina Veterinária, 20*(11), 1-22.

Goering, H. K., & Van Soest, P. J. (1970). *Forage fiber analysis: apparatus, reagents, procedures and some applications.* Agricultural Handbook.

Gonçalves, M. F., Silva Martins, J. M., Oliveira, M. V., Carvalho, C. C. M., Antunes, M. M., Ferreira, I. C., & Olivalves, L. C. (2012). Ionóforos na alimentação de bovinos. *Veterinária Notícias, 18*(2), 131-146.

Goularte, S. R., Ítavo, L. C. V., Santos, G. T., Ítavo, C. C. B. F., Oliveira, L. C. S., Favaro, S. P., & Bittar, C. M. M. (2011). Ácidos graxos voláteis no rúmen de vacas alimentadas com diferentes teores de concentrado na dieta. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 63*(6), 1479-1486. doi: 10.1590/S010209352011000600027

Heker, J. C. H., Jr., Neumann, M., Ueno, R. K., Falbo, M. K., Galbeiro, S., Souza, A. M., & Askel, E. J. (2018). Effect of monensin sodium associative to virginiamycin and/or essential oils on the performance of feedlot finished steers. *Semina: Ciências Agrárias, 39*(1), 261-274. doi: 10.5433/1679-0359.2018v39n1p261

Herring, W. O., Miller, D. C., Bertrand, J. K., & Benyshek, L. L. (1994). Evaluation of machine, technician and interpreter effects on ultrasonic measures of backfat and longissimus muscle area in beef cattle. *Journal Animal Science, 72*(9), 2216-2226. doi: 10.2527/1994.7292216x

Hoffman, P. C., Mertens, D. R., Larson, J., Coblentz, W. K., & Shaver, R. D. (2012). A query for effective mean particle size of dry and high moisture corns. *Journal of Dairy Science, 95*(6), 3467-3477. doi: Jafari 10.3168/jds.2011-5126

Jafari, S., Ebrahimi, M., Goh, Y. M., Rajion, M. A., Jahromi, M. F., & Al-Jumaili, W. S. (2019). Manipulation of rumen fermentation and methane gas production by plant secondary metabolites (saponin, tannin and essential oil): a review of ten-year studies. *Annals of Animal Science, 19*(1), 3-29. doi: 10.2478/aoas-2018-0037

Kholif, A. E., Kassab, A. Y., Azzaz, H. H., Matloup, O. H., Hamdon, A., Olafadehan, O. A., & Morsy, T. A. (2018). Essential oils blend with a newly developed enzyme cocktail works synergistically to enhance feed utilization and milk production of Farafra ewes in the subtropics. *Small Ruminant Research, 161,* 43-50. doi: 10.1016/j.smallrumres.2018.02.011

Kozloski, G. V. (2009). *Bioquímica dos ruminantes.* Universidade Federal de Santa Maria.

Maciel, I. C. F., Saturnino, H. M., Barbosa, F. A., Maia, G. H. B., Fº., Costa, P. M., & Malacco, V. M. R. (2015). Virginiamicina na alimentação de ruminantes*. Caderno de Ciências Agrárias, 7*(1), 271-285.

Millen, D. D., Pacheco, R. D. L., Arrigoni, M. D. B., Galyean, M. L., & Vasconcelos, J. T. (2009). A snapshot of management practices and nutritional recommendations used by feedlot nutritionists in Brazil. *Journal of Animal Science, 87*(10), 3427-3439. doi: 10.2527/jas.2009-1880

Miller, G. L. (1959). Use of Dinitrosalicylic Acid Reagent for Determination of Reducing Sugar. *Analytical Chemistry, 31*(3), 426-428. doi: 10.1021/ac60147a030

Monteschio, J. O., Souza, K. A., Vital, A. C. P., Guerrero, A., Valero, M. V., Kempinski, E. M., Barcelos, V. C., Nascimento, K. F., & Prado, I. N. (2017). Clove and rosemary essential oils and encapsuled active principles (eugenol, thymol and vanillin blend) on meat quality of feedlot-finished heifers. *Meat Science, 130*(1), 50-57. doi: 10.1016/j.meatsci.2017.04.002

Moron, I. R., Teixeira, J. C., Oliveira, A. I. G., Perez, J. R. O., & Oliveira, J. S. (2000). Kinetics of ruminal digestion of starch from corn and sorghum grains submitted to different forms of processing. *Ciência e Agrotécnologia, 24*(1), 208-212.

Müller, L. (1987). *Normas para avaliação de carcaças e concurso de carcaças de novilhos.* UFSM.

Navarrete, J. D., Montano, M. F., Raymundo, C., Salinas-Chavira, J., Torrentera, N., & Zinn, R. A. (2017). Effect of energy density and virginiamycin supplementation in diets on growth performance and digestive function of finishing steers. *Asian-Australasian Journal of Animal Sciences, 30*(10), 1396-1404. doi: 10.5713/ajas.16.0826

Neumann, M., Leão, G. F. M., Vigne, G. L. D., Santos, L. C., Venancio, B. J., & Dochwat, A. (2018). Xylanase complex efficacy in hight-energy diet for bulls finished in feedlot. *Acta Scientiarum. Animal Sciences, 40*, 1-7. doi: 10.4025/actascianimsci.v40i1.37321

Nogueira, S. C. P., Bertpáglia, L., Leandro, G. S., Reis, R. A., Jorge, J. A., & Polizeli, M. L. T. (2013). Estabilidade xilanásica no rúmen e digestibilidade in vitro de volumosos tratados com extrato enzimático de Aspergillus niveus. *Revista Brasileira de Higiene e Sanidade Animal, 7*(1), 46-60. doi: 10.5935/1981-2965.20130004

Robinson, K., Becker, S., Xiao, Y., Lyu, W., Yang, Q., Zhu, H., Yang, H., Zhao, J., & Zhang, G. (2019). Differential impact of subtherapeutic antibiotics and ionophores on intestinal microbiota of broilers. *Microorganisms, 7*(9), 282-295. doi: 10.3390/microorganisms7090282

Rossi, C. A., Soares, M., Luchese, F. C., & Santurio, J. M. (2015). Uso de óleos essenciais no controle dos sinais clínicos das diarreias neonatais em leitões nascidos de fêmeas com diferentes ordens de parto. *Ciência Animal Brasileira, 16*(1), 93-102. doi: 10.1590/1089-6891v16i119669

Santos, G. C. L., Gonzaga, S., Neto, Bezerra, L. R., & Medeiros, A. N. (2020). Use of cakes to feed dairy cows: a review. *Brazilian Journal of Animal and Environmental Research, 3*(1), 89-113.

Schären, M. C., Drong, K., Kiri, S., Riede, M., Gardener, U., Meyer, J., Hummel, T., Urich, G., Breves, S., & Dänicke, S. (2017). Differential effects of monensin and a blend of essential oils on rumen microbiota composition of transition dairy cows. *Journal of Dairy Science, 100*(4), 2765-2783. doi: 10.3168/jds.2016-11994

Silveira, L. G. G., Piona, M. N. M., Mousquer, C. J., Gomes, R. S., & Silveira, A. C. (2021). Sistemas de cria em áreas tropicais: desmama precoce. *Revisão de literatura. Revista Brasileira de Higiene e Sanidade Animal, 15*(1), 1-14.

Soares, M. S., Silva, L. G., Frazão, O. S., & Silva, A. L. N. (2015). Aditivos alimentares na nutrição de ruminantes. *Revista Eletrônica Nutritime, 12*(4), 4162- 4174.

Tedeschi, L. O., & Buenfil, M. A. G. (2018). An assessment of the effectiveness of virginiamycin on liver abscess incidence and growth performance in feedlot cattle: a comprehensive statistical analysis. *Journal of Animal Science, 96*(6), 2474-2489. doi: 10.1093/jas/sky121

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of Dairy Science, 74*(10), 3583-3597. doi: 10.3168/jds.s0022-0302(91)78551-2

Vargas, J. G. D., Mendoza, M., Lozano, M. S. R., & Castrejon, F. A. (2013). Effect of exogenous fibrolytic enzymes on the carcass characteristics and performance of grain-finished steers. *Animal Nutritional Feed and Technology, 13*(3), 435-439.

Vigne, G. L. D., Neumann, M., Santos, L. C., Stadler, E. S., Pontarolo, G. B., Petkowicz, K., & Cristo, F. B. (2019). Digestibility of starch and ingestive behavior of feedlot steers by effect of enzymatic complex doses in high-energy diets. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 71*(3), 1015-1026. doi: 10.1590/1678-4162-10538

Weiss, W. P., Conrad, H. R., & Pierre, N. R. S. (1992). A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. *Animal Feed Science and Technology, 39*(1), 95-110. doi: 10.1016/0377-8401(92)90034-4