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Effects of Monensin, Calcareous Algae, and Essential Oils on Performance, Carcass Traits, and Methane Emissions Across Different Breeds of Feedlot-Finished Beef Cattle

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Simple Summary: This study evaluated the effects of three feed additives on the performance of Nellore and crossbred cattle in a feedlot finishing diet. With growing use of crossbreeds and the demand to reduce antibiotics, this research aimed to identify additives that improve cattle growth and feed efficiency in different breeds. Ninety Nellore and ninety crossbred bulls were fed for 112 days with diets formulated with monensin (MON), monensin with *Lithothamnium calcareum* (LCM), and a blend of essential oils (BEO). Crossbreeds had greater weight gain, carcass weight, and feed intake than Nellore cattle but similar feed efficiency. MON was more efficient than the BEO, and LCM reduced the feed intake but did not improve efficiency compared to MON alone. Crossbreeds fed MON showed greater energy efficiency than those fed the BEO. These findings suggest that monensin is a more effective additive for improving cattle performance.

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Abstract: With the growing use of crossbred cattle in Brazilian feedlots and increasing pressure to reduce antibiotic use as growth promoters, this study examines the impact of three feed additives—monensin (MON), monensin with *Lithothamnium calcareum* (LCM), and a blend of essential oils (BEO)—on the performance of Nellore (NEL) and crossbred (CROSS) cattle. A total of 90 Nellore and 90 crossbred bulls were assigned to a completely randomized block design with a 2 × 3 factorial design for 112 days, and all received the same diet with varying additives. Their methane (CH_4) emissions were estimated. All data were analyzed using the emmeans package of R software (version 4.4.1). Crossbred cattle outperformed Nellore in average daily gain (ADG), hot carcass weight (HCW), and dry matter intake (DMI), though feed efficiency remained unaffected. Across additives, no significant differences were observed in ADG, HCW, or dressing percentage. However, LCM had a lower DMI than the BEO, while MON showed better feed efficiency than the BEO. A breed-by-additive interaction trend was noted for DMI as a percentage of body weight (DMI%BW), with Nellore bulls on LCM diets showing the lowest DMI%BW. Crossbreeds had greater net energy (NE) requirements for maintenance (NEm) and gain (NEg), and MON-fed animals had greater NEm and NEg than the BEO. Crossbred bulls had greater daily methane (CH_4) emissions than Nellore bulls. Animals on the BEO had greater daily CH_4 emissions and greater g CH_4/kg metabolic BW than LCM bulls. In conclusion, the addition of *Lithothamnium calcareum* to monensin did not enhance performance compared to monensin alone. Monensin outperformed the BEO in feed efficiency and nutrient utilization.

Keywords: antibiotic; buffer; essential oil blend; ionophore; seaweed

1. Introduction

Ruminant nutrition researchers strive to continuously improve their understanding of nutrient use efficiency, aiming to increase productivity and sustainability through more efficient use of nutrients and reduced greenhouse gas emissions, particularly methane.

Strategies to improve feed efficiency and nutrient use include manipulating the ruminal microbiota through diet formulation, synchronizing the energy and protein balance [1], optimizing the ratio of concentrate to roughage [2], and the use of feed additives [3]. As for the latter, the ideal feed additives are those that can increase propionate production, enhance net energy (NE) balance, reduce methane emissions, lower the incidence of metabolic disorders, and improve nitrogen use efficiency [4].

Among all the feed additives, monensin is the most used in beef cattle diets in Brazil [5] and the USA [6]. Monensin is known for improving animal growth performance [7], preventing acidosis [1], and reducing methane (CH_4) emissions [8]. Cattle responses are widely reported in the literature; thus, it serves as a unique comparison with other feed additives [9]. Monensin acts on Gram-positive bacteria, changing the fermentation of substrates toward more efficient patterns that improve feed efficiency by maintaining the average daily gain while reducing dry matter intake (DMI) [7].

Plant secondary metabolites, such as essential oils (EOs), have been used in the diet of finishing cattle with similar results on growth performance [10]. In addition, the antiseptic and antimicrobial properties of EOs [11] and their effects on rumen microorganisms and fermentation patterns have been demonstrated, leading to speculations of their potential to mitigate methane emissions [12]. However, due to the widespread use of ionophores, there is comparatively much less research undertaken on EOs [13]. Despite this, there is a push from the European Union to ban the use of antibiotics as growth promoters in animal production [14], and interest in EOs has risen again [15]. This is linked to a concern that the wide use of antibiotics, including ionophores, in animal production could lead to the appearance of resistant bacteria that is harmful to humans [16].

Feed efficiency (i.e., the gain-to-feed ratio) can also be manipulated by increasing the ratio of concentrate to roughage, as diets with a greater inclusion of concentrate are more energy-dense and, therefore, animals consume greater amounts of energy with a lower feed intake [17]. However, reducing the inclusion of roughage with the aiming of greater feed efficiency also increases the chances of subacute ruminal acidosis (SARA) occurrence. In order to prevent this type of metabolic disorder, buffers are frequently used in dairy cow diets [18]. However, the results of adding buffers to beef cattle diets are controversial. Nonetheless, Enemark [19] stated that a calcified seaweed buffer has more than twice the buffering capacity of sodium bicarbonate, with the potential to improve the performance of dairy cows.

The inclusion of concentrates in feedlot diets in Brazil has increased over the years, and monensin is the main additive recommended by nutritionists [5,20]. Their surveys show no indication of the use of buffers. Despite not being generally adopted, the use of essential oils has gained some momentum, reaching 3.3% in the latest survey [21]. Another characteristic is the increase in the number of animals from two-breed cross systems being finished in feedlots. Livestock producers often speculate about the advantages and disadvantages of the performance of such animals compared to Nellore cattle.

The present study was based on the hypotheses that (i) the addition of a calcareous algae buffer in combination with monensin would have a synergistic effect when fed in high-concentrate diets; (ii) a commercial blend of essential oils could replace monensin and have the same impact on the growth performance of animals; and (iii) the effects may potentially be different between breeds. The objectives of this experiment were to evaluate the potential benefits of essential oils and the association of calcareous algae with monensin on the performance of finishing feedlot cattle of different breeds.

2. Materials and Methods

2.1. Experimental Site, Animals, Treatments, and Management

This experiment was carried out for 112 days at the experimental feedlot cattle facilities of the Department of Animal Science of the Luiz de Queiroz College of Agriculture at the University of São Paulo (ESALQ/USP) in Piracicaba, State of São Paulo, Brazil. All experimental procedures using animals followed the guidelines required by the Animal Care and Use Committee of ESALQ/USP, protocol number 2017.5.1617.11.2all.

A total of 180 bulls were used for the experiment, divided into ninety Nellore and ninety crossbred (*Bos indicus* × *Bos taurus*), with an initial body weight (BW ± SD) of 393 ± 34 kg and 406 ± 31 kg, respectively. The animals were blocked according to breed group and initial BW in a completely randomized block design with a factorial arrangement, evaluating the addition of three different additives [monensin (MON); monensin + *Lithothamnium calcareum* (LCM); and a blend of essential oils (BEO)], and their interactions with the two different racial groups [Nellore (NEL) and crossbred bulls (CROSS)], resulting in six treatments. Animals were housed by treatment in 36 adjacent pens, totaling 6 replicates (experimental units). The pens measured 32 m^2 each, were partially roofed, and had a concrete floor. At the start of the experiment, the animals were deprived of feed and water for 16 h and were weighed individually, identified with ear tags, vaccinated against clostridiosis (Ourovac Poli-BT; Ourofino S/A Cravinhos, SP, Brazil), and dewormed with algebeldazole sulfoxide (1 mL per 44 kg BW; Algebendazol 15%, União Química S/A, São Paulo, SP, Brazil).

Both NEL and CROSS bulls in the control group were offered diets containing monensin as a single feed additive (31.3 mg/kg DM; Rumensin, Elanco Animal Health, Indianapolis, IN, USA), whereas animals in the LCM treatment group were fed monensin (31.3 mg/kg DM) plus the calcareous seaweed buffer *Lithothamnium calcareum* (5 g/kg DM; LithoNutri, Oceana Minerals, Jundiaí, SP, Brazil). The third treatment used included a commercial blend of essential oils (0.3 g/kg DM; BioPhytus, ProPhytus Agroindustrial, São José dos Campos, SP, Brazil) composed of copaene from the copaiba tree (*Copaifera* spp.), ricinoleic acid from the castor bean (*Ricinus communis* L.), and cardol, cardanol, and anacardic acid from cashew nuts (*Anacardium occidentale*).

The animals were adapted to the finishing diet (Table 1) through a step-up adaptation protocol (Table 2) for 21 days. The bulls were fed once a day in the morning at 7:00 h, aiming at bunk management, with a maximum of 3% of orts, which were collected twice a week, weighed, sub-sampled, and frozen at −18 °C for posterior dry matter (DM) analyses and calculation of the DMI. Water was added to the total mixed ration (TMR) to adjust the DM of the diet to 70%. The nutrient composition of the ingredients used is described in Table 3.

Table 1. Ingredient and nutrient composition of the experimental finishing diet.

Ingredient, %DM Unless Otherwise Specified	Dietary Proportion
Sugarcane bagasse	8.50
Ground corn [1]	42.20
Citrus pulp	41.70
Soybean meal	5.00
Urea	1.30
Minerals and vitamin supplement [2]	0.95
Sodium chloride	0.35
Net energy for maintenance [3], Mcal/kg	1.65
Net energy for gain [3], Mcal/kg	1.04
Nutrient composition, %DM unless otherwise specified	
Crude protein	12.87
Ash	4.97
Ether extract	2.60
Starch [4]	34.42
Neutral detergent fiber	23.45
Acid detergent fiber	19.86
Starch/NDF ratio [5]	1.33

[1] Mean particle size of ground corn of 1.42 mm (calculated according to methodology described by Yu et al. [22]). [2] Mineral and vitamin supplement contained 160 g/kg Ca, 131 g/kg P, 18 g/kg S, 82 mg/kg Co, 2283 mg/kg Cu, 15 mg/kg Cr, 2686 mg/kg Fe, 112 mg/kg I, 1940 mg/kg Mn, 22 mg/kg Se, 5417 mg/kg Zn, and 1310 mg/kg F. Manufactured by DSM Nutritional Products, São Paulo, SP, Brazil. [3] Net energies for maintenance and gain estimated according to the equations proposed by NASEM [23], with the addition of ionophore from the sum of individual TDN values from each ingredient that were calculated using the software NRC [24] with the equations described by Weiss et al. [25]. [4] Dietary starch content estimated using each ingredient's starch tabular value [23]. [5] Starch/NDF ratio calculated to be used as covariate to predict methane yield (Mcal of CH_4/kg of DMI) [26].

Table 2. Ingredient inclusion (%DM basis) of the diets in the step-up adaptation protocol (A1, A2, and A3; seven days on each diet) and final diet.

Ingredients, %DM	A1	A2	A3
Sugarcane bagasse	25.00	20.00	15.00
Ground corn	33.20	35.70	38.70
Citrus pulp	33.20	35.70	38.70
Soybean meal	6.00	6.00	5.00
Urea	1.30	1.30	1.30
Minerals and vitamin supplement [1]	0.95	0.95	0.95
Sodium chloride	0.35	0.35	0.35

[1] Mineral and vitamin supplements contained 160 g/kg Ca, 131 g/kg P, 18 g/kg S, 82 mg/kg Co, 2283 mg/kg Cu, 15 mg/kg Cr, 2686 mg/kg Fe, 112 mg/kg I, 1940 mg/kg Mn, 22 mg/kg Se, 5417 mg/kg Zn, and 1310 mg/kg F. Manufactured by DSM Nutritional Products, São Paulo, SP, Brazil.

Table 3. Nutrient composition of the feed ingredients of experimental finishing diet.

Nutrient Composition [1], %DM Unless Otherwise Specified	Sugarcane Bagasse	Ground Corn	Citrus Pulp	Soybean Meal
CP	2.16	8.47	7.44	51.17
Ash	7.07	1.55	5.73	7.07
EE	0.70	5.00	2.00	2.20
NDF	84.15	15.5	20.97	26.35
ADF	55.70	3.70	18.90	11.16
TDNs [2]	39.2	84.23	70.05	71.57

[1] CP = crude protein; EE = ether extract; NDF = neutral detergent insoluble fiber; ADF = acid detergent insoluble fiber; TDNs = total digestible nutrients. [2] TDN values from each ingredient were calculated using the NRC [24] software and the equations described by Weiss et al. [25].

On the 112th day of the experimental period, the bulls were weighed without fasting, and 4% of their live full BW was discounted to predict their live shrunk weight [23], and they were slaughtered at a commercial abattoir. The hot carcasses were weighed, and the dressing percentage (DP) was calculated as the ratio between the hot carcass weight (HCW) and final shrunk BW.

2.2. Feed Analysis and Calculations

Sugarcane bagasse was sampled every three days for DM content analysis to adjust its inclusion in the TMR. Ground corn was sampled in each incoming shipment for the mean particle size assessment according to the methodology proposed by Yu et al. [22]. Samples of each ingredient and the TMR were collected every two weeks and stored at −18 °C for further analyses. Bulk samples were thawed at the end of the experiment, dried at 55 °C for 72 h, and ground to 1 mm using a Wiley-type mill (MA-680; Marconi Ltd., Piracicaba, SP, Brazil). The samples were analyzed for dry matter (method 930.15) [27], ash (method 942.05) [27], ash-corrected neutral digestible fiber (aNDF) [28] using sodium sulfite and heat-stable α-amylase, acid detergent fiber (ADF) [29], and nitrogen via the combustion method [(N); Leco FP-528; Leco Corp., St Joseph, MI, USA]. Crude protein (CP) was calculated using a conversion factor of N × 6.25. The fat content of the ingredients was measured as ether extract (EE; method 920.85) [27].

The NEs observed for maintenance (NEm) and gain (NEg) for each treatment were calculated according to Zinn and Shen [30] using the mean values for the shrunk BW, mean DMI, and average daily gain (ADG) of the bulls in each pen. Predicted NEm and NEm were calculated in two different ways. They were first calculated with the TDN equations as suggested by Weiss et al. [25] and converted to NE, as in the NASEM [23], with the inclusion of ionophores. The second method required the tabular TDN values proposed by the NASEM [23] to calculate the NE. The observed NE for maintenance and gain were compared to the predicted NEm and NEg.

2.3. Methane Calculation

The methane yield was estimated using the following equation from Galyean and Hales [26]:

$$\text{Mcal of } CH_4/\text{kg of DMI} = [0.3227 - (0.0334 \times \text{starch:NDF}) - (0.00868 \times \%\text{EE})]$$

Tabular data from the NASEM [23] were used for diet starch content calculations, and the NDF value was obtained from the chemical analysis of the diet. Methane production (g/d) was derived using the value from the first equation [26], multiplied by the DMI of each treatment, and converted from Mcal to grams by multiplying the result by 75.43 g CH_4/Mcal of CH_4. The methane intensity was calculated by dividing CH_4 production and ADG, and the g CH_4/kg metabolic BW was calculated using the average metabolic BW ($BW^{0.75}$) of each animal.

2.4. Statistical Analysis

The data were tested using Shapiro–Wilk and Kolmogrov–Smirnov tests for normality and homocedasticy, respectively. Outliers were removed based on an absolute studentized residual value ≥3 of the overall data, and means were calculated sequentially. Pen was used as the experimental unit for the variables of DMI, feed efficiency (G:F ratio), methane emission, methane intensity, methane/kg metabolicBW, observed Nem (ONEm), observed NEg (ONEg), and observed/expected energy ratios, whereas initial BW, final BW, ADG, HCW, and DP were analyzed with individual animals being the experimental unit. As the animals from different breed groups had different initial BWs, the variables were also tested with the statistical model, including the effect of initial BWs; however, no significance was found for any variable. Thus, the statistical model included the random effect of the weight block and the fixed effect of treatment (breed group, feed additive, and their interactions). The results are reported as least-square means. Significance was set as $p \leq 0.05$, and $p \leq 0.10$ was discussed as a trend. Means were compared by the Tukey test using the emmeans package [31] of R software (version 4.4.1) [32].

3. Results

Data regarding cattle performance, carcass traits, and methane are presented in Table 4. The observed NE for maintenance and gain and the observed/expected NE ratios are presented in Table 5.

Table 4. Effect of breed, feed additives, and interactions on growth performance and carcass traits of feedlot-finished bulls.

Item [1]	Breed [2]		Additive [3]			SEM	*p*-Value		
	NEL	CROSS	MON	LCM	BEO		Breed	Additve	B × A
Performance									
Initial BW, kg	393.9	406.3	400.1	400.1	400.1	2.49	<0.0001	0.996	0.995
Final BW, kg	524.85	568.41	552.2	538.87	549.45	3.72	<0.0001	0.130	0.582
ADG, kg/d	1.13	1.41	1.31	1.22	1.27	0.002	<0.0001	0.292	0.550
DMI, kg/d	7.88	9.47	8.64 [ab]	8.13 [b]	9.25 [a]	0.230	<0.0001	0.031	0.102
DMI_{BW}, %	1.71	1.94	1.81 [ab]	1.71 [b]	1.95 [a]	0.04	<0.0001	0.003	0.009
G:F ratio	0.143	0.149	0.154 [a]	0.146 [ab]	0.138 [b]	0.002	0.128	0.008	0.622
Carcass traits									
HCW, kg	295.9	319.7	311	303.3	309.9	2.26	<0.0001	0.141	0.352
DP, %	56.30	56.19	56.30	56.00	56.40	0.10	0.777	0.531	0.354
Methane emissions									
CH_4 production, g/d	151.22	181.76	165.86 [ab]	155.97 [b]	177.63 [a]	4.42	<0.0001	0.030	0.102
CH_4 intensity, g/kg	132.14	130.43	127.42	130.84	135.48	1.830	0.596	0.186	0.404
g CH_4/kg metabolic BW	1.553	1.751	1.625 [ab]	1.589 [b]	1.745 [a]	0.031	<0.0001	0.045	0.165

[1] NEL = Nellore bulls; CROSS = crossbred bulls. [2] MON = sodium monensin (31.3 mg/kg DM); LCM = sodium monensin (31. mg/kg DM) + *Lithothamnium calcareum* (5 g/kg DM); BEO = blend of essential oils (0.3 g/kg DM). Sodium monensin (Rumensin™) was obtained from Elanco Animal Health (Indianapolis, IN, USA). The *Lithothamnium calcareum* (LithoNutri®) was from OCEANA Minerals (Jundiaí, SP, Brazil). The blend of essential (BIOPhytus®) oils was from ProPhytus Agroindustrial (São José dos Campos, SP, Brazil). [3] BW = body weight; ADG = average daily gain; DMI = dry matter intake; G:F = feed utilization efficiency; HCW = hot carcass weight, DP = dressing percentage. [a,b] Rows that do not have common superscript letter are different ($p \leq 0.05$).

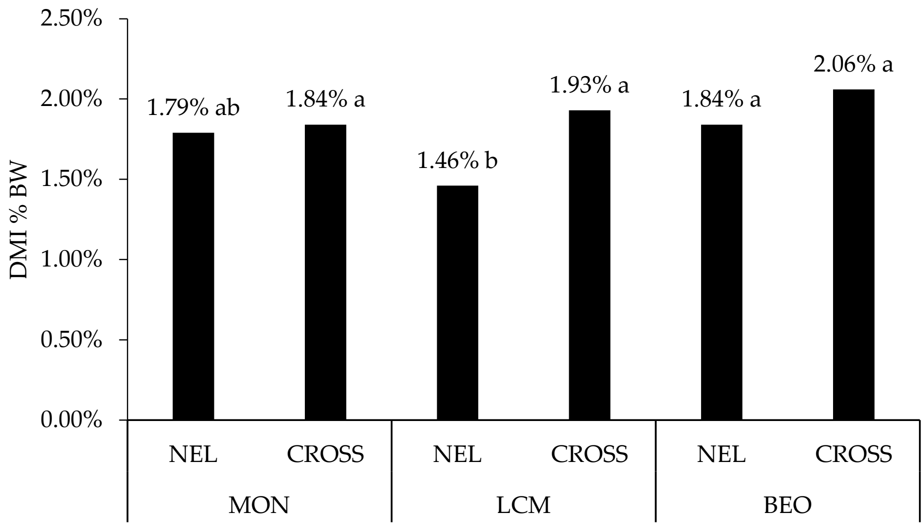
Table 5. Effect of breed, feed additives, and their interactions on observed dietary net energy concentration for maintenance and gain.

Item	Breed		Additive [1]			SEM	*p*-Value		
	NEL	CROSS	MON	LCM	BEO		Breed	Additive	B × A
Observed NE [2]									
Maintenance	1.996	2.219	2.184 [a]	2.131 [ab]	2.019 [b]	0.030	<0.0001	0.01	0.11
Gain	1.341	1.528	1.491 [a]	1.461 [ab]	1.341 [b]	0.025	<0.0001	0.02	0.68
Observed/expected NE ratios [3]									
Maintenance	1.209	1.345	1.323 [a]	1.291 [ab]	1.224 [b]	0.018	<0.0001	0.02	0.12
Gain	1.289	1.468	1.432 [a]	1.403 [ab]	1.310 [b]	0.024	<0.0001	0.03	0.20
Observed/expected NE ratios [4]									
Maintenance	1.095	1.220	1.199 [a]	1.168 [ab]	1.110 [b]	0.016	<0.0001	0.02	0.12
Gain	1.126	1.128	1.252 [a]	1.222 [ab]	1.144 [b]	0.021	<0.0001	0.03	0.20

[1] MON = sodium monensin [31.3 mg/kg dry matter (DM)]; LCM = sodium monensin (31.3 mg/kg DM) + *Lithothamnium calcareum* (5 g/kg DM); BEO = blend of essential oils (0.3 g/kg DM). Sodium monensin (Rumensin) was obtained from Elanco Animal Health (Indianapolis, IN, USA). The *Lithothamnium calcareum* (LithoNutri®) was from OCEANA Minerals (Jundiaí, SP, Brazil). The blend of essential (BIOPhytus®) oils was from ProPhytus Agroindustrial (São José dos Campos, SP, Brazil). [2] Calculated according to equations described by Zinn and

Shen [30]. [3] The expected net energies were calculated according to NASEM [23], with addition of ionophore, based on the total digestible nutrient values of each ingredient [25]. [4] The expected net energies were calculated according to NASEM [23], with addition of ionophore, based on the NASEM [23] tabular values of total digestible nutrient values of each ingredient. [a,b] Rows that do not have common superscript letter are different ($p \leq 0.05$).

A breed × feed additive interaction was observed for the DMI when expressed as a percentage of body weight (DMI%BW; Figure 1). Nellore bulls offered diets with LCM had the lowest DMI%BW.



[a,b] Rows that do not have common superscript letter are different ($p \leq 0.05$).

Figure 1. Interaction between breed and different feed additives on dry matter intake expressed as percentage of body weight (DMI%BW).

3.1. Feed Additives

The daily DMI was greater for bulls offered diets containing the BEO (9.26 kg) when compared to animals receiving LCM (8.13 kg). The dry matter intake of bulls offered diets from the MON treatment (8.64 kg/d) was similar to animals offered LCM and the BEO. The ADG and final BW were not affected by feed additives ($p > 0.05$). The feed efficiency (G:F) was different between treatments ($p = 0.008$). The bulls offered diets with monensin (MON and LCM) presented greater G:F (0.151 and 0.142) and, therefore, were more efficient than the BEO (0.138). Carcass traits were not affected by feed additives ($p > 0.05$). The BEO-fed animals had greater daily emissions of methane and a greater CH_4:100 kgBW ratio than animals offered the LCM diet ($p = 0.03$ and 0.039, respectively).

The effects on the observed dietary NEm ($p = 0.01$) and NEg ($p = 0.02$) concentrations, as well as the observed/expected NEm ($p = 0.02$) and NEg ($p = 0.03$) ratios (Table 5), either when calculated using Weiss et al.'s [25] equations or the NASEM [23] tabular values for TDN, were different between feed additives. Animals offered monensin presented greater NEm (2.184 Mcal/kg) and NEg (1.491 Mcal/kg) than animals offered the BEO (2.019 Mcal/kg and 1.341 Mcal/kg, respectively).

3.2. Breed Type

The crossbred bulls were heavier ($p < 0.0001$) than the Nellore bulls at the beginning (406.3 kg vs. 393.9 kg) and at the end (568.41 vs. 524.85 kg) of the experiment, and they had a greater ($p < 0.0001$) HCW (319.7 vs. 295.9 kg), ADG (1.41 vs. 1.13 kg), and DMI (9.47 vs. 7.88 kg). Both the G:F ratio and DP did not differ between breed types ($p = 0.128$ and

$p = 0.777$). Methane production and the g CH_4:kg metabolic BW ratio were greater for the crossbred bulls than the Nellore bulls ($p < 0.0001$ and $p = 0.002$), whereas the CH_4 intensity was similar ($p = 0.591$).

The observed NE for maintenance and gain was greater for crossbred bulls ($p < 0.001$; 2.219 and 1.528 Mcal/kg, respectively) than for Nellore bulls (1.996 and 1.341 Mcal/kg, respectively). The observed/expected NE ratios for maintenance and gain were greater for the two-breed cross bulls when compared to the Nellore bulls, both when the TDN values were calculated using the equations of Weiss et al. [25] and when the calculations were made using the tabular TDN values of the NASEM [23], as presented in Table 5.

4. Discussion

4.1. Effects of Feed Additives on Performance, Their Buffering Capacity, and Mineral Content

The inclusion of a seaweed buffer in LCM resulted in a lower DMI compared to the BEO and similar to MON. Beauchemin and McGinn [33] reported no differences in the DMI when comparing the inclusion of 1 g/animal-daily of a commercial blend of essential oils of thymol, eugenol, vanillin, guaiacol, and limonene and animals offered no feed additives (control treatment). Chaves et al. [34] reported that the inclusion of carvacrol or cinnamaldehyde (0.2 g/kg DM) had no influence on the DMI in lambs. Silva et al. [35], testing the inclusion of 3 g/animal-daily of a commercial blend of essential oils of cashew nut and castor bean, reported that the DMI was the same between bulls receiving diets with Essential® and bulls offered a diet without any feed additive. On the other hand, Ornaghi et al. [36] testing two essential oils separately (cinnamaldehyde or clover oil) at two doses (3.5 or 7.0 g/d) reported a positive linear response to the inclusion of oils on DMI. These authors attribute the increased DMI to the palatability effect of the essential oils. However, this may be dependent on the source. Cardozo et al. [37] reported that essential oils reduced the feed intake of beef heifers fed high-concentrate diets. The authors tested a mixture of cinnamaldehyde plus eugenol (0.18 and 0.09 g/d, respectively) and speculated a possible antinutritional effect of the product used; however, the actual cause was not concluded.

Benchaar et al. [38], testing increasing doses (2 and 4 g/animal-daily) of a commercial blend of essential oils of thymol, eugenol, vanillin, and limonene, found no difference in the DMI of the BEO when compared to control animals offered diets without any additive, whilst monensin reduced the DMI compared to the control. Accordingly, Meyer et al. [9], comparing the inclusion of a mixture of essential oils of thymol, eugenol, vanillin, and limonene at 1 g/d (EOM), a blend of guaiacol, linalool, and α-pinene (EXP) at 1 g/d, EOM + tylosin (EOM +T; 1 g + 90 mg/d, respectively), and monensin + tylosin (MON + T; 300 mg +90 mg/d, respectively), reported that only MON + T had the effect of reducing the DMI, whereas steers offered EOM, EXP, and EOM + T had the same DMI as steers offered diets without feed additives. Similarly, Meschiatti et al. [39] reported that animals offered monensin presented with a lower DMI than bulls offered a blend of essential oils during the feedlot period. Dry matter intake was reduced by about 4% with the inclusion of monensin in diets compared to the absence of feed additives [7,40], whereas the inclusion of EOs has little impact on the DMI, and usually animals offered no feed additives or offered EOs have similar feed intakes [11,41]. Although the DMI of animals consuming the BEO was greater than others, this is mainly the monensin depressing the feed intake, and it may not be attributed to a possible effect of the BEO increasing the DMI. *Lithothamnium calcareum*, a red marine algae harvested from North Europe or South America, is valued for its high content of bioavailable calcium and magnesium, with suggestions that it is an effective supplement in cattle diets. The source of the algae may play a role, with some studies indicating that its strong buffering capacity helps stabilize rumen pH, reducing the risk of acidosis and improving feed efficiency in high-concentrate feedlot diets [42].

Differences in the mineral composition between the two geographic sources may affect its nutritional value and efficacy [43]. The research also suggests that *Lithothamnium calcareum* supports bone health in equines [44], and it has shown positive impacts on milk production [45] and milk solids [46], positioning it as a sustainable alternative to synthetic mineral supplements in dairy production systems. However, the feed intake of bulls offered MON in the current study was not statistically different from LCM. Therefore, there were no advantages or synergistic effects of combining MON and *Lithothamium calcareum* in the current experiment. The same was reported by Zinn and Borgues [47], who saw no interactions between monensin and sodium bicarbonate (BICARB) and DMI, which was the same for steers offered no additive, monensin, sodium bicarbonate, or monensin + sodium bicarbonate. Similarly, Adams et al. [48] observed no differences in the DMI for treatments with monensin or sodium bicarbonate included at 2.5 or 5.0% of the diet's DM. Russell et al. [49], testing the inclusion of 0.9% of $NaHCO_3$ (DM basis), 1.8% of limestone (DM basis), the combination of both buffers (0.9% of $NaHCO_3$ + 1.8% of limestone), or no buffers (control diet), found no differences in DMI.

The use of limestone in high-grain diets is a common practice for adjusting the calcium supply to meet ruminant requirements [23]. Mineral-related challenges may be more pronounced in high-producing animals, where potential differences in bioavailability between minerals in different algae sources could play a more significant role [50]. Nevertheless, caution with the amount of a mineral used may be required as Clark et al. [51] observed a decreased DMI of dairy cows when calcium carbonate ($CaCO_3$) was included both at 1.4% and 2.1% in the diet. Since $CaCO_3$ is the main constituent of *Lithothamnium calcareum*, it might also be expected that the seaweed buffer could have a negative influence on DMI. Despite that, it has been reported that the inclusion of limestone [49], calcium magnesium carbonate [52], and calcareous seaweed buffers [53,54] does not change the DMI of animals offered diets without feed additives. Therefore, the lower DMI observed for animals offered LCM may be a combination of the possible adverse effects of the seaweed buffer, as reported by Clark et al. [51], but it seems to be much more a result of the traditional and consistent effect of monensin reducing the feed intake [7,40,55]. As the amount of Ca in the seaweed buffer is a minimum of 320 g/kg, the addition of the seaweed buffer caused the calcium/phosphorus ratio to change from 3.9:1 to approximately 4.6:1 (Table A1). Despite the differences being minor only, it has been reported in some experiments that an excess of Ca and/or increase in Ca:P ratios can impair ADG and total weight gain [56], reduce DMI [56], and decrease protein and energy digestibility [57]. No changes in DMI were observed between beef calves offered diets with calcium/phosphorus ratios of 1.3:1 and 4.3:1 [56]. However, these authors state that a critical Ca:P ratio may exist between 4.3:1 and 9.1:1, which may lead to an explanation as to why LCM reduced the DMI compared to MON.

In the present experiment, bulls offered LCM presented numerically lower ADG, followed by animals offered the BEO. The animals offered MON presented with numerically greater ADG values. It is important to note that numerical differences are reported; however, they are not considered statistically significant. Despite the fact that the DMI explains 60 to 90% of the variations in animal performance [24], the changes observed in the DMI in this trial were not enough to result in significant differences in ADG. Nevertheless, according to the reviewed literature in high-concentrate diets, the use of monensin has minimal influences on weight gain, acting mainly on feed intake and thus improving feed efficiency [40,55,58], similar to the findings in this experiment.

Meschiatti et al. [39] reported greater ADG for bulls offered a mixture of essential oils plus α-amylase than for bulls offered a diet with monensin. However, when compared with a control diet (no feed additives), there were no differences in ADG between animals offered diets with or without essential oils, or a mixture of essential oils [35,58–61]. In their meta-analysis, Khiaosa-Ard and Zebeli [41] observed that supplementation of EOs (pure bioactive compounds, individual essential oils or blend of essential oils) for dairy cows had no significant influence on milk production, fat content, or feed efficiency. However, according to these authors, regarding the effects of essential oil supplementation on beef cattle performance, the amount of data for analysis at the time was not enough for it to be assessed.

Regarding the effects of buffers, in general, on the performance of ruminants, a slight improvement in ADG or DMI might be observed during the period of adaptation to high-grain diets; however, when analyzing the entire feedlot period, the positive effects of prolonged use of buffers did not sustain itself in some studies [62,63] and may even negatively impact the performance [49], which may elucidate the reason why animals offered LCM presented lower values of ADG. Differently, some authors have observed cases in which feed intake [64] and ADG were improved with the addition of buffers [65,66] with no improvements in feed efficiency.

The feed efficiency of animals offered MON was greater than that of those offered the BEO. In the reviewed papers wherein monensin and essential oils (pure or a mixture of different ones) were compared and differed in G:F, they also differed in ADG or DMI [58,67,68]. Jedlicka et al. [67] compared two levels of inclusion of cashew nut and castor bean essential oils (0.25 and 0.5 g/kg DM), the combination of the same blend of essential oils with monensin (0.25 g/kg DM and 223 mg/animal-daily), monensin straight (223 mg/animal-daily) or no feed additives. These authors reported that monensin resulted in better feed conversion (lower DM kg/kg ADG) than all other treatments but was only greater in ADG from the treatment with greater inclusion of essential oils (dose of 0.5 g/kg DM). Purevjav et al. [58], testing the same blend of essential oils at a level of 0.5 g/kg DM, reported that animals receiving monensin had greater weight gain and greater feed utilization efficiency than those offered a blend of essential oils. Meyer et al. [9], comparing a blend of essential oils of thymol, eugenol, d-limonene, and vanillin associated with tylosin (EOM + T) and monensin associated with tylosin (MON + T), found that even though the animals treated with MON + T had a lower DMI than those of the control and EOM + T treatments, they did not differ in G:F. However, the authors attribute the improvement in feed efficiency observed for EOM + T to the presence of tylosin. Differently, Moura et al. [68], testing copaiba oil (0.5 g/kg DM), observed a better performance in weight gain and greater feed efficiency of lambs supplemented with essential oils than those supplemented with monensin. Even though the data on the beef cattle performance were not enough to be analyzed in the authors' meta-analysis [41], the absence of differences in DMI, ADG, and G:F between the control treatments (no feed additive) and essential oils have been reported recurrently [34,36,38,60,61,68,69], contrary to what is generally the result of monensin on the feed utilization efficiency of ruminants [7,40].

However, the hot carcass weight and dressing percentage were the same among the treatments. Similarly, Meschiatti et al. [39] observed that feeding diets with either a blend of essential oils or monensin resulted in bulls with the same HCW and dressing percentage. Differently, Ornaghi et al. [36] observed that clover oil (3.5 and 7.0 g/day), when compared to a diet without additives, increased bulls' cold carcass weights (CCWs) linearly, with no influence on the dressing percentage. These authors also observed that cinnamon oil (3.5 and 7.0 g/day) improved the CCW without changing the DP. Purevjav et al. [58] reported that even though the HCW did not differ between cattle offered the control diet, monensin, or essential oils, monensin decreased the dressing percentage when compared to control cattle and high doses of essential oils. In the present experiment, the greater G:F presented by the animals offered MON when compared to the BEO, coupled with no differences observed in the carcass traits, shows that the feed efficiency is not masked by visceral fat and visceral deposition and that MON was indeed more efficient in converting feed into the carcass, contrary to what was reported by Purevjav et al. [58]. The latter authors reported that animals offered monensin had greater G:F due to a lower dressing percentage.

Even though the DMI did not differ statistically between MON and the BEO, the numerically lower DMI of MON, combined with the greater feed efficiency presented, could imply a reduced cost during the total period of feedlot finishing in the current experiment. The greater G:F implies a greater nutrient utilization, which was indeed observed in the NE for maintenance and gain with the use of MON, resulting in greater NEm and NEg, as well as improved ratios of observed/expected NE for maintenance and gain when compared with supplementation with the BEO.

When the TDN of ingredients calculated by the equations of Weiss et al. [25] were used to calculate the expected NE for maintenance and gain, the observed NEms were greater than the predicted (+32.2%, +28.7%, and +22.4% for MON, LCM, and the BEO, respectively), as well as the NEg (+43.2%, +39.7%, and +31.0% for MON, LCM, and the BEO, respectively). When the diets' expected NE values were calculated using the TDN tabular values from the NASEM [23] for each ingredient, the differences between the observed and expected NEs were lower (+20.0%, +16.8%, and +10.9% for NEm and +25.2%, +22.3%, and +14.4% for NEg for MON, LCM, and the BEO, respectively). Therefore, the equations proposed by Weiss et al. [25] underestimated the TDN values of ingredients, resulting in a lower diet NE for maintenance and gain and, consequently, in greater differences between the observed and expected NE. Nevertheless, regardless of the methodology employed to calculate the TDN and subsequent net energies and ratios between the observed/expected net energies, MON was always more efficient in nutrient utilization.

Bergen and Bates [70] pointed out that monensin alters the route of ruminal fermentation for a greater molar proportion of propionate and a lower molar proportion of acetate, which results in a lower caloric increase. Also, the use of this additive improves the retention of nitrogen (N) in the animal [71]. Thus, monensin increases the metabolizable energy (ME) value of the diet, and as the diet ME increases, more of the intake is available for production, which reduces the proportion of the diet used for maintenance [40].

Khiaosa-Ard and Zebeli [41] presented results in which shifts of fermentation caused by EOs were similar to those provided by monensin, increasing propionate whilst reducing acetate without changing the total VFA production. These same authors also indicated EOs' potential to mitigate methane emissions. All these effects show the potential of EOs to increase nutrient utilization efficiency. However, according to the authors, the effect on acetate, propionate, and methane formation disappeared in terms of proportional changes relative to the control. Additionally, the authors found no beneficial effects of EOs on protein utilization. In addition, data compiled from in vitro and in vivo studies of different essential oils and their combinations [12,72] show that effects on ruminal fermentation (a shift in the acetate/propionate proportion and retention of N) are type- and dose-dependent, which explains the lack of consistency between results. In the studies where EOs positively influenced the ruminal fermentation processes, the impacts were not as great as those caused by monensin, which reflects the differences in the diet ME, similar to what was observed when analyzing the observed/expected ratios of NE for maintenance and gain in the present trial when compared to other treatments.

Khiaosa-Ard and Zebeli [41] stated that the average inclusion of EOs in in vivo experiments was 0.10 g/kg diet, and the effect of EOs on VFA composition was most pronounced in beef cattle with the maximum dose of 0.25 g/kg (DM basis) and that increasing doses could lead to adverse effects. In the present study, the dose used for the BEO was 0.30 g/kg.

Although each essential oil and blend of essential oils has its own optimum dosage, the average and maximum doses pointed out by the authors could be an indication that the current dose used in the present experiment was too high. Regarding the results of the combination of *Lithothamnium calcareum* and monensin, the reasons for the lack of a positive synergistic effect remain uncertain.

4.2. Breed

The crossbred bulls started the trial 12.5 kg in BW heavier than the Nellore cattle. After 112 days of feeding, the crossbred bulls were 42.89 kg heavier than the Nellore bulls.

The final difference in body weight between the two race types is partly explained by the initial difference. However, animals in CROSS had greater ADG than NEL, which explains the difference in the final BW being larger than only the 12.5 kg difference in the initial BW. Several authors have reported greater gains for crossbreeds (*Bos taurus taurus* × *Bos taurus indicus*) or British cattle (*Bos taurus taurus*) in comparison to zebu cattle (*Bos taurus indicus*) [73–76], which corroborates the results observed in this trial. Putrino et al. [73] reported that Brangus bulls had lower protein requirements for gain when compared with Nellore bulls, which may partially elucidate the difference observed in ADG as the diet was the same for both racial groups.

Crossbreeds presented a greater DMI than NEL, which is in accordance with the literature that reports that *Bos taurus taurus* presents with a greater DMI than *Bos taurus indicus* [74,75]. Nevertheless, the feed efficiency did not differ between the two racial groups; therefore, the difference observed in ADG is most likely a result of the greater DMI in the CROSS animals. Similarly, Goulart et al. [74] observed that Aberdeen Angus × Nellore crossbred steers presented with a greater final shrunk BW, ADG, and DMI than Nellore purebred steers.

The Beef Cattle Nutrient Requirements Model 2016 [23] indicates that European breeds have greater NE requirements for maintenance and gain than zebu breeds; however, in this trial, there were no differences across breeds for feed efficiency. Our results suggest that the CROSS bulls were more efficient in nutrient utilization than NEL as they presented greater observed dietary NE for maintenance and gain as well as greater observed/expected NE, contrarily to what *Bos taurus inducus* and *Bos taurus taurus* comparative studies have shown [73,74]. Comparisons of different European breeds reveal that those with lower maintenance weights tend to be more efficient in live weight gain over a fixed period [77]. In the current experiment, the animals with greater initial BW (CROSS) were more efficient in energy utilization for maintenance and gain.

Valadares-Filho and Chizzotti [78] compiled data to explain the differences in energy requirements for maintenance between *B. taurus taurus* and *B. taurus indicus*, noting that cattle from the latter group have a lower total organ-to-body weight ratio and liver-to-body weight ratio. This implies that *Bos taurus indicus* requires less energy for maintenance compared to *Bos taurus taurus*. Nevertheless, the dressing percentage was the same for CROSS and NEL, indicating that the percentage of organs expressed over live BW should be approximately the same for both groups, thus failing to align with the previous theory on energy requirements.

The greater DMI and ADG observed in CROSS bulls combined with the unaltered feed efficiency is most likely the reason why the observed NE for maintenance and gain was greater for CROSS than for NEL.

In the present study, the performance (DMI, ADG, and G:F) and carcass traits (HCW and DP) of feedlot-finished bulls offered a commercial blend of essential oils or a seaweed buffer + monensin were compared to bulls offered monensin. Monensin has been one of the most described and updated feed additives for ruminants [7,40,55], and its acceptance on feedlot protocols has been sustained throughout the years. Therefore, monensin serves as a unique comparison against other growth promoter feed additives.

4.3. Methane Emission

Methane calculations were derived from the constant expressed in Mcal of CH_4/kg DMI, based on the equation proposed by Galyean and Hales [26]. Daily CH_4 production (g/d) varies between treatments due to the differences in DMI. Therefore, the differences in the magnitude of CH_4 reduction other than just the variation in the DMI cannot be concluded from these results.

Torres et al. [79] reported that monensin and essential oils did not differ in CH_4 yield (g CH_4/kgDM), thus corroborating our results. The latter authors reported that EOs increased the DMI compared to monensin, which would likely impact the daily CH_4 emission, evidenced by the reported trend of an increase in CH_4 emissions presented ($p = 0.064$) for EOs compared to monensin. Torres et al. [79] indicated that final body weight and ADG were the same; thus, it is likely, if calculated, that the BEO would have a greater CH_4 intensity and greater g CH_4/kg metabolic BW ratio as well. Essential oils have gained attention for their potential to reduce CH_4 emissions from ruminants; however, the efficacy of the specific sources and types can vary based on factors such as animal species, diet, and the concentration of the oils used. Tomkins et al. [80] reported that a daily intake of 25 mg of monensin reduced the total CH_4 daily emission as well as the CH_4 yield (g CH_4/kg DMI) compared to the control diet containing no feed additive and compared to 1 or 2 g/day of the blend of essential oils of thymol, eugenol, d-limonene, and vanillin without any impacts on the DMI of steers fed Rhodes grass hay. Similarly, Batley et al. [81] used two doses of the blend of EO Agolin delivered via water to steers fed Rhodes grass hay and saw no differences in the DMI or productivity, although the latter authors reported a significant effect on CH_4 daily emissions, with a reduction of about 15% over an 8-week period. In our work, monensin was used as a positive control as it represents what has been widely accepted in commercial production systems. Cooke et al. [82], in a meta-analysis, reported that monensin decreased CH_4 production by 20.89 g/day and 14.6 g/day in high-forage and high-concentrate diets, respectively, with no differences across diets, indicating that monensin is effective in reducing CH_4 emissions despite the diet type.

5. Conclusions

Crossbred bulls outperformed Nellore bulls, presenting with a greater final body weight, hot carcass weight, and average daily gain, likely due to greater dry matter intake, both daily and expressed as a percentage of body weight, which also supports the same observed feed efficiency. Nevertheless, when comparing dietary net energy, the concentrations for maintenance and gain were greater for crossbreeds, which may suggest that they were more efficient in energy utilization. The higher energy utilization indicated by the observed energy concentrations was not reflected in lower methane emissions per daily weight gain. Methane emissios estimates were driven by dry matter intakeC rossbred bulls emitted more methane than Nellore bulls, and animals offered essential oils had greater daily methane emissions than bulls offeredseaweed and monensin.

In the present trial, the utilization of the seaweed buffer *Lithothamnium calcareum* associated with monensin brought no advantages over the single use of monensin on the performance of cattle finished with a high-concentrate diet in a feedlot. The blend of essential oils composed of castor beans, cashew nuts, and copaiba at the inclusion of 3 g/kg DM was not as efficient as monensin on feed efficiency and nutrient utilization.

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Appendix A

Table A1. Calcium (Ca) and phosphorus (P) daily intake and Ca:P ratios in the experimental diets.

Item	MON	LCM	BEO
DMI, kg/d	8.641	8.126	9.255
Dietary amount of Ca [1], g/d	84.54	79	90.54
Dietary amount of P [2], g/d	21.27	20	22.78
LitoNutri® amount of Ca [3], g/d	0	13	0
Ca:P ratio	3.9:1	4.6:1	3.9:1

[1,2] Calculated from concentrations of Ca and P in the feed ingredients as adopted by NASEM [23] and concentrations in the mineral and vitamin supplement [composed (DM basis) of 160 g/kg Ca, 131 g/kg P, 18 g/kg S, 82 mg/kg Co, 2283 mg/kg Cu, 15 mg/kg Cr, 2686 mg/kg Fe, 112 mg/kg I, 1940 mg/kg Mn, 22 mg/kg Se, 5417 mg/kg Zn, and 1310 mg/kg F. Manufactured by DSM Nutritional Products, São Paulo, SP, Brazil]. [3] Calculated according to the amount of Lithothamnium calcareum added in the diet (5 g/kg DM) and its Ca concentration (320 g Ca/kg). The Lithothamnium calcareum (LithoNutri®) was from OCEANA Minerals (Jundiaí, SP, Brazil).

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