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Ruminants

Doses of enzyme complex in a high-energy diet on performance and carcass traits of feedlot steers

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ABSTRACT - The objective of this study was to evaluate the production performance and carcass traits of feedlot steers fed a high-energy diet supplemented with doses of an enzyme complex (0, 2.5, 5.0, and, 7.5 g animal^{-1} day^{-1}). Thirty-two ½ Angus ½ Nellore crossbred steers at an average age of 12 months and an average initial weight of 422 kg, were kept in a feedlot for 77 days. The roughage-free diet was composed of a mixture of whole corn grain and a protein-mineral-vitamin mix at a constant ratio of 85:15, on a dry matter basis. A completely randomized block design was adopted, consisting of four treatments and four replicates, in which each replicate was represented by a stall with two animals. Each gram of product added to the diet led to a decrease of 0.0818 kg in daily dry matter intake (DMI), whereas fat thickness at the ribs and at the hindquarter increased by 0.3850 and 0.080 mm, respectively. Feed efficiency increased by 0.0054 kg BW kg DMI^{-1} per gram of enzyme added. Apparent dry matter digestibility had a quadratic response, with maximum digestion manifested at the dose of 4.78 g animal^{-1} day^{-1}. The gradual inclusion of enzyme complex reduces the DMI but increases feed efficiency and carcass fat cover of feedlot steers.

Key Words: cellulase, digestibility, feed intake, non-carcass component, ultrasonography

Introduction

In feedlot systems, there has been a trend towards the use of low-roughage or roughage-free diets, constituted entirely by concentrate ingredients.

However, the digestion potential of grain starch by ruminants depends on the structural characteristics of the starch and interactions with other non-starch components (Giuberti et al., 2014). Therefore, techniques that improve the efficiency of feed digestion and manipulation of ruminal fermentation have been increasingly used (Amaro et al., 2002).

In this scenario, the inclusion of exogenous enzymes in high-energy diets has stood out for producing positive results in the feed digestibility (Morsy et al., 2016) and in animal performance (Salem et al., 2013). In addition, supplementation of exogenous enzymes has provided improvements in bovine carcass traits by increasing production of short-chain fatty acids in the body (Beauchemin et al., 2003).

However, the use of exogenous enzymes to supplement or stimulate digestive activity in rumen has shown varied responses in animal production (Wang et al., 2001). Martins et al. (2006) did not observe any effect of inclusion of enzyme complex in cattle diet on dry matter intake, feed conversion, or apparent dry matter digestibility. Vargas et al. (2013) also did not observe statistical differences for animal-performance parameters. Eun et al. (2009) found a decrease in subcutaneous fat thickness and marbling fat score with supplementation of exogenous enzymes.

Another obstacle to the use of enzymes in ruminant nutrition is insufficient research related to adequate doses of enzyme complexes and their effects in high-energy diets under Brazilian conditions.

In view of these considerations, this study was developed to evaluate the productive performance and carcass traits of feedlot steers fed high-energy diets supplemented with doses of an enzyme complex.

Material and Methods

All experimental procedures were approved by the local ethics committee (case no. 03/2016 of February 19, 2016). The experiment was conducted in Guarapuava, PR, Brazil (25º23'02" S, 51º29'43" W, and 1098 m asl).

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Thirty-two ½ Angus ½ Nellore crossbred steers belonging to the same herd, with an average initial body weight (BW) of 422±6.2 kg and an average age of 12±2 months, were housed in 16 semi-covered feedlot stalls with an area of 15 m² equipped with a concrete feeder and float-valve drinker. Steers were allocated to the experimental units based on their BW, loin eye area (LEA), and fat thickness at the rump cap [FTRC, measured by an ultrasound machine (ALOKA SSD 500 VET®, Aloka, Japan) with a 17-cm linear probe, at a frequency of 3.5MHz].

The experiment was arranged as randomized block design consisting of four enzyme complex doses (0, 2.5, 5.0, and 7.5 g animal^{-1} day^{-1}) and four replicates, each represented by a stall with two animals.

The enzyme complex used was the commercial product Potenzya® (JBS, USA), obtained from the fermentation of the fungi *Aspergillus niger* and *Trichoderma reesei*, which underwent a previous analysis of enzymatic activity by 3.5-dinitrosalicylic acid (DNS) assay (adapted from Miller, 1959), revealing 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 respective pH and temperature conditions of the tests were: xylanase – 4.5 and 40 ºC; cellulase – 4.8 and 50 ºC; β-glucanase, mannanase, and amylase – 5 and 40 ºC; and α-galactosidase – 5.5 and 37 ºC.

The experiment lasted 77 days, with the first 14 days used for the adaptation of animals to the diet and facilities and the remaining 63 days divided into three 21-day experimental periods.

Prior to the experiment, the total diet of animals had a constant roughage-to-concentrate (corn silage and protein-vitamin-mineral mixture) ratio of 50:50, on a dry matter (DM) basis. For the adaptation of animals to the experimental diet, in the first five days, 1.2 kg DM 100 kg BW^{-1} of a concentrate mixture were provided (constant ratio of 85:15 between whole corn grain and protein-vitamin-mineral mix) along with corn silage *ad libitum*. From the sixth to the tenth day, the animals received 1.6 kg DM 100 kg BW^{-1} of the concentrate mixture plus *ad libitum* corn silage. Lastly, on the eleventh day, 1.8 kg DM were provided for each 100 kg BW^{-1} and the roughage supply was reduced by 25% per day relative to the intake from the tenth to the fifteenth day, when the forage supply was interrupted and only the concentrate mixture was provided in the feeder.

The protein-vitamin-mineral mix was formulated based on soybean meal, wheat bran, malt radicle, calcitic limestone, dicalcium phosphate, livestock urea, salt, and a mineral-vitamin premix, presented in pelleted form.

Feed was supplied twice daily (6:00 and 16:00 h), and the enzyme complex was added to the diet at the time of feeding the animals in a brief mixing, to ensure the expected ingestion of the enzyme complex. Dry matter intake (DMI) was determined daily, as the difference in weight between the amount offered and leftovers from the previous day. Feed supply was adjusted daily, aiming at *ad libitum* supply, considering leftovers of 100 g kg DM^{-1}, on the diet DM basis.

During the feedlot period, samples of the diet were collected to determine its chemical composition (Table 1). Samples were dried in a forced-air oven at 55 °C until reaching a constant weight and subsequently ground through a Wiley mill with a 1-mm sieve. Analysis of DM, crude protein (CP), ash, and fat were performed according to AOAC (1995). The neutral detergent fiber (NDF) content was obtained according to Van Soest et al. (1991) with thermo-stable α-amylase, while acid detergent fiber (ADF) and lignin were determined according to Goering and Van Soest (1970). For the determination of P and Ca levels, analyses were conducted according to methodology described by Tedesco et al. (1995). The total digestible nutrient (TDN) coefficient was calculated according to Weiss et al. (1992). Starch was analyzed according to

Table 1 - Chemical composition of diet components and total diet (g kg^{-1} DM)

Parameter	Corn (whole grain)	Concentrate	Total diet[1]
Dry mater (g kg^{-1})	834.6	902.2	844.7
Ash	7.7	163.1	31.0
Crude protein	77.2	422.3	129.0
Neutral detergent fiber	240.8	246.1	241.6
Acid detergent fiber	57.3	122.8	67.1
Total digestible nutrients	838.3	697.0	817.1
Starch	560.1	257.4	514.7
Ca	0.3	27.7	4.4
P	2.5	11.1	3.8

DM - dry matter.
[1] Experimental diet consisting of a constant ratio of 85:15 between whole corn grain and protein-mineral-vitamin mixture.

methodology described by Hendrix (1993), based on the starch hydrolysis contained in the sample, after extraction of soluble carbohydrates with successive washes with 80% alcohol and colorimetric analysis of reducing sugars (glucose), followed by a conversion of the result for starch.

Steers were weighed at the beginning and at the end of the experiment as well as at the end of each 21-day trial period, after 10 h of solids fasting, to determine the average daily gain (ADG). Average daily gain was calculated as the difference between the final (BWf) and initial (BWi) body weight of each experimental period divided by the number of experimental days (ADG = BWf – BWi/21). Dry matter intake was expressed in kilograms per day (kg day^{-1}) and relative to the average body weight of the period (DMI_{BW} = DMI/BW*100). Feed efficiency (FE) was determined as the ratio between ADG and DMI (FE = ADG/DMI).

In each period in the feedlot, total fecal collection was performed for two consecutive days, in each experimental unit, to determine the apparent dry matter digestibility (ADMD) of the diet. Feces samples were weighed and sampled at every six hours and later stored in a freezer at –18 °C until analysis.

The DM content of feces from each stall was determined using the same procedures adopted in the analysis of the feed. The ADMD, expressed in g kg^{-1} DM, was calculated by the following formula, according to Neumann et al. (2007):

ADMD = {1 – [(DM ingested – DM excreted) ÷ DM ingested]} × 100

At the beginning and at the end of the feedlot period, ultrasound images were obtained from the LEA, subcutaneous fat thickness (SFT), marbling fat, and FTRC measured between the 12th and 13th ribs, transversely to the *longissimus dorsi* muscle, following the recommendations of Herring et al. (1994). Based on the measurements, we calculated the LEA ratio (LEAR), which is represented by the division between its height and width. Images were interpreted by the laboratory responsible for data-quality assurance, using the BIA/DGT Brasil software.

Marbling was evaluated based on the existence of fat depots between the muscle fibers in the *longissimus dorsi* muscle and graded from 1 (nonexistent) to 5 (excessive), in an adaptation of the system proposed by Müller (1987).

We also measured the gains in LEA (LEAg), SFT (SFTg), marbling, FTRC (FTRCg), and LEAR (LEARg). These were calculated as the difference between the respective values recorded at the end of the feedlot period and at the beginning of the experiment.

At the end of 77 days of feedlot and after 10 h of solid-feed deprivation period, animals were weighed to obtain final body weight and transported to a local commercial slaughterhouse (Guarapuava, PR, Brazil), located at a distance of 5 km from the experiment site. Slaughter procedures followed standards adopted by the slaughterhouse in accordance with the current laws for the slaughter of cattle. Total carcass gain, expressed in kg, was determined as the difference between hot carcass weight (HCW), at the time of slaughter, and initial carcass weight (ICW), which was estimated considering a theoretical initial carcass yield of 52 kg 100 kg^{-1} BW (ICW = initial BW*0.52). Based on the 77-day feedlot period, we also calculated the average carcass gain, obtained as the ratio between total carcass gain and feedlot period and expressed in kg day^{-1}; the dry matter-carcass transformation efficiency, expressed in kg DM kg carcass^{-1}; and the weight gain-carcass transformation efficiency, as the ratio between average carcass gain and ADG, expressed in kg kg^{-1}.

The carcasses were evaluated individually according to methodology of Müller (1987), by measuring the following parameters: hot carcass weight (HCW), carcass yield (CY), carcass length, arm length, arm girth, thigh thickness; and fat thickness measured *in locu* at the *longissimus dorsi* (FTLD), at the hindquarter (FTHQ), at the ribs (FTRI), and at the forequarter (FTFQ).

At the time of slaughter, non-carcass components were also measured to estimate their weight in relation to BW of steers. For this, we weighed the heart, kidneys, liver, lungs, spleen, empty rumen-reticulum, full rumen-reticulum, empty abomasum, full abomasum, and full intestines (vital organs); and head, tongue, tail, hide, and feet (external components).

The data collected for each variable were tested for homogeneity of variances by Bartlett's test (PROC GLM) and normality of errors by the Shapiro-Wilk test (PROC UNIVARIATE), prerequisites for the analysis of variance. Afterwards, the data were tested by an analysis of variance. Data corresponding to the analyses for the periods were subjected to means compared at 0.05 significance by Tukey's test, via PROC GLM procedures. Data on enzyme doses were subjected to regression test, via the PROC REG procedures, using SAS software (Statistical Analysis System, version 6). Each variable was analyzed by the statistical model below:

$$Y_{ijk} = \mu + V_i + P_j + B_k + (V \times P)_{ij} + E_{ijk},$$

in which Y_{ijk} = dependent variables; μ = overall mean of all observations; V_i = effect of enzyme dose of order "i", in which i = 1 (control diet), 2 (2.5 g animal^{-1} day^{-1}), 3 (5.0 g animal^{-1} day^{-1}), and 4 (7.5 g animal^{-1} day^{-1}); P_j = effect of the feedlot period of order "j", in which j = 1 (first period), 2 (second period), and 3 (third period); B_k = effect of the block of order "k", in which k = 1 (first), 2 (second),

3 (third), and 4 (fourth); $(V\times P)_{ij}$ = effect of the interaction between dose of enzyme "i" and feedlot period "j"; and E_{ijk} = residual random effect.

Results

Apparent dry matter digestibility was not affected by the interaction between enzyme dose and feedlot period (P>0.05) or by the feedlot period alone. However, in the overall mean, the tested enzyme doses elicited a quadratic response from ADMD, with maximum digestibility obtained at the daily enzyme complex supplementation dose of 4.78 g animal^{-1} day^{-1} (Table 2).

The parameters ADG, DMI, DMI_{BW}, and FE were not significantly affected by the interaction between enzyme dose and feedlot period (Table 3). However, with respect to the feedlot periods, there was a significant difference (P<0.05) for DMI, while ADG, DMI_{BW}, and FE did not differ (P>0.05) between the evaluation periods. The average values of DMI, expressed in kg day^{-1}, increased gradually by 0.8200 kg animal day^{-1} between the first and the last 21-day experimental periods, irrespective of the enzyme dose included in the diet (Table 3).

Average daily gain was not affected by the inclusion of enzyme doses in the diet (P>0.05) (Table 3). However, DMI, DMI_{BW}, and FE showed a significant difference (P<0.05) with the increasing levels of enzyme complex (Table 3), responding linearly.

Dry matter intake decreased by 0.0818 kg animal^{-1} day^{-1} for each gram of enzyme included in the diet, while DMI_{BW} declined by 0.0141 kg 100 kg BW^{-1} day^{-1} with each additional gram of enzyme complex included in the diet.

The average FE of feedlot steers improved with the increasing enzyme doses. Each gram of supplemented enzyme increased this variable by 0.0054 kg BW kg DM^{-1} ingested.

With the progression of the feedlot periods, the FE of the groups receiving enzyme doses remained stable as the doses increased, whereas the FE of control group tended to worsen from the first to the second and from the second to the third evaluation periods.

The initial and final values of the parameters LEA, SFT, FTRC, marbling, and LEAR evaluated by ultrasonography did not present statistical differences (P>0.05) with the enzyme doses included in the diet. The same was true for LEAg, marbling gain, and LEARg. However, SFTg and FTRCg were significantly affected (P<0.05) by the enzyme doses, with a linear response (Table 4).

Increases of the orders of 0.0787 and 0.0492 mm were detected for SFTg and FTRCg, respectively, with each gram of enzyme added to the high-energy diet.

Results for HCW, CY, FTLD, FTFQ, carcass length, thigh thickness, arm length, and arm girth did not reveal significant differences with enzyme supplementation. The enzymatic dose effect was observed only on FTHQ and FTRI (P<0.05) (Table 5).

Both FTHQ and FTRI had a linear response, increasing by 0.0800 and 0.3850 mm, respectively, with the inclusion of each gram of enzyme in the diet. Fat thickness at the ribs increased by 61.47% when we compare control group with the group that received the enzyme complex dose of 7.5 g animal day^{-1} (Table 5).

Non-carcass components, which were evaluated at the time of slaughter in kg 100 kg BW^{-1}, did differ significantly between the enzyme doses added to the diet (Table 6).

Total carcass gain, average carcass gain, dry matter-carcass transformation efficiency, and weight gain-carcass transformation efficiency did not show statistically significant differences (P>0.05) with the enzyme doses included in the diet (Table 7).

Table 2 - Apparent dry matter digestibility (ADMD) of steers fed a diet supplemented with doses of an enzymatic complex according to feedlot period

Enzymatic complex dose	Feedlot period			Mean
	1-21 days	22-42 days	43-63 days	
	Apparent dry matter digestibility (g g^{-1} DM)			
Control (0 g)	0.825	0.805	0.828	0.820
2.5 g	0.849	0.863	0.866	0.859
5.0 g	0.828	0.828	0.847	0.835
7.5 g	0.833	0.853	0.854	0.847
Mean	0.834a	0.837a	0.849a	
Regression equation	ADMD = 0.825 + 0.010495D – 0.001096D^2 (R^2 = 0.170; CV = 4.2%; P = 0.04)			

DM - dry matter; D - dose of enzyme ranging from 0 to 7.5 g animal day^{-1}; R^2 - coefficient of determination; CV - coefficient of variation.
Means followed by different lowercase letters in the row differ by Tukey's test at 5%.

Table 3 - Performance of steers fed a diet supplemented with doses of an enzymatic complex according to feedlot period

Enzymatic complex dose	Feedlot period			Mean
	1-21 days	22-42 days	43-63 days	
	Average daily gain (ADG; kg day^{-1})			
Control (0 g)	1.274	1.077	1.048	1.133
2.5 g	1.167	1.411	1.601	1.393
5.0 g	1.167	1.363	1.327	1.286
7.5 g	1.315	1.292	1.488	1.365
Mean	1.231a	1.286a	1.366a	
Regression equation	ADG = 1.294 kg day^{-1} (R^2 = 0.051; CV = 22.3%; P = 0.12)			
	Dry matter intake (DMI, kg day^{-1})			
Control (0 g)	7.36	7.34	7.84	7.51
2.5 g	6.87	7.10	7.88	7.28
5.0 g	6.46	7.23	7.22	6.97
7.5 g	6.40	6.97	7.44	6.94
Mean	6.77b	7.16ab	7.59a	
Regression equation	DMI = 7.4829 – 0.0818D (R^2 = 0.279; CV = 11.1%; P = 0.05)			
	DMI relative to body weight (DMI_{BW}, kg 100 kg BW^{-1})			
Control (0 g)	1.63	1.54	1.57	1.58
2.5 g	1.56	1.52	1.58	1.55
5.0 g	1.46	1.55	1.45	1.49
7.5 g	1.45	1.49	1.50	1.48
Mean	1.53a	1.52a	1.52a	
Regression equation	DMI_{BW} = 1.5781 – 0.0141D (R^2 = 0.279; CV = 8.9%; P = 0.05)			
	Feed efficiency (FE; ADG DMI^{-1})			
Control (0 g)	0.173	0.147	0.133	0.151
2.5 g	0.167	0.201	0.204	0.191
5.0 g	0.187	0.185	0.185	0.186
7.5 g	0.204	0.186	0.203	0.198
Mean	0.183a	0.180a	0.181a	
Regression equation	FE = 0.1612 + 0.0054D (R^2 = 0.231; CV = 21.8%; P = 0.01)			

D - dose of enzyme ranging from 0 to 7.5 g animal day^{-1}; R^2 - coefficient of determination; CV - coefficient of variation.
Means followed by different lowercase letters in the row differ by Tukey's test at 5%.

Table 4 - Carcass gain measurements of steers fed a diet supplemented with doses of an enzymatic complex, at the end of feedlot period

Parameter	Enzymatic complex dose				Mean	CV (%)	P-value (P<0.05)
	Control (0 g)	2.5 g	5.0 g	7.5 g			
LEAg (cm^2)	6.900	8.139	6.025	8.636	7.425	34.6	0.685
SFTg[1] (mm)	0.628	1.295	0.929	1.406	1.064	58.9	0.049
FTRCg[2] (mm)	1.059	2.218	1.650	1.658	1.646	36.1	0.039
Mg (points)	0.231	0.275	0.373	0.468	0.336	55.7	0.582
Rg (cm)	0.038	0.024	0.023	0.015	0.025	44.7	0.189

LEAg - loin eye area gain; SFTg - subcutaneous fat thickness gain; FTRCg - subcutaneous fat thickness gain at the rump cap; Mg - marbling gain; Rg - LEA height:width ratio gain; R^2 - coefficient of determination; CV - coefficient of variation.
[1] SFTg = 0.7705 + 0.0787D (R^2 = 0.158; CV = 58.8%; P<0.05), in which D represents enzyme dose ranging from 0 to 7.5 g animal day^{-1}.
[2] FTRCg = 1.4642 + 0.0492D (R^2 = 0.116; CV = 49.6%; P<0.03).

Discussion

In the present study, there was an improvement in ADMD up to the enzyme complex dose of 4.78 g animal^{-1} day^{-1} added to the high-energy diet. This result is consistent with those obtained by Jalilvand et al. (2008) and López-Aguirre et al. (2016), who also evaluated doses of enzyme complexes. Both author groups reported that ADMD also had a quadratic effect with the increasing enzyme levels, suggesting that exogenous enzymes produce better results at a certain dose (Jalilvand et al., 2008).

Martins et al. (2006), however, did not observe a significant difference (P>0.05) in ADMD after adding a fibrolytic enzyme complex to a diet composed of maize silage and Tifton 85 hay for feedlot cattle. This can be explained by the dose of 12 g animal^{-1} day^{-1} used, reinforcing the fact that exogenous enzymes do not have a dose-response effect and that intermediate doses are more interesting for this parameter.

The mechanisms by which exogenous enzymes improve dietary digestion are not fully elucidated, although Jalilvand et al. (2008) suggested that exogenous enzymes improve dietary digestion by increasing rumen microbial colonization and fixation on the feed surface. Other mechanisms of action are also noteworthy, e.g., stimulation of the microbial population and enzymatic synergism (Morgavi et al., 2000; Tadele and Animut, 2015) or direct

Table 5 - Carcass measurements of steers fed a diet supplemented with doses of an enzymatic complex, at slaughter

Parameter	Enzymatic complex dose				Mean	P-value (P<0.05)	CV (%)
	Control (0 g)	2.5 g	5.0 g	7.5 g			
HCW (kg)	291.6	293.9	287.5	290.6	290.9	0.966	6.27
CY (kg 100 kg BW^{-1})	56.01	55.35	55.68	55.84	55.72	0.869	2.06
FTLD (mm)	5.00	5.38	5.38	6.25	5.50	0.081	13.55
FTHQ[1] (mm)	3.63	3.88	4.00	4.25	3.94	0.049	25.83
FTRI[2] (mm)	4.88	5.75	6.38	7.88	6.22	0.011	15.64
FTFQ (mm)	5.00	5.13	5.38	6.00	5.38	0.082	17.54
CL (m)	1.29	1.32	1.34	1.33	1.32	0.254	2.17
TT (cm)	22.08	21.18	20.09	20.79	21.03	0.301	6.63
AL (cm)	37.63	39.44	37.25	37.06	37.84	0.101	1.58
AG (cm)	40.19	40.94	40.06	39.19	40.09	0.359	3.24

HCW - hot carcass weight; CY - carcass yield; FTLD - fat thickness determined *in locu* at the *longissimus dorsi*; FTHQ - fat thickness determined *in locu* at the hindquarter; FTRI - fat thickness determined *in locu* at the ribs; FTFQ - fat thickness determined *in locu* at the forequarter; CL - carcass length; TT - thigh thickness; AL - arm length; AG - arm girth; CV - coefficient of variation; R^2 - coefficient of determination.
[1] FTHQ = 3.6375 + 0.0800D (R^2 = 0.157; CV = 24.6%; P = 0.04), in which D represents the enzyme dose ranging from 0 to 7.5 g animal day^{-1}.
[2] FTRI = 4.7750 + 0.3850D (R^2 = 0.501; CV = 18.5%; P = 0.00).

Table 6 - Non-carcass components (kg 100 kg BW^{-1}) of steers fed a diet supplemented with doses of an enzymatic complex, at slaughter

Parameter	Enzymatic complex dose				Mean	P-value	CV (%)
	Control (0 g)	2.5 g	5.0 g	7.5 g			
Vital organs							
Heart	0.34	0.33	0.35	0.37	0.35	0.423	9.36
Liver	1.09	1.14	1.16	1.16	1.14	0.556	7.12
Lungs	0.85	0.94	0.91	0.89	0.90	0.349	7.88
Kidneys	0.21	0.20	0.20	0.21	0.20	0.446	7.17
Spleen	0.33	0.34	0.34	0.33	0.34	0.949	13.70
Empty rumen-reticulum	8.63	7.92	8.46	8.23	8.31	0.434	7.41
Full rumen-reticulum	2.33	2.32	2.37	2.31	2.33	0.998	24.14
Empty abomasum	0.93	1.28	1.21	1.19	1.15	0.198	19.02
Full abomasum	0.83	1.02	1.05	1.15	1.01	0.292	21.89
Full intestines	4.68	4.30	4.57	4.76	4.57	0.585	10.75
External components							
Head	2.34	2.34	2.41	2.34	2.36	0.670	3.97
Tongue	0.18	0.18	0.18	0.19	0.19	0.848	7.89
Hide	8.78	10.46	9.75	9.41	9.60	0.106	5.20
Tail	0.26	0.27	0.27	0.25	0.26	0.689	10.56
Feet	1.96	2.10	2.23	1.98	2.07	0.337	10.61

BW - body weight; CV - coefficient of variation.

Table 7 - Average carcass gain (ACG), weight gain-carcass transformation efficiency (WGCTE), total carcass gain (TCG), and dry matter-carcass transformation efficiency (DMCTE) of steers fed a diet supplemented with doses of an enzymatic complex

Complex enzymatic dose	ACG (kg day^{-1})	WGCTE (kg kg^{-1})	TCG (kg)	DMCTE (kg DM kg $carcass^{-1}$)
Control (0 g)	1.011	0.8896	63.7	7.49
2.5 g	1.127	0.8088	71.0	6.51
5.0 g	1.022	0.7928	64.4	7.09
7.5 g	1.098	0.8030	69.2	6.36
Mean	1.064	0.8235	67.0	6.86
P-value	0.721	0.287	0.722	0.340
CV (%)	15.91	8.92	15.92	13.53

DM - dry matter; CV - coefficient of variation.

hydrolysis of the substrates by enzymes (Beauchemin et al., 2003; Moharrery et al., 2009).

The increase in DMI with the advance of the feedlot periods ($P<0.05$) can be explained by a reaction of the animals in the phase of adaptation to the high-energy diet, which had a constant roughage:concentrate ratio of 50:50 before the experiment.

This transition phase to the high-energy diet involves an adaptation of ruminal microorganisms, which increase the number of amylolytic over fibrolytic bacteria (Tajima et al., 2001). This allows for an effective use of readily fermentable carbohydrates without leading to metabolic disorders (Owens et al., 1998), or reduced intensity of subclinical acidosis and variations in feed intake (Krehbiel et al., 2007).

Despite the increase in DMI over the course of the evaluation periods, ADG did not show significant statistical differences with the inclusion of enzyme doses in the diet.

In this study, the improvement in ADMD up to the daily enzyme supplementation dose of 4.78 g animal^{-1} day^{-1} and the decrease in DMI without reductions in ADG and improvement in FE with the progressive inclusion of enzyme doses in the high-energy diet promoted a better utilization of the dietary nutrients.

This improved utilization of the diet likely increased the flow of propionate in the liver, exceeding gluconeogenesis and leading to the oxidation of the short-chain fatty acid. As a consequence, the sensation of satiety is triggered by metabolic signals rather than ruminal distension, as usually occurs in high-energy diets (Allen et al., 2009).

Improved FE following addition of an enzyme complex at the dose of 40 g animal^{-1} day^{-1} to a high-concentrate diet was also reported by Salem et al. (2013). In the same experiment, the authors observed an increase in ADG; however, DMI was not affected, probably because of the presence of forage in the diet.

Yang et al. (1999) worked with cows that received supplementation with exogenous enzymes and a total diet composed of 45% concentrate, 10% barley silage, and 45% cubed alfalfa hay and observed that, although DMI was similar between treatments with or without the exogenous enzyme, FE was better in cows that received supplementation. Therefore, a 7% increase in milk yield was observed in cows treated with enzymes.

Eun et al. (2009), however, did not observe effects of the addition of a fibrolytic enzyme complex at the doses of 1 and 2 g kg DM^{-1} in a diet composed mainly of alfalfa hay, corn silage, and rolled barley grain on the DMI and performance of steers, possibly due to the low dose of enzyme used as supplement.

The significant effect ($P<0.05$) on SFTg and FTRCg, assessed by ultrasound, with the progressive inclusion of the enzyme doses included in the diet, can be confirmed by Beauchemin et al. (2003) and Vargas et al. (2013). According to those authors, the use of exogenous enzymes may improve the cattle carcass traits by increasing production and/or changing the proportion of short-chain fatty acids in the body (Tricarico et al., 2006; Eun and Beauchemin, 2007), which, by contrast, may alter fat synthesis and carcass traits of animals, contrasting with the present findings.

According to Eun and Beauchemin (2007), enzyme complexes containing cellulases or xylanases may alter the composition of the ruminal bacterial population as well as their physiological activities; thus, changes are not uncommon in the proportions of short-chain fatty acids.

Silva (2017) evaluated doses of exogenous fibrolytic enzymes (0, 0.37, and 0.74% DM) added to a diet with a 78:21 roughage:concentrate ratio for Nellore cattle and observed that the average LEA, evaluated according to feedlot periods by ultrasonography using the same apparatus used in the current experiment, were not affected by the addition of enzyme doses. However, the average SFT was significant for the inclusion of the fibrolytic complex doses, also showing a linear response.

In an experiment evaluating the supplementation of steers with extracts of *Aspergillus oryzae* containing amylolytic activity at the doses of 0, 580, and 1160 dextrinizing units (DU), comparing diets composed of ground maize or cracked maize, Tricarico et al. (2006) also found that SFT increased linearly. They also observed a quadratic response of the parameters HCW and LEA resulting from the supplementation of α-amylase doses, regardless of the processing of corn grain, which can be explained by the increase in ADG.

Eun et al. (2009), on the other hand, found that supplementation with fibrolytic enzymes reduced SFT at the 12th rib and marbling fat score and did not affect HCW, which can be explained by the enzyme doses used in the experiment, which were possibly not sufficient to modify ruminal fermentation positively. This suggests that changes in ruminal fermentation triggered by supplementation with exogenous enzymes are decisive to the fat deposition in finishing steers.

Thus, SFTg and FTRCg conflict with the linear increase observed in FTHQ and in FTRI with the increasing doses of the enzyme complex added to the diet, suggesting positive changes in the production and proportion of short-chain fatty acids.

Those are interesting results when we relate SFT to better preservation of the carcass, minimization of damages due to cooling, and criterion of the current consumer when evaluating the meat quality. Furthermore, earlier deposition of fat allows for an advancement and standardization of lots of animals for trade, thereby providing faster and better return on investments when the carcass is evaluated by the slaughterhouse on its quality besides weight and CY.

The inclusion of enzyme complex doses in the high-energy diet of the feedlot cattle did not change HCW, CY, thigh thickness, arm length, or carcass length. The inclusion of enzyme-complex doses to high-energy diets is believed to influence the parameters HCW and CY only indirectly, since the carcass weight increases as a function of ADG as long as it is deposited in carcass rather than as non-carcass components, or by an increase in deposition of the fat that makes up the carcass. As for the bone-development characteristics thigh thickness, arm length, and carcass length, Felício et al. (1979) declared they are influenced by the growth rate of the animals, which was not addressed in the present study.

Oliveira et al. (2015) also found that addition of enzymes with amylolytic activity did not significantly affect ($P>0.05$) the CY of feedlot cattle, probably because the amount of enzyme complex applied to the high-energy diets (48.7 and 83.1 saccharifying units kg DM^{-1} of the diet) was not sufficient to promote the cleavage of a significant number of starch molecules to change the availability of nutrients in the rumen and significantly modify the production of short-chain fatty acids.

Brito (2010), in turn, noted that CY responded quadratically to the inclusion of an enzyme complex with high activity of pectinase in a high-energy diet provided to lambs. According to that author, the improvement observed in ruminal fermentation parameters was not sufficient to generate a supply of nutrients to be deposited in the carcass, considering that BW at slaughter and HCW were not changed.

Vargas et al. (2013) also compared different doses of enzyme complexes composed of xylanases and cellulases for feedlot cattle receiving a diet whose constant concentrate:roughage ratio was 88:22 (DM basis) and observed a quadratic response of the CY of the evaluated animals. The best values were obtained for the animals that received intermediate enzymes doses in their diet (2 and 4 mg kg^{-1}), even though no statistical difference was observed for performance parameters. However, in the present study, the inclusion of exogenous-enzyme doses to the diet of steers caused changes in parameters related to animal performance and carcass traits, suggesting that enzyme doses can affect performance and are effective in modifying some carcass traits.

Non-carcass components did not differ significantly across the enzyme doses. These findings indicate that the nutrient uptake, which increased with ADMD up to the dose of 4.78 g $animal^{-1}$ day^{-1}, was not directed towards visceral and/or mesenteric fat deposition, but rather to deposition of subcutaneous fat. This is because when animals reach the finishing stage, earlier-developing fat depots such as intermuscular, perirenal, and mesenteric have already completed the hyperplasic development of adipocytes, which then start to accumulate fat in their cytoplasm, whereas the subcutaneous and intramuscular fats, which are deposited later, continue to recruit new adipocytes while undergoing hyperplasia (Sainz and Hasting, 2000; Paulino et al., 2009).

Sparse literature data can be found on non-carcass components, average carcass gain, weight gain-carcass transformation efficiency, total carcass gain, and dry matter-carcass transformation efficiency related to the use of exogenous enzymes.

Conclusions

In high-energy diets, enzyme complexes at the dose of 4.78 g $animal^{-1}$ day^{-1} provide maximum dry matter digestibility. The gradual inclusion of an enzyme complex in high-energy diets for feedlot steers reduces their dry matter intake but leads to higher feed efficiency and higher subcutaneous fat deposition.

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