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Roughage-free finishing diet based on whole corn grain and a mixture of additives for Nellore heifers

Raphael Marques de Paula[1], Claiton André Zotti[2], Léa Furlan D'Abreu[1], Nara Regina Brandão Cônsolo[1], Paulo Roberto Leme[1], Saulo da Luz e Silva[1], Arlindo Saran Netto[1*]

[1] Universidade de São Paulo, Faculdade de Zootecnia e Engenharia de Alimentos, Departamento de Zootecnia, Pirassununga, SP, Brasil.
[2] Universidade do Oeste de Santa Catarina, Departamento de Zootecnia, Xanxerê, SC, Brasil.

***Corresponding author:**
saranetto@usp.br

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ABSTRACT - This study was carried out to evaluate the effect of a blend of additives (choline, methionine, selenium, and organic zinc) on performance, feed efficiency, rumen parameters, and carcass traits of Nellore heifers finished with roughage-free diet. Nellore heifers (n = 36; average BW = 244±24.1 kg; average 24 months of age) were maintained in a feedlot system for 86 d. Heifers were separated into two groups: control and additive. Heifers in control group were fed a based diet composed of 850 g kg^{-1} corn grain and 150 g kg^{-1} of a mineral-vitamin-protein pellet. The additive group was fed a diet supplemented with a blend of choline, methionine, selenium, and organic zinc at 1,667, 4,000, 1, and 24.37 mg kg^{-1} of the diet dry matter, respectively. The animals were allotted to 18 pens (two heifers/pen), with nine pens per treatment. Heifers were weighed, blood samples were collected, ultrasonography examinations were performed periodically, and hot carcass and papillae samples were taken at slaughter. Data were analyzed as a completely randomized design. The model included the fixed effect of treatments (control and additive). Additive supplementation did not change dry matter intake, performance, or feed efficiency. There was no effect of additives on muscle or fat tissue deposition. Consequently, no changes in hot carcass weight and dressing were found. Overall, additive inclusion did not alter blood parameters, blood electrolyte balance, and rumen traits. Nellore heifers finished with roughage-free diets have no improvement on production traits nor in their rumen health by supplementation with a blend of choline, methionine, selenium, and organic zinc.

Keywords: amino acid, feedlot, metabolic modulator, minerals

Introduction

Roughage is traditionally included in beef cattle finishing diets to maintain rumen health; however, in Brazil, the forage quantity has been reduced over the years in an attempt to improve feed efficiency and facilitate the feedlot management. Oliveira and Millen (2014) observed a decrease in the roughage part of the diet, from 288 g kg^{-1} of the diet dry matter (DM) in 2009 to 200 g kg^{-1} of the diet DM in finishing diets in 2014.

The benefits of including a concentrate source in finishing diets are elevation of the dietary net energy for gain, reduction of the cost per unit of metabolizable energy, and easiness of diet handling and management in commercial feedlots (Britton and Stock, 1987; Owens et al., 1998). However, roughage-free diets can lead to higher ruminal lactate production, greater fluctuations in the rumen pH and in feed intake, and rumenitis (Nagaraja and Lechtenberg, 2007). They may also render the rumen epithelium susceptible to injury, resulting in translocation of endotoxin and bacteria into the bloodstream (Kleen et al., 2003; Emmanuel et al., 2008); nonspecific immune responses (Werling et al., 1996; Ametaj et al., 2009); and infection and abscess formation in the liver and in the foot (Nagaraja and Lechtenberg, 2007). Those problems are normally associated with suboptimal performance in growing cattle, which has a significant impact on the profitability of the feedlot system.

Some strategies have been employed to prevent digestive disorders, e.g., the use of metabolic modulators like choline, methionine, selenium, and zinc. Those are known by improving hepatic function (Batistel et al., 2016; Zhou et al., 2017) and supporting anti-inflammatory activity, modulating the immune response, and lowering oxidative stress in cattle (Prasad, 2008; Batistel et al., 2016; Zhou et al., 2017).

Considering this scenario, we hypothesize that animals fed diets with additives can have some improvement in health and performance compared with the others. The present study was developed to evaluate the effect of a blend of additives (choline, methionine, selenium, and organic zinc) on performance, feed efficiency, rumen parameters, and carcass traits of Nellore heifers finished with roughage-free diet.

Material and Methods

All procedures involving animal care were conducted in accordance with the Institutional Animal Care and Use Committee Guidelines and approved under case no. 6558230218.

The feedlot study was conducted at an experimental station, located in Pirassununga, state of São Paulo, in southeastern Brazil (21°59'46" S, 47°25'36" W, and 625 m above sea level). The animals were kept in the feedlot for 86 d, the first 14 d of which were used for their adaptation to the feedlot facilities and diets. Thirty-six Nellore heifers of 24±3 months of age and 244±24 kg of initial live body weight were randomly allocated to 18 pens (two animals per pen) with *ad libitum* access to feed and water.

Heifers were fed a corn grain-based diet with no roughage source (Table 1) twice daily (08:00 and 16:00 h). The animals were distributed into two treatments: control – with no inclusion of additives; and additives – a mixture of choline, methionine, selenium, and organic zinc at 1,667, 4,000, 1, and 24.37 mg kg^{-1} diet DM, respectively. The diet was formulated to meet their requirements, allowing for an average daily gain (ADG) of 1.0 kg/d (NRC, 2001). Dry matter intake (DMI) was measured daily by weighing feed and orts, and the amount offered was adjusted daily, allowing for a minimum of 5% and maximum of 10% of orts throughout the experiment. Ingredients were sampled weekly and pooled to determine their chemical composition. Heifers were weighed with no feed restriction upon arrival and every 21 d to measure performance and feed efficiency.

Table 1 - Composition and analyzed nutrient content (DM basis) of the finishing diet

Item	g kg^{-1} of DM
Ingredient	
Whole corn grain	850
Pellet[1,2]	150
Analyzed composition	
Dry matter (DM)	885
Crude protein	153
Neutral detergent fiber	345
Acid detergent fiber	182

[1] Additive diet: choline, 1,667 mg; methionine, 4,000 mg; selenium, 1 mg; organic zinc, 24.37 mg. Control diet with no inclusion of choline, methionine, selenium, and organic zinc.
[2] The trace mineral mixture contained (per kg) in both diets: Ca, 35 g; Co, 10 mg; Cu, 68.9 mg; S, 36 g; P, 14 g; F, 14 mg; I, 2.58 mg; Mg, 18 mg; Mn, 300 mg; K, 26 g; Na, 67 g; Zn (inorganic), 207 g; vitamin A, 6,500 IU; vitamin E, 3,035 IU; *Saccharomyces cerevisae,* 0.0162×10^7 UFC; virginamicin, 134 mg.

Feed samples were collected weekly during the morning feeding and frozen for analyses of DM, crude protein, and ether extract according to AOAC (1990) methods 930.15 and 988.05. Neutral detergent fiber was determined as proposed by Van Soest et al. (1991).

Blood samples were collected at the beginning and at the end of the experimental period by puncture of the jugular vein or artery prior to the morning feeding. The samples (10 mL) were collected into 10-mL tubes (BD Vacutainer, São Paulo, SP, Brazil) without anticoagulant for the measurement of pH, partial pressure of carbon dioxide (pCO_2), excess bases, bicarbonate (HCO_3^-), and lactate concentration. Shortly after the collection, a few drops of blood were placed in an i-STAT EC8+® cartridge for reading the blood gas using a portable clinical analyzer (i-STAT® Co. – Abbott Laboratories - USA).

Muscle and fat thickness were evaluated by ultrasonography (Hitachi Aloka SSD500, 178 mm, 3.5-MHz; Wallingford, CT, USA) at the beginning of the experiment and every 21 d. The following measurements were taken: *longissimus* muscle area (LMA); fat thickness, obtained between the 12th and 13th ribs, across the *longissimus*; and fat thickness over the rump, measured at the intersection of the *gluteus medius* muscle and the *biceps femoris*, located between the ileum and ischium. Images were interpreted using the Lince 1.2 program (M&S Consultoria Agropecuaria Ltda, Pirassununga, SP, Brazil).

Heifers were slaughtered after an 18-h fast at a commercial plant located in Piracicaba, SP, Brazil, according to normal commercial practices. Hot carcass weight was recorded at slaughter, and dressing percentage was calculated. In addition, the rumen was examined to determine the incidence of rumenitis, papillae number, and absorption area.

For rumenitis index analyses, the ruminal papillae were visually classified by a trained person according to incidence of lesions on a scale of 0 to 10, in which each point represents 10% of the rumen compromised, according to methodology described by Bigham and McManus (1975). The following are considered lesions: ruminal epithelial defects, parakeratosis papillae, and inflammation or other alteration in the epithelial papillae color. Rumenitis incidence was considered at any score above zero.

For morphological analyses of the rumen wall, including papillae number, area, and absorption area, a 3-cm2 sample of the mucosa from the cranial region of the ventral sac was obtained and stored with alcohol 70%. Average papillae number (number/cm^2) was counted by three independent evaluators and the final count was considered the average papillae number between those three evaluators. The papillae representative participation on absorption superficies (PA, %) and papillae mean absorption area (cm^2) were measured through digitalized images (UTHSCSA Image Tool, free software) as previously described by Resende Junior et al. (2006). Papillae mean area was measured in twelve randomized papillae removed from the ruminal epithelium.

All statistical analyses were performed using Statistical Analysis System, version 9.1.2 for Windows. Firstly, the normality of residuals and the homogeneity of variances were verified using the UNIVARIATE procedure. Then, the data were analyzed according to the following model:

$$Yi = \mu + Ai + ei,$$

in which Yi = dependent variable, μ = general mean, Ai = effect of additive inclusion on DM diet, and ei = error. Data were analyzed as a completely randomized design using the MIXED procedures. The model included the fixed effect of treatments (control and additive). Pens were considered the experimental units for performance, intake, and feed efficiency, but animals were considered the experimental units for ultrasonography, carcass traits, and rumen parameters. The carcass traits measured by ultrasonography were analyzed as repeated measurements over time using the Mixed procedure of SAS. Rumenitis incidence data were considered nonparametric and were evaluated by the Kruskal-Wallis test using the PROC NPAR1WAY procedure. For all comparisons, significance was declared at $P \leq 0.05$.

Results

Initial BW was similar between the treatments, demonstrating homogeneity at the initial allocation (Table 2). Heifers that received additives had no improvements (P>0.05) in DMI, performance, or feed efficiency. Consequently, there was no effect of additives on hot carcass weight (HCW) and dressing percentage (P>0.05) or performance data (Table 2). There were no changes in LMA (P>0.05) or rump fat thickness (P>0.05) measured by ultrasonography between the treatments; however, backfat thickness was 6.6% higher (P<0.05) for heifers in control compared with those receiving the additive treatment (Table 2).

Overall, additive inclusion did not alter blood parameters (P>0.05) or blood electrolyte balance (P>0.05; Table 3), which can be supported by lack of differences in blood concentrations of PCO_2 and HCO_3. There was no effect (P>0.05) of additives on rumen traits, papillae number, or absorption area (Table 4).

Table 2 - Effects of additives on performance and intake of Nellore heifers

Trait	Treatment[1]		SEM	P-value
	Control	Additive		
Body weight (kg)				
Initial	245.1	244.2	8.27	0.943
Final	330.7	329.0	7.45	0.872
DMI (kg day^{-1})	6.2	5.7	0.28	0.210
ADG (kg day^{-1})	1.012	0.980	0.09	0.809
G:F	0.163	0.169	0.01	0.698
Carcass traits				
HCW (kg)	173.4	176.1	3.58	0.607
Dressing (kg 100 kg^{-1})	52.0	52.9	0.45	0.151
Ultrasonography traits				
LMA (cm^2)	60.1	62.8	1.29	0.176
BF (mm)	4.5	4.2	0.33	0.017
Rump (cm^2)	7.3	7.2	0.44	0.685

DMI - dry matter intake; ADG - average daily gain; G:F - gain:feed ratio; HCW - hot carcass weight; LMA - *longissimus* muscle area; BF - backfat thickness; Rump - rump fat thickness; DM - dry matter; SEM - standard error of the mean.
[1] Control with no additive on diet; additive with inclusion of a mix of choline, methionine, selenium, and organic zinc supplementation at 1,667, 4,000, 1, and 24.37 mg kg^{-1} of DM diet, respectively.

Table 3 - Effects of additives on blood parameters

Metabolite	Treatment[1]		SEM	P-value
	Control	Additive		
pH	7.38	7.37	0.07	0.675
pCO_2 (mm Hg)	43.21	45.82	7.65	0.156
Bases excess (mmol L^{-1})	1.17	1.38	3.39	0.784
HCO_3^- (mmol L^{-1})	26.08	27.35	4.16	0.204
Lactate (mmol L^{-1})	0.46	0.51	2.98	0.550

SEM - standard error of the mean; DM - dry matter.
[1] Control with no additive on diet; additive with inclusion of a mix of choline, methionine, selenium, and organic zinc supplementation at 1,667, 4,000, 1, and 24.37 mg kg^{-1} of DM diet, respectively.

Table 4 - Effects of additives on rumen papillae of Nellore heifers

Trait	Treatment[1]		SEM	P-value
	Control	Additive		
Rumenitis incidence[2]	0.12	0.16	8.27	0.504
APN (n/cm^2)	64.3	60.3	7.45	0.500
PA (%)[3]	96.4	95.8	0.28	0.213
PMA (cm^2)[3]	26.8	22.7	0.01	0.132

APN - average papillae number per cm^2 of epithelium ruminal; PA - representative participation of the papillae on absorption superficies (%); PMA - papillae mean absorption area (cm^2); SEM - standard error of the mean; DM - dry matter.
[1] Control with no additive on diet; additive with inclusion of a mix of choline, methionine, selenium, and organic zinc supplementation at 1,667, 4,000, 1, and 24.37 mg kg^{-1} of DM diet, respectively.
[2] Following the methodology described by Bigham and McManus (1975).
[3] Following the methodology described by Resende Junior et al. (2006) and measured by images on UTHSCSA Image Tool, free software.

Discussion

An obvious response observed in feedlot cattle fed roughage-free diets with subacute ruminal acidosis and other metabolic problems is reduced feed intake (Owens et al., 1998). In this study, DMI was lower compared with values reported in other studies with roughage inclusion (Turgeon et al., 2010; Contadini et al., 2017). A higher DMI for roughage-containing diets could also be the result of increased saliva flow and ruminal motility (Nagaraja and Lechtenberg, 2007). However, in the present study, no differences were found between the treatments for DMI, which may suggest that heifers must have adapted to the roughage-free diets, mainly because they were fed whole corn grain. As reported by Owens and Soderlund (2006), the unprocessed corn grain has a slower rate and lower extent of ruminal starch digestion when compared with steam-flaked and high-moisture corn. Therefore, whole corn should help to prevent digestive disorders by regulating ruminal starch fermentation and reducing accumulation of organic acids in the rumen. In this sense, the mixture of additives would not be able to improve intake.

No growth responses (ADG, LMA, and HCW) were detected in the finishing beef heifers when metabolic modulators were added to diets containing 850 g kg^{-1} corn (DM basis). The absence of responses in these finishing trials may be explained firstly by the lack of changes in DMI and, secondly, because the basal diet can provide the micro ingredients for increased development of cattle. Titgemeyer and Merchen, 1990 studied amino acid (AA) requirements of finishing beef steers using N retention as the response criterion and reported that absorbable sulfur-containing AA requirement was 14.7 g/day. The authors suggested that this amount would be supplied by diets containing corn as the primary energy source, and no benefits would be obtained with any additional supplementation of AA, indicating that the basal diets in the present study were able to meet the AA, vitamin, and trace mineral requirements of heifers for growth. Similar results were found by Genther and Hansen (2014), who reported no effects on DMI, performance, and gain:fat ratio for Angus crossbred steers fed diet supplemented with Cu, Mn, Se, and Zn at 13.8, 43.9, 0.1, and 56.1 mg kg^{-1} of the diet DM, respectively. However, when the authors evaluated steer performance associated with transport, they reported that the animals which did not receive a mixture of trace minerals tended to lose more weight per day than those which received supplementation. They also reported that the higher Cu and Se status provided protection against stress-induced weight loss during transport (Genther and Hansen, 2014).

More recently, Genther-Schroeder et al. (2016) worked with Angus crossbred steers in the finishing phase fed 88 mg kg^{-1} (diet DM) of a Zn amino-acid complex and reported no effects on DMI, ADG, gain:fat ratio, or carcass traits. Zhou et al. (2017), on the other hand, reported greater DMI and milk yield in peripartum dairy cows fed diet supplemented with methionine (at 0.08 g kg^{-1} of DM), but no effect for choline (at 60 g day^{-1}) supplementation. The authors explained that methionine supplementation improved liver function and reduced metabolic disorders, ultimately improving cow health and production levels.

Real-time ultrasonography is a tool used to predict carcass composition and is an important measure to monitor animal growth and predict the point of slaughter. In the present study, LMA and rump fat thickness did not differ between the treatments, which may be because no changes were found in performance and HCW. However, the lower fat thickness in heifers fed additives may be due to a numerical decrease in DMI in that group. Despite the lack of changes in DMI, heifers fed additives consumed 0.5 kg less DM per day than control heifers, and it is well known that greater adipose tissue deposition depends on the energy intake.

Furthermore, the values were within the standards observed in studies using high-grain diets for finishing beef cattle (Bohrer et al., 2014; Cônsolo et al., 2014, 2015; Genther-Schroeder et al., 2016; Contadini et al., 2017). It is worth noting that the results for rump fat were higher than those for fat thickness, since the deposition of adipose tissue begins from the end towards the middle of the carcass. Similarly, Bohrer et al. (2014) reported no changes in feedlot performance, LMA, or fat thickness with additional supplementation of Zn and Cr at levels above the NRC requirements when animals fed ractopamine. Additionally, Hussein and Berger (1995) offered rumen-protected lysine and methionine to Holstein steers during the growing and finishing phases and reported no effects on HCW, dressing percentage, LMA, or fat thickness. These authors suggested that AA requirements for maximum ADG and HCW by the steers were met from the basal dietary ingredients.

Knowledge of the blood electrolyte balance and its physiology and regulation is relevant, because the animal health depends directly on the normal composition of fluid in body compartments (Freitas et al., 2010). The blood parameters analyzed in this study are known to provide evidence that indicates subacute and metabolic acidosis, but although the heifers were fed a roughage-free diet, their blood parameters did not indicate incidence of metabolic disorders and did not differ between the treatments. In both treatments, blood pH was above 7.35 (7.38 and 7.37 for control and additive treatments, respectively), which, according Owens et al. (1998), is the limit value for the clinical diagnosis of acidosis. Lower concentrations of blood lactate were observed in the present study, regardless of the treatment, compared with those published by Brown et al. (1993), who studied crossed steers with metabolic acidosis. In addition, all blood parameters in both treatments were within the accepted normal range (Kaneko et al., 2008). As previously described, this may be due to the use of whole corn and the period the animals were allowed to adapt to the roughage-free diet, which led to the maintenance of the health of heifers. Additionally, they did not show any blood parameters indicative of disorders, and the treatments did not lead to changes in blood parameters.

Papillae number, representative participation of the papillae on absorption superficies, and papillae mean absorption area are important parameters to increase the absorptive capacity of short-chain fatty acids without excessive accumulation thereof in the rumen, thus reducing the incidence and severity of ruminal acidosis (Melo et al., 2013). Because the diet had no roughage inclusion, it may lead to higher lactate production, rumen pH decline, inflammation or degenerative processes of the ruminal mucosa, rumenitis, and damage to papillae number and absorptive area. Nevertheless, those variables were not compromised by the tested diets, and the additives also did not affect rumen parameters.

Conclusions

Nellore heifers finished with roughage-free diets have no improvement in production traits nor in their rumen health by supplementation with a blend of choline, methionine, selenium, and organic zinc.

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References

Ametaj, B. N.; Koenig, K. M.; Dunn, S. M.; Yang, W. Z.; Zebeli, Q. and Beauchemin, K. A. 2009. Backgrounding and finishing diets are associated with inflammatory responses in feedlot steers. Journal of Animal Science 87:1314-1320. https://doi.org/10.2527/jas.2008-1196

AOAC - Association of Official Analytical Chemistry. 1990. Official methods of analysis. 15th ed. AOAC International, Arlington, VA.

Batistel, F.; Osorio, J. S.; Ferrari, A.; Trevisi, E.; Socha, M. T. and Loor, J. J. 2016. Immunometabolic status during the peripartum period is enhanced with supplemental Zn, Mn, and Cu from amino acid complexes and Co from Co glucoheptonate. PLoS ONE 11:e0155804. https://doi.org/10.1371/journal.pone.0155804

Bigham, M. L. and McManus, W. R. 1975. Whole wheat grain feeding of lambs: Effects of roughage and wheat grain mixtures. Australian Journal of Agricultural Research 26:1053-1062. https://doi.org/10.1071/AR9751053

Bohrer, B. M.; Edenburn, B. M.; Boler, D. D.; Dilger, A. C. and Felix, T. L. 2014. Effect of feeding ractopamine hydrochloride (Optaflexx) with or without supplemental zinc and chromium propionate on growth performance, carcass characteristics, and meat quality of finishing steers. Journal of Animal Science 92:3988-3996. https://doi.org/10.2527/jas.2014-7824

Britton, R. A. and Stock, R. A. 1987. Acidosis, rate of starch digestion and intake. Oklahoma Agricultural Experiment Station, Stillwater. p.125-137.

Brown, M. S.; Krehbiel, C. R.; Galyean, M. L.; Remmenga, M. D.; Peters, J. P.; Hibbard, B. and Moseley, W. M. 1993. Evaluation of models of acute and subacute acidosis on dry matter intake, ruminal fermentation, blood chemistry, and endocrine profiles of beef steers. Journal of Animal Science 78:3155-3168.

Cônsolo, N. R. B.; Gardinal, R.; Gandra, J. R.; de Freitas Junior, J. E.; Rennó, F. P.; Santana, M. H. A.; Pflanzer Junior, S. B. and Pereira, A. S. C. 2014. High levels of whole raw soybean in diets for Nellore bulls in feedlot: Effect on growth performance, carcass traits and meat quality. Journal of Animal Physiology and Animal Nutrition 99:201-209. https://doi.org/10.1111/jpn.12237

Cônsolo, N. R.; Rodriguez, F. D.; Goulart, R. S.; Frasseto, M. O.; Ferrari, V. B. and Silva, L. F. P. 2015. Zilpaterol hydrochloride improves feed efficiency and changes body composition in nonimplanted Nellore heifers. Journal of Animal Science 93:4948-4955. https://doi.org/10.2527/jas.2015-9291

Contadini, M. A.; Ferreira, F. A.; Corte, R. R. S.; Antonelo, D. S.; Gómez, J. F. M. and Luz e Silva, S. 2017. Roughage levels impact on performance and carcass traits of finishing Nellore cattle fed whole corn grain diets. Tropical Animal Health and Production 49:1709-1713. https://doi.org/10.1007/s11250-017-1381-x

Emmanuel, D. G. V.; Dunn, S. M. and Ametaj, B. N. 2008. Feeding high proportions of barley grain stimulates an inflammatory response in dairy cows. Journal of Dairy Science 91:606-614. https://doi.org/10.3168/jds.2007-0256

Freitas, M. D.; Ferreira, M. G.; Ferreira, P. M.; Carvalho, A. U.; Lage, A. P.; Heinemann, M. B. and Facury Filho, E. J. 2010. Equilíbrio eletrolítico e ácido-base em bovinos. Ciência Rural 40:2608-2615. https://doi.org/10.1590/S0103-84782010001200028

Genther-Schroeder, O. N.; Branine, M. E. and Hansen, S. L. 2016. The influence of supplemental Zn-amino acid complex and ractopamine hydrochloride feeding duration on growth performance and carcass characteristics of finishing beef cattle. Journal of Animal Science 94:4338-4345. https://doi.org/10.2527/jas.2015-0159

Genther, O. N. and Hansen, S. L. 2014. Effect of dietary trace mineral supplementation and a multi-element trace mineral injection on shipping response and growth performance of beef cattle. Journal of Animal Science 92:2522-2530. https://doi.org/10.2527/jas.2013-7426

Hussein, H. S. and Berger, L. L. 1995. Effects of feed intake and dietary level of wet corn gluten feed on feedlot performance, digestibility of nutrients, and carcass characteristics of growing-finishing beef heifers. Journal of Animal Science 73:3246-3252.

Kaneko, J.; Harvey, J. and Brus, M. 2008. Clinical biochemistry of domestic animal. 6th ed. USA Elsevier, California.

Kleen, J. L.; Hooijer, G. A.; Rehage, J. and Noordhuizen, J. P. T. M. 2003. Subacute ruminal acidosis (SASA): a review. Journal of Veterinary Medicine 50:406-414.

Melo, L. Q.; Costa, S. F.; Lopes, F.; Guerreiro, M. C.; Armentano, L. E. and Pereira, M. N. 2013. Rumen morphometrics and the effect of digesta pH and volume on volatile fatty acid absorption. Journal of Animal Science 91:1775-1783. https://doi.org/10.2527/jas.2011-4999

Nagaraja, T. G. and Lechtenberg, K. F. 2007. Liver abscesses in feedlot cattle. Veterinary Clinics of North America: Food Animal Practice 23:351-369. https://doi.org/10.1016/j.cvfa.2007.05.002

NRC - National Research Council. 2001. Nutrient requirements of laboratory animals. 7th ed. National Academy Press, Washington, DC.

Oliveira, C. A. and Millen, D. D. 2014. Survey of the nutritional recommendations and management practices adopted by feedlot cattle nutritionists in Brazil. Animal Feed Science and Technology 197:64-75. https://doi.org/10.1016/j.anifeedsci.2014.08.010

Owens, F. N.; Secrist, D. S.; Hill, W. J. and Gill, D. R. 1998. Acidosis in cattle: A review. Journal of Animal Science 76:275-286.

Owens, F. and Soderlund, S. 2006. Ruminal and postruminal starch digestion by cattle. p.116-128. In: Proceeding of the Cattle Grain Processing Symposium. Johnston, Iowa.

Prasad, A. 2008. Zinc in human health: Effect of zinc on immune cells. Molecular Medicine 14:353-357.

Resende Junior, J. C.; Alonso, L. S.; Pereira, M. N.; Roca, M. G.; Duboc, M. V.; Oliveira, E. C. and Melo, L. Q. 2006. Effect of the feeding pattern on rumen wall morphology of cows and sheep. Brazilian Journal of Veterinary Research and Animal Science 43:526-536.

Titgemeyer, E. C. and Merchen, N. R. 1990. Sulfur-containing amino acid requirement of rapidly growing steers. Journal of Animal Science 68:2075-2083. https://doi.org/10.2527/1990.6872075x

Turgeon, O. A.; Szasz, J. I.; Koers, W. C.; Davis, M. S. and Vander Pol, K. J. 2010. Manipulating grain processing method and roughage level to improve feed efficiency in feedlot cattle. Journal of Animal Science 88:284-295. https://doi.org/10.2527/jas.2009-1859

Van Soest, P. J.; Robertson, J. B. and Lewis, B. A. 1991. Methods of dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74:3583-3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Werling, D.; Sutter, F.; Arnold, M.; Kun, G.; Tooten, P. C. J.; Gruys, E.; Kreuzer, M. and Langhans, W. 1996. Characterisation of the acute phase response of heifers to a prolonged low dose infusion of lipopolysaccharide. Research in Veterinary Science 61:252-257. https://doi.org/10.1016/S0034-5288(96)90073-9

Zhou, Z.; Trevisi, E.; Luchini, D. N. and Loor, J. J. 2017. Differences in liver functionality indexes in peripartal dairy cows fed rumen-protected methionine or choline are associated with performance, oxidative stress status, and plasma amino acid profiles. Journal of Dairy Science 100:6720-6732. https://doi.org/10.3168/jds.2016-12299