Evaluation of active dried yeast in the diets of feedlot steers. II. Effects on rumen pH and liver health of feedlot steers¹

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ABSTRACT: The objective of this trial was to determine the benefits of supplementing active dried yeast (ADY; 3×10^{10} CFU/d of *Saccharomyces cerevisiae*) in diets of growing and finishing steers on ruminal pH and liver health, and evaluate the relationship of these variables with performance traits. Growing beef steers ($n = 120$) were blocked by weight (i.e., heavy and light) and allocated to 1 of 4 pens in an automated feed intake monitoring system. Steers were fed either control (CON; no ADY) or ADY supplemented in 4 sequential diets: grower diet from days 0 to 70, 2 step up diets (STEP1 and STEP2) for 7 d each, and finishing diet from days 85 to 164. Indwelling rumen boli were administered to monitor rumen pH during days 56 to 106 during the dietary transition. An exchange of pen assignment, within block, occurred on day 70 resulting in 4 final treatment (TRT) assignments: steers fed CON before and after the exchange (CC; $n = 30$), steers fed CON before and ADY after the exchange (CY; $n = 30$), steers fed ADY before and CON after the exchange (YC; $n = 30$), and steers fed ADY (YY; $n = 30$). Ruminal parameters were analyzed as a randomized complete block design with repeated measures of day, diet and TRT as fixed effects, and

block as random effects, using 2 approaches: preliminary analysis of the means or drift analysis (DA; units change from basal values over time). Ruminal pH duration (DUR) below 6.0 ($P = 0.05$) and 5.8 ($P = 0.05$) was greater for CY steers than CC steers. Acidosis bout prevalence (pH < 5.6 for 180 consecutive minutes; $P < 0.01$) and bout DUR ($P = 0.05$) were greater for CY than other TRT groups. The DA indicated that the ruminal pH variables range, variance, and amplitude of steers in the YC group drifted further from basal pH values than CY and YY steers during the dietary transition ($P \leq 0.02$), indicating that removing ADY during the dietary transition was not favorable, but including ADY may reduce ruminal fluctuation. Steers with fewer days experiencing bouts (DEB) had numerically greater ADG ($P = 0.11$) and tended to have greater G:F ($P = 0.06$). Liver abscess severity negatively affected ADG ($P = 0.04$). However, liver abscess severity was not affected by DEB ($P = 0.90$). There is evidence to suggest that the addition of the specific ADY strain in the diets of beef cattle during the dietary transition may aid in ruminal stabilization, but our study did not find evidence that acidosis bouts were related to abscess prevalence or severity.

Key words: abscess, acidosis, beef cattle, feed additives, yeast

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INTRODUCTION

Increased scrutiny over feeding low-dose antimicrobial feed additives for growth promotion in livestock has prompted greater research discovery of antibiotic alternatives. Active dried yeast (ADY), specifically *Saccharomyces cerevisiae*, when added to the diets of ruminants seems to moderate ruminal pH, improve digestibility, and increase performance in intensive management systems. Research results of ADY inclusion to dairy cattle diets seem promising (Humer et al., 2018), but its effectiveness in feedlot cattle has not been as well established. A meta-analysis of live *S. cerevisiae* supplementation in dairy cattle indicated there are subtle effects on organic matter digestibility, rumen pH, and fermentation end-products (Desnoyers et al., 2009). Magrin et al. (2018) added 5 g/d of a strain of *S. cerevisiae* to high-concentrate finishing diets fed to Charolais bulls and reported that although average daily gain (ADG) was not affected by the supplementation, ruminal acetate and butyrate concentrations, and acetate-to-propionate ratio were increased and rumen wall hyper-keratinization was reduced for yeast-supplemented bulls.

Practical areas in which ADY supplementation may be useful for diets of growing beef cattle include the high-risk transition from low to high concentrate diets where cattle may experience prolonged or more frequent bouts of ruminal acidosis (Nagaraja and Titgemeyer, 2007). It has been indicated that animals that experience a bout of acidosis may be more susceptible to future challenges (Dohme et al., 2008). Chronically low ruminal pH has been implicated in decreased efficiency of feeding and growth performance and linked to liver abscesses (Brink et al., 1990; Owens et al., 1998; Nagaraja and Lechtenberg, 2007). Supplementation of ADY may modulate ruminal pH during dietary transition leading to subtle changes in measurable production traits such as ADG and G:F.

Our companion paper evaluates the effect of adding ADY in the diets of feedlot steers on feedlot performance and carcass characteristics and will be referenced later. The objectives of this experiment were to determine the benefits of adding ADY to the diets of growing and finishing steers on 1) the stabilization of ruminal pH through the transition period and 2) the tissue quality and animal health impacts on the liver and lungs.

MATERIALS AND METHODS

Animal Description and Care

All animals were cared for under the Institutional Animal Care and Use Committee of Texas A&M University approved Animal Use Protocol (number 2016-0269). One hundred twenty steers ($\frac{3}{4}$ *Bos taurus* $\times$ $\frac{1}{4}$ *Bos indicus*, BW = 254 ± 40 kg, and age = 246 ± 32 d) born and raised at the McGregor AgriLife Research center, McGregor, TX, were randomly selected from approximately 300 contemporaries, 30 d after weaning. Steers were assigned an RFID tag (Allflex USA, Inc., Dallas, TX) and adapted to the GrowSafe feeding system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) for 21 d consuming a backgrounding diet before the commencement of the 164-d trial. Facilities included 4 pens, each equipped with 4 GrowSafe feed bunks ($n = 16$ feed bunks). Upon day 21, steers were blocked by BW according to the median BW resulting in 2 pens of light and 2 pens of heavy BW steers (221 ± 26 and 288 ± 16 kg, respectively). Within blocks, steers were randomly assigned to 1 of 2 pens. Animals in the light and heavy blocks weighed 253 ± 32 and 322 ± 21 kg, respectively, on day 0.

Diets and Feeding

Steers were fed 4 diets over the course of the trial (Table 1) in 2 phases: growing (days 0 to 70) and finishing (days 71 to 164). Chemical analysis of the diet was performed by Cumberland Valley Analytical Services (Waynesboro, PA) on composite batch samples, obtained weekly, within diets. The physically effective NDF (peNDF) was determined by Penn State Particle Size separator and multiplying the proportion of particles > 4 mm by the proportion of NDF in the diet. The Large Ruminant Nutrition System (LRNS; <http://www.nutritionmodels.com/lrns.html>, accessed on January 21, 2018; Tedeschi and Fox, 2018) was used to formulate the diets using the following ingredients: cracked corn, dried distiller's grain, alfalfa hay (theoretical chop length 15 mm), molasses, and mineral supplements (Table 1).

The grower diet (net energy for growth [NE_g] concentration of 1.0 Mcal/kg) was fed for 70 d to yield a mean BW of 365 kg between blocks at the time of dietary transition. The first and second transition diets (STEP1 and STEP2, respectively) were fed for 7 d each (days 71 to 85) and the

Table 1. Ingredient and chemical composition of diets fed to growing steers with or without the inclusion of active dried yeast

Items ¹	Diets ²							
	Grower		STEP1		STEP2		Finisher	
	CON	ADY	CON	ADY	CON	ADY	CON	ADY
% of diet, DM								
Alfalfa hay	30	30	25	25	20	20	15	15
Cracked corn	40	40	50	50	60	60	70	70
Dried distiller's grain	20	17	15.5	12.5	10.5	7.5	5.5	2.5
Molasses	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Mineral ³	2.5	2.5	1	1	1	1	1	1
Limestone	0	0	1	1	1	1	1	1
Urea	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Premix ⁴		3		3		3		3
DM, % of diet	82.7		82.5		82.3		82.2	
CP	16.3		14.9		13.3		11.8	
Soluble protein, % CP	21.4		20.7		19.9		19.1	
NDF	30.1		27.4		24.5		21.7	
ADF	20.2		17.6		15.0		12.4	
Lignin	4.4		3.8		3.3		2.7	
Crude fat	4.1		3.9		3.7		3.5	
Sugar	4.9		4.8		4.7		4.6	
Starch	29.0		35.8		42.5		49.2	
Ash	7.2		6.1		5.5		4.9	
Calcium	0.7		0.8		0.8		0.7	
Phosphorus	0.6		0.4		0.4		0.4	
peNDF ⁵	16		14		12		10	
TDN	76		78		80		82	
NEm, Mcal/kg	1.57		1.63		1.68		1.74	
NEg, Mcal/kg	1.00		1.05		1.10		1.14	

¹Items are feed ingredients and chemical composition of diets (DM basis) evaluated by Cumberland Valley Analytical Services (Hagerstown, MD). Alfalfa hay theoretical chop length = 15 mm.

²Diets are grower (fed days 1 to 70); STEP1 = transition step 1 (fed days 71 to 77); STEP2 = transition step 2 (fed days 78 to 85); finisher (fed days 86 to 164); CON = no active dried yeast supplement; ADY = control diet + 1.5 g/d of an active dried yeast (3×10^{10} CFU per day).

³Mineral: Proprietary blend of 17% calcium, 7% phosphorus, 2% sodium chloride, 1.5% magnesium, 850 ppm copper, 23 ppm selenium, 300,000 IU/lb vitamin A, 20,000 IU/lb vitamin D, 200 IU/lb vitamin E.

⁴Premix was included in 3% of the diet where DDG was the carrier ingredient. The additive was Vistacell (ABVista, Marlborough, UK) and its amount (g) was based on the average of the inner quartile range of the previous week's DMI to allow for feed delivery containing 1.5 g of Vistacell per subject each day.

⁵peNDF (physically effective NDF = proportion of particles larger than 4 mm $\times$ NDF proportion of the diet).

finishing diet (NEg of 1.14 Mcal/kg) was fed from days 86 to 164 to yield a final mean BW of 500 kg. Feed delivery occurred at approximately 0800 and 1700 h, and feed calls allowed for 5% residual orts for ad libitum intake of the diet.

Treatment Assignment

Pens, within a weight block, were randomly assigned to receive either control (CON) or diets supplemented daily with approximately 1.5 g/hd (3×10^{10} CFU/d) of ADY, *S. cerevisiae* (Vistacell, AB Vista, Marlborough, UK) per the label recommended dosage for growing beef cattle. To ensure proper daily dosage of ADY under an ad

libitum feeding scenario, individual intake was downloaded weekly from the GrowSafe Feed Intake System, and the interquartile mean of DMI between blocks was used to formulate a fresh premix to allocate approximately 1.5 g/d of ADY per steer throughout the trial. Treatment was the sequence of ADY supplementation. On day 70, at the conclusion of the GROW phase, 15 steers from each pen were randomly exchanged within their block to the opposite pen to proceed through the dietary transition (days 71 to 164) with or without ADY. This exchange yielded 4 treatment assignments: steers fed CON before and after the exchange (CC), steers fed CON before and ADY after the exchange (CY), steers fed ADY before

and CON after the exchange (YC), and steers fed ADY before and after the exchange (YY).

Data Collection

On day 56, steers ($n = 64$) within each block and TRT were randomly selected to receive a wireless, indwelling rumen pH, temperature, and activity bolus (smaXtec Premium Bolus, smaXtec Animal Care GmbH, Graz, Austria). Bolus ID was assigned to each subject's visual ID tag, calibrated using a buffer solution of pH 7 for a minimum of 5 min, and inserted orally using the manufacturer provided balling gun. Two extra boluses were provided in case of bolus failure on the day of calibration or animal removal from the trial. Between days 56 and 70, 2 steers from the heavy YY treatment group, one of which had previously received a bolus, were removed from the trial due to respiratory illness; therefore, on day 70, 2 steers from the heavy YY treatment group were randomly chosen to receive a bolus later than the original subset in the case that another steer from that group was removed for respiratory disease (total number of steers with a bolus = 65). The bolus produced an average pH reading on 10-min intervals, automatically transmitting data when in range of the base station radio system or repeaters. Individual steer data were downloaded from smaXtec messenger for the selected days during the dietary transition. The analysis was limited to 50 d per the manufacturer's guarantee (trial days 56 to 106) beyond which it is subject to drift. Daily summary statistics were computed for each steer: pH minimum, mean, maximum, range, variance, and the accrued variance over time (cumulative variance). Bouts of acidosis were considered to be frames of bolus readings displaying 180 consecutive minutes below a pH of 5.6. Bouts were summarized by prevalence within a treatment group and the mean duration (DUR) of those bouts.

Animal growth, feeding performance, and carcass data collection are described in our companion paper. Postmortem data were collected at Kane Beef (Corpus Christi, TX) where liver and lung scoring was conducted after evisceration by trained personnel from Texas A&M Kingsville and Texas A&M AgriLife Research. Liver scores were assigned based on a modification of the Elanco Animal Health classification method (Brown et al., 1975), where 0 is no abscess, A is 1 or 2 small to large abscesses and inactive scars, and A+ is multiple large abscesses often involving collateral tissue. The tissue health of lungs was scored by visual

appraisal as in Schneider et al. (2009), where 0 is normal, no lesions observed, 1 is affected area less than 1 anterior ventral (AV) lobe and less than 5% lung volume; 2 is adhesions, affected area, or both in more than 1 AV lobe and between 5% and 10% of lung volume; 3 is adhesions affecting more than 1 AV lobe, and between 10% and 15% lung volume affected, a small portion of lung missing, or a combination of these; 4 is more than 15% missing lung volume; and 5 is active bronchial lymph nodes.

Calculations

The area under the curve (AUC) and DUR below pH thresholds were calculated with an R script, using the *rootSolve* and *MESS* packages (R Core Team, 2017). For accurate calculation of the AUC, the period was subdivided into 2 halves to facilitate the spline interpolation and the integration of the area by the *auc* function of the *MESS* package. When the interpolation failed, the sub-period was further split into 2 halves. This direct recursion was done until the period was successfully interpolated and integrated, or until no root was identified in the period. Roots were identified by a sign change in the y -variate. Then, the areas of the periods were summed up to compute the AUC of the whole period. The DUR is the length of time the pH was below the threshold. The unit for AUC and DUR is h. All AUC and DUR variables were summarized by day (daily means) and diets (grower, STEP1, STEP2, or finisher).

Statistical Analyses

Three steers in the heavy block (2 from the YY group: one of which contained a bolus and one from the YC group) were removed from the analysis due to respiratory illness and, therefore, $n = 65$ for the rumen bolus variable analysis and $n = 117$ for feeding performance and feeding behavior. Due to a sorting error, the CY group contained one additional steer intended to be in the CC group. However, this did not exceed the recommended number of head per bunk due to the removal of other animals.

Preliminary rumen pH analysis. The primary drawback of Balaam's design is that it inflates the variance of an estimate of the treatment effect which reduces statistical power for detecting more subtle effects (Mori and Kano, 2015). Rumen pH data between subjects are known to be highly variable and, therefore, an additional analysis was

pursued. Because steers were fed different diets and the re-sort occurred during this window of time, a randomized complete block design (RCBD) with repeated measures design analysis was deemed appropriate. Rumen bolus data were summarized within each steer by diet. The variables pH variation, AUC, and DUR displayed a Poisson distribution, and the nonparametric procedure (e.g., PROC RANK) was used within diet to produce a Gaussian distribution for parametric analysis (Mitchell et al., 1994; Nariñ and Aygün, 2017). Respective means and ranks were reported. Rumen variables were analyzed with the MIXED procedure of SAS (SAS Institute Inc., Cary, NC) as an RCBD with diet as a repeated measure within animal subject resulting in the final model:

$$Y_{ijk} = \mu + \text{TRT}_i + \text{Diet}_j + \text{TRT}_i \times \text{Diet}_j + b_k + e_{ijkl},$$

where Y is the variable of interest (rumen pH variables: minimum pH, maximum pH, Mean pH, variance, cumulative variance, AUC and DUR < pH 6, 5.8, 5.6, and 5.4, and bout duration), i is the treatment (CC, CY, YC, and YY), j is the Diet (grower, STEP1, STEP2, and finisher), k is the weight block (HVY or LT), μ and TRT_i are fixed parameters such that the mean for the i th treatment is $\mu_i = \mu + T_i$, Diet_j is the fixed effect associated with the j th Diet, b_k is the random effect associated with the k th block, and e_{ijkl} is the random error associated with the experimental unit l , consuming Diet k , in block j that received treatment i .

An autoregressive variance-(co)variance structure was chosen for the repeated measures design to account for the potential of greater correlation between measurements taken closer together than those that were further apart. Acidosis bout was defined as 180 consecutive minutes in which ruminal pH was below 5.6, and prevalence was treated as a categorical variable and analyzed using the χ^2 test of probability using the strata of the block effect in the FREQ procedure of SAS (SAS Institute Inc., Cary, NC), observing the likelihood ratio statistic for statistical significance. Acidosis bout duration analysis included only those steers who were experiencing bouts.

Rumen pH variable drift analysis. More sensitive analysis of rumen variables involved a similar repeated measures design in which the days consuming the GROWER diet served to establish baseline values for each subject before the resort and dietary transition. Deviations from each subject's basal values were then computed for each

remaining day. In the drift analysis, *days* refers to the days of the guaranteed lifespan of the bolus (days 1 to 50), where days 1 to 14 correspond to the GROWER diet, days 15 to 21 correspond to the STEP1 diet, days 22 to 28 correspond to the STEP2 diet, and days 29 to 50 correspond to the finisher diet. Two new variables are introduced here to aid in the characterization of the wave of the diurnal fluctuation of ruminal pH: the upper amplitude (**Up_amp**) and the lower amplitude (**Low_amp**) as amplitude may not be evenly distributed across the daily mean pH. The amplitude variables were calculated by measuring the distance from the upper and lower peak to the mean within each subject (i.e., animal) per day. The baseline variables were analyzed similarly to the feeding trial analysis in which TRT was fixed and the block was random. The drift data were normally distributed, and the following model was analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC), and henceforth known as the *drift analysis*, modeled after concepts by Denwood et al. (2018):

$$Y_{ijkl} = u + \text{TRT}_i + \text{DAY}_j + \text{TRT}_i \times \text{DAY}_j + b_k + e_{ijkl},$$

where Y is the variable of interest (rumen pH variable change from baseline: Minimum pH (**MinΔ**), Maximum pH (**MaxΔ**), Mean pH (**MeanΔ**), variance (**VarΔ**), range (**RangeΔ**), Up_amp (**Up_ampΔ**), Low_amp (**Low_ampΔ**), i is the treatment (CC, CY, YC, and YY), j is the DAY (15, 16 ..., 50), k is the weight block (HVY or LT), μ and TRT_i are fixed parameters such that the mean for the i th treatment is $\mu_i = \mu + T_i$, Diet_j is the fixed effect associated with the j th Diet, b_k is the random effect associated with the k th block, and e_{ijkl} is the random error associated with the experimental unit l , consuming Diet k , in block j that received treatment i .

Similarly, the first-order auto-regressive variance-(co)variance structure was chosen for the time-series analysis. In the drift analysis, two steers were removed for receiving their boluses late (on day 70) and therefore failed to establish reliable baseline values; thus $n = 63$.

Liver and lung scores. Ordinal data (liver abscess prevalence and severity and lung score) were analyzed using the χ^2 test of probability using the strata of the block effect in the FREQ procedure of SAS (SAS Institute Inc., Cary, NC), observing the Mantel-Haenszel statistic. The distribution of count data is provided for reference and was discussed as significant at $P \leq 0.05$ and tendencies discussed at $P \leq 0.10$.

RESULTS AND DISCUSSION

Rumen pH Characteristics

Preliminary analysis. In the preliminary repeated measures analysis of rumen pH variables, one interaction of treatment and diet was observed for maximum pH ($P < 0.05$). Figure 1 shows the interaction plot over the course of the transition diets. After steers were exchanged, there was a brief divergence ($P < 0.05$) of maximum daily pH that appeared between the CON (CC and YC) and ADY-fed (CY and YY) steers during the STEP1 diet before reconvening during the STEP2 and finisher diet. Figure 1 illustrates that the maximum daily pH achieved by steers not consuming yeast (i.e., CON treatments: CC and CY) increases as dietary energy increases compared with those steers consuming yeast (i.e., ADY treatments: YY and YC) that do not change over the dietary transition until they have reached the finisher diet. It was expected that steers of similar BW have similar buffering capacity and the biological significance of a difference in maximum pH is complex and difficult to interpret. One plausible reason could be due to differences in digestibility, and VFA concentration in the rumen of ADY fed steers identified in a meta-analysis by Desnoyers

et al. (2009) which may reduce the maximum pH reached in a day. Furthermore, Magrin et al. (2018) indicated that yeast-supplemented bulls had greater concentrations of acetate and butyrate, thus reducing the relative proportion of lactate in the rumen. One or more factors may have contributed to this separation of means. There was a tendency for the interaction of treatment and diet on acidosis bout prevalence ($P = 0.09$). The distribution of bout prevalence is shown in Figure 2, and it shows that while the prevalence amongst the CC group was steady throughout the transition, the bout prevalence increased for the CY group through the finisher diet, but was greatest during the STEP2 diet for YC and YY groups. Figure 2 also showed that steers supplemented ADY during the GROWER diet phase (i.e., groups YY and YC) had fewer bouts of acidosis than those that were not supplemented at this dietary phase.

Table 2 has the main effects of treatment on ruminal activity. The average daily minimum pH was not affected by treatment (5.39, 5.27, 5.36, and 5.34 for CC, CY, YC, and YY, respectively; $P = 0.45$). The average daily mean pH was affected by treatment in which the CC and YC groups had the greatest average pH and were different from the CY group, with the YY group being intermediate and not different (6.26 and 6.23 vs. 6.09 and 6.19,

Figure 1. Interaction of treatment and diet on the average daily maximum ruminal pH achieved by growing steers. Values are least squares means and (*) indicate estimates that differ at $P < 0.05$. Exchange indicates the event of steers being exchanged within block to different pens to proceed through the dietary transition with the treatments as follows: CC = control, no ADY fed throughout the transition; YY = yeast fed throughout the entire transition; CY = control fed during the grower diet and transitioned onto diets containing yeast; YC = yeast fed during the grower diet and transitioned onto diets without yeast. Diets are grower = growing diet (30% roughage); STEP1 = transition 1 diet (25% roughage); STEP2 = transition 2 diet (20% roughage); finisher = finisher diet (15% roughage).

Figure 2. Distribution of growing steers experiencing bouts of acidosis during dietary transition with or without an active dried yeast. Treatments are CC = control, no ADY fed throughout the transition; YY = yeast fed throughout the entire transition; CY = control fed during the grower diet and transitioned onto diets containing yeast; YC = yeast fed during the grower diet and transitioned onto diets without yeast.

respectively; $P = 0.05$). This is likely a result of the lower maximums observed for the CY and YY groups over the dietary transition mentioned earlier ($P < 0.05$; Figure 1). Neither average daily range, variance, nor cumulative variance was affected by treatment groups according to their ranks in the population ($P \geq 0.72$, respectively).

There was a tendency for the AUC pH = 6.0 to be different across treatments, being the greatest for the CY group and different from CC, YC, and YY (31.6 vs. 18.1, 19.9, and 19.7 min, respectively; $P = 0.10$). However, treatments did not affect the AUC pH = 5.8, 5.6, or 5.4. Treatments affected the DUR pH < 6.0 ($P = 0.05$) and pH < 5.8 ($P = 0.05$) where steers in the CY group spent more time below the thresholds than those in the CC group while the YC and YY groups were intermediate. Interestingly, DUR of pH < 5.6 was not different between treatment groups ($P = 0.22$), but acidosis bout prevalence was different ($P < 0.01$). It should be noted here that DUR below a threshold on a given day does not indicate that the minutes are consecutive but rather DUR is simply the summation of minutes. A greater percentage of steers in the CY group experienced bouts of acidosis each day than CC, YC, and YY groups (12.4% vs. 7.9%, 8.3%, and 8.8% of subjects/d, respectively; $P < 0.01$). Mean bout duration of pH below 5.6 was different between treatment groups CY and

YC (352 vs. 260 min/bout), but CC and YY were intermediate (327 and 346 min/bout, respectively; $P = 0.05$). The estimates for mean bout duration are larger than DUR pH < 5.6 because bout duration only included those steers experiencing bouts vs. DUR < pH 5.6 includes all 63 steers fit with a bolus including steers which may have never crossed the pH threshold.

Table 3 shows the main effects of diet on rumen pH variables. It was expected that as the percentage of concentrate increased in the diet, the minimum daily pH achieved would decrease. Although there was an effect of diet on minimum daily pH, only STEP1 and finisher were different (5.40 vs. 5.24, respectively) in which grower and STEP2 were intermediate and not different from the finisher diet (5.37 and 5.34, respectively; $P < 0.01$). As expected, the daily mean pH was greater for grower than STEP1, STEP2, and finisher (6.22 vs. 6.19, 6.18, and 6.19, respectively; $P = 0.03$). The daily range in pH was greatest on the finisher diet vs. the grower, STEP1, and STEP2 diets (1.91 vs. 1.50, 1.49, and 1.64 pH units, respectively; $P < 0.01$). Although the daily pH variance and cumulative pH variance numerically increased over the transition, they were not different between diets according to their ranks in the population ($P = 0.99$ and $P = 0.62$, respectively). There was no effect of diet on AUC or DUR variables likely due to between-subject variation

Table 2. The effects of feed treatment regimen on rumen characteristics of growing steers during the transition from a grower diet to a finishing diet

Items ¹	Treatment ²				SEM	P-value
	CC	CY	YC	YY		
Ruminal pH						
Minimum	5.39	5.27	5.36	5.34	0.087	0.45
Maximum	7.00	6.89	7.04	6.96	0.063	0.20
Mean	6.26 ^a	6.09 ^b	6.23 ^a	6.19 ^{ab}	0.061	0.06
Range	1.61	1.63	1.68	1.62	0.063	0.84
Variance	0.095	0.101	0.105	0.099	0.013	
Rank	31.7	33.6	34.3	32.0	5.10	0.95
Cumulative variance	1.62	1.75	1.83	1.70	0.251	
Rank	28.8	35.3	33.6	32.8	5.69	0.72
AUC pH 6.0	18.1	31.6	19.9	19.7	8.14	
Rank	26.8	39.4	32.3	32.2	5.52	0.10
DUR < 6.0, min/d	316.4	533.8	387.5	367.8	74.6	
Rank	26.5 ^b	40.6 ^a	31.7 ^{ab}	31.7 ^{ab}	4.81	0.05
AUC pH 5.8	8.27	14.4	6.91	8.38	5.69	
Rank	27.8	39.0	32.0	32.1	5.97	0.15
DUR < 5.8, min/d	158.4	277.2	162.1	166.4	64.2	
Rank	26.9 ^b	40.5 ^a	31.7 ^{ab}	31.5 ^{ab}	5.72	0.05
AUC pH 5.6	3.56	6.25	2.52	3.51	3.18	
Rank	28.7	37.4	32.4	32.5	5.73	0.33
DUR < 5.6, min/d	75.9	119	63.1	75.2	42.83	
Rank	28.6	38.6	31.9	31.8	5.98	0.22
AUC pH 5.4	1.43	2.88	0.795	1.31	1.64	
Rank	29.3	35.7	32.1	33.9	4.93	0.50
DUR < 5.4, min/d	37.9	53.1	22.9	35.6	25.2	
Rank	29.6	36.1	31.7	33.7	5.43	0.52
Acidosis bouts ³						
Prevalence, %/d	7.9 ^b	12.4 ^a	8.3 ^b	8.8 ^b		< 0.01
DUR, min/bout	327 ^{ab}	352 ^a	260 ^b	346 ^{ab}	36.1	0.05

^{a,b}Least squares means within a row with different superscripts differ at $P < 0.06$.

¹Variables AUC = area under the curve (dimensionless) and DUR = duration (min/d), under the given pH threshold. Rank = the relative position of a data point in the given data set. Bout = an instance of a subject having ruminal pH < 5.6 for 180 consecutive minutes.

²Treatments are CC = control, no ADY fed throughout the transition; YY = yeast fed throughout the entire transition; CY = control fed during the grower diet and transitioned onto diets containing yeast; YC = yeast fed during the grower diet and transitioned onto diets without yeast.

³Bout prevalence was analyzed by the χ^2 analysis. Percentage of subjects displaying bouts are reported within TRT.

($P \geq 0.92$). As expected, acidosis bout prevalence increased over the transition where the number of steers experiencing bouts increased by nearly twice from grower to STEP1 (3.91% to 7.03%/d) and tripled by STEP2 and finisher (12.31% and 12.24%/d, respectively; $P < 0.01$). The bout duration, however, was not different between diets ($P = 0.27$).

As mentioned earlier, the between-subject variation in the sample population for rumen pH variables was greater than expected, but this variation concurs with other research (Dohme et al., 2008). The summary statistics of rumen variables for young growing beef calves (Table 4), on a single diet (GROWER), highlight this matter of between-subject variation and offer valuable insight for future research planning. When considering the coefficient of variation (CV) between subjects for daily pH

variation, AUC and DUR variables, acquiring the appropriate sensitivity to detect subtle differences is largely unattainable due to the required number of necessary replicates and the relative expense of the bolus technology. It also reiterates the necessity of using a repeated measures analysis and, regarding data distribution (in the case of thresholds for AUC and DUR, Poisson), the need for data transformation for meaningful comparison without violating parametric analysis assumptions. To account for non-Gaussian distributed data, some experiments reporting significant differences in AUC have done so by blocking experimental animals based on their pretrial tendency to spend time below a pH threshold (Chung et al., 2011). However, this approach may only apply to cannulated animals and the use of reprogrammable boluses. Other researchers have

Table 3. The effect of diet on rumen characteristics of growing steers during transition from a grower diet to a finishing diet

Items ¹	Diets ²				SEM	P-value
	Grower	STEP1	STEP2	Finisher		
Ruminal pH						
Minimum	5.37 ^{ab}	5.40 ^a	5.34 ^{ab}	5.24 ^b	0.075	<0.01
Maximum	6.87 ^b	6.89 ^b	6.98 ^{ab}	7.14 ^a	0.049	<0.01
Mean	6.22 ^a	6.19 ^b	6.18 ^b	6.19 ^b	0.053	0.03
Range	1.50 ^b	1.49 ^b	1.64 ^b	1.91 ^a	0.044	<0.01
Variance	0.058	0.089	0.121	0.120	0.012	
Rank	33.0	33.1	33.1	32.4	4.32	0.99
Cumulative variance	0.548	1.00	1.66	3.69	0.269	
Rank	33.0	33.0	33.1	31.4	6.68	0.62
AUC pH 6.0	17.5	12.2	14.7	44.9	6.85	
Rank	33.0	32.9	32.9	31.9	4.76	0.95
DUR < 6.0, min/d	334	389	443	440	58.8	
Rank	32.9	32.9	32.9	31.7	3.90	0.92
AUC pH 5.8	5.38	5.44	7.00	20.14	4.77	
Rank	33.0	32.9	32.9	31.9	5.40	0.96
DUR < 5.8, min/d	120	177	233	234	53.3	
Rank	32.9	32.9	32.9	31.8	5.06	0.94
AUC pH 5.6	2.04	2.57	3.23	7.99	2.67	
Rank	33.0	33.0	32.9	31.9	5.12	0.96
DUR < 5.6, min/d	43	81	105	104	37.1	
Rank	33.0	32.9	32.9	31.9	5.35	0.96
AUC pH 5.4	0.76	1.21	1.50	2.94	1.36	
Rank	33.0	32.9	33.0	31.9	4.39	0.97
DUR < 5.4, min/d	18	40	51	41	21.6	
Rank	33.0	33.0	33.0	31.9	4.88	0.96
Acidosis bouts ³						
Prevalence, %/d	3.91	7.03	12.3	12.2		< 0.01
DUR, min/bout	283	329	350	324	36.7	0.27

^{a,b}Least squares means within a row with different superscripts differ at $P < 0.05$.

¹Variables represent rumen characteristics of growing steers over the dietary transition; AUC = area under the curve (unit-less) and DUR = Duration (min/d), under the given pH threshold. Rank = the relative position of a data-point in the given data set. Bout = an instance of a subject having ruminal pH <5.6 for 180 consecutive minutes.

²Diets are grower diet (30% roughage), STEP1 = transition 1 diet (25% roughage), STEP2 = transition 2 diet (20% roughage), and finisher diet (15% roughage).

³Bout prevalence was analyzed by χ^2 analysis. Percentage of subjects displaying bouts are reported at the diet level ($n = 65$).

used log transformations to enhance distribution normality and decrease variation (Dohme et al., 2008). However, log transformation of a data set may not always result in a normal distribution and should not be conducted for variables when observations contain values of zero or values less than 1 (e.g., Duration below or AUC of given thresholds, pH variation; Sileshi, 2012; Changyong et al., 2014), and moreover, may not be appropriate for variables already on a log scale, such as pH. More recent research suggests that data derived from continuous monitoring systems should focus on deviations from the expected outcomes based on individual animal patterns rather than predefined pH thresholds (Denwood et al., 2018). The following drift analysis is based on the idea of deviations

from the expected values within a subject over time and offers its own unique value to our knowledge of rumen pH characteristics.

Drift analysis. The daily pH fluctuation and corresponding coefficient of determination for the basal period (grower diet) and each treatment group are shown in Figure 3. The drift analysis does not include the AUC or DUR variables due to the large CV of the sample population mentioned previously. In the drift analysis, based on the claims that supplemental ADY may help stabilize ruminal pH over the dietary transition, there were certain expectations for the outcome of treatment groups: 1) that changes, or drift, from baseline means of YY steers would be less than for CC steers and 2) that

Table 4. Summary statistics of ruminal pH characteristic variables of growing steers fed a 30% roughage grower diet

Items ¹ <i>n</i> = 63	Summary statistics					
	Mean		SD	Minimum	Maximum	CV, % ²
Basal pH values						
Minimum	5.75	±	0.23	5.01	6.13	4.04
Mean	6.21	±	0.18	5.77	6.57	2.91
Maximum	6.64	±	0.15	6.31	7.02	2.23
Range	0.89	±	0.16	0.65	1.47	18.41
Variation	0.06	±	0.03	0.02	0.17	55.17
Cumulative variation	0.56	±	0.30	0.24	1.89	52.93
Up_amp	0.42	±	0.08	0.31	0.71	17.75
Low_amp	−0.47	±	0.10	−0.75	−0.32	21.90
AUC < 6.0	17.93	±	26.75	0.04	149.34	149.19
AUC < 5.8	5.57	±	10.61	0.00	58.24	190.33
AUC < 5.6	2.11	±	5.48	0.00	31.96	259.03
DUR < 6.0, min/d	23.67	±	23.41	0.13	93.19	98.88
DUR < 5.8, min/d	8.54	±	11.59	0.00	52.73	135.72
DUR < 5.6, min/d	3.12	±	6.09	0.00	32.71	195.16

¹Variables are the population average of ruminal pH values during the 14 d prior to dietary transition while consuming a 30% grower diet. Cumulative variation = the accrued variation over 14 d; Up_amp = the upper amplitude and maximum distance above the daily mean; Low_amp = the lower amplitude and maximum distance below the daily mean; AUC = area under the curve of the given pH threshold; DUR = the duration of time spent below the given pH threshold in min/d.

²Percent coefficient of variation.

Figure 3. Diurnal fluctuations in ruminal pH of steers fed a grower diet for 14 d prior to dietary transition (days 56 to 70 of feeding trial). These data were used to establish baseline variables to determine drift during the dietary transition. Treatments are CC = control, no ADY fed throughout the transition; YY = yeast fed throughout the entire transition; CY = control fed during the grower diet and transitioned onto diets containing yeast; YC = yeast fed during the grower diet and transitioned onto diets without yeast. Blue (left panels) and gold (right panels) series represent steers consuming either control or yeast, respectively. Red dashed series indicates the fit line of the unadjusted *R*-squared estimate.

the pH values of YC steers would drift further from baseline means than the pH values of CY steers.

There were no treatment by day interactions observed in the drift analysis ($P \geq 0.18$). Table 5 shows the effect of treatment and Figures 4 and 5 show the effect day on the deviations of rumen

variables from their basal values. In Table 5, the mean basal values are given as a reference, and the direction of the variable Δ is shown next. There was no difference between treatment groups for Min Δ ($P = 0.46$) or Mean Δ ($P = 0.28$). The result of Min Δ is similar to the preliminary data analysis

Table 5. Effects of TRT and DAY on ruminal characteristic variable drift from baseline values

Items ¹	Treatment ²				SEM	P-value		
	CC	CY	YC	YY		TRT	DAY ³	TRT × Day
Basal min pH	5.80	5.68	5.78	5.76	0.091	0.41		
MinΔ	-0.107	-0.118	-0.143	-0.107	0.019	0.46	<0.01	0.85
Basal mean, pH	6.26	6.13	6.25	6.23	0.057	0.16		
MeanΔ	0.017	0.051	0.029	0.047	0.014	0.28	<0.01	0.18
Basal max, pH	6.67	6.58	6.66	6.65	0.040	0.23		
MaxΔ	0.120 ^{ab}	0.090 ^b	0.165 ^a	0.088 ^b	0.018	<0.01	<0.01	0.63
Basal range, pH	0.86	0.90	0.88	0.90	0.064	0.92		
RangeΔ	0.227 ^{ab}	0.208 ^b	0.310 ^a	0.194 ^b	0.029	<0.01	<0.01	0.99
Basal variance, pH	0.041	0.047	0.041	0.044	0.008	0.87		
VarΔ	0.035 ^b	0.038 ^b	0.058 ^a	0.039 ^b	0.005	<0.01	<0.01	0.95
Basal up_amp, pH	0.409	0.442	0.413	0.423	0.024	0.58		
Up_ampΔ	0.137 ^b	0.141 ^{ab}	0.194 ^a	0.135 ^b	0.016	0.02	<0.01	0.85
Basal low_amp, pH ⁴	-0.454	-0.457	-0.472	-0.473	0.042	0.93		
Low_ampΔ	-0.089 ^{ab}	-0.068 ^b	-0.116 ^a	-0.059 ^b	0.020	<0.01	<0.01	0.80

^{a,b}Least squares means within a row with different superscripts differ at $P < 0.05$.

¹Variables represent rumen characteristics of growing steers over the dietary transition; basal values indicate the average of the 14-d period steers received a grower diet (30 % roughage) and subsequent Δ in pH units from basal values in which the sign indicates the distance and direction of the change.

²Treatments are CC = control, no ADY fed throughout the transition; YY = yeast fed throughout the entire transition; CY = control fed during the grower diet and transitioned onto diets containing yeast; YC = yeast fed during the grower diet and transitioned onto diets without yeast.

³Main effects of day are shown in figure format.

⁴Up_amp = upper amplitude and greatest average distance above the mean pH; Low_amp = lower amplitude and greatest average distance below the mean pH.

Figure 4. Effect of the day on the maximum, minimum, variance, and range of ruminal pH. Distance from 0 is the distance from the baseline value in pH units. Max = drift of average daily maximum pH from baseline maximum; min = drift of average daily minimum pH from baseline minimum; variance = drift of variance from baseline variance; range = drift distance of the range between maximum and minimum pH from baseline. *Denote days that were different at $P < 0.05$.

where pH minimums were not different between treatments. However, the result for MeanΔ is different. The difference is that the preliminary analysis compared group means of the raw pH values, and

the drift analysis compares how far each subject's mean pH drifted from its baseline established on the grower diet. Analysis of the baseline mean pH shows that there was a numeric effect ($P = 0.16$) for

Figure 5. Effect of the day on the mean, upper, and lower amplitude drift from basal values. Distance from 0 is the distance from the baseline value in pH units. Up_amp = upper amplitude distance from the mean; Low_amp = lower amplitude distance from the mean. *Denote days that were different at $P < 0.05$.

treatment group CY to be lower than CC, YC, and YY (6.13 vs. 6.26, 6.25, and 6.23, respectively), and this predisposition for lower mean pH may have had a confounding effect with the treatment during the transition phase. However, using the drift analysis, deviations from baseline values offer greater accounting for the between-subject variation and therefore may be more meaningful to isolating the treatment effect. Similar to the preliminary analysis, there was an effect of treatment on Max Δ , where the YC group had the greatest increase from basal values, being different from CY and YY groups, whereas the CC group was intermediate and not different (0.165 vs. 0.089, 0.087 and 0.120, respectively; $P < 0.01$). This likely contributed to the outcome for Range Δ , where again the YC group was greater than CY and YY, and CC was intermediate and not different (0.310 vs. 0.208, 0.194, and 0.226, respectively; $P < 0.01$). This result indicated that there was less change in the daily fluctuation of CY and YY groups than for the YC group, and confirms the hypothesis of pH stabilization during the dietary transition. There was a significant treatment effect on Var Δ , where the YC group was significantly greater than CC, CY, and YY (0.058 vs. 0.035, 0.038, and 0.039, respectively; $P < 0.01$). This finding may indicate that when ADY is removed from the diet (i.e., YC treatment), the variance may increase within a subject whereas the addition of ADY (i.e., CY treatment) may aid in stabilizing the variance. Since the CC and YY groups were not subjected to a supplement change, it was expected

that the pH variance would not change from their baseline values, but we expected to potentially see a difference in the cross-over groups, CY and YC. The change in pH range and variation confirms that removing ADY during the dietary transition is not favorable, but including ADY may reduce ruminal fluctuation. There was a treatment effect on the Up_amp Δ , where the YC group had the greatest change from baseline and was different from the CC and YY groups but did not differ from CY which was intermediate (0.194 vs. 0.137, 0.135, and 0.141, respectively; $P = 0.02$). Again the upper amplitude is different from the maximum in that it measures the distance from the mean to the maximum value, but again the YC group drifts further from baseline than other treatments. There was also a treatment effect on the Low_amp Δ in which the YC group drifted further downward from the mean more than CY and YY, but was not different from CC which was intermediate (0.116 vs. 0.068, 0.059, and 0.089, respectively; $P < 0.01$). This confers with the Range Δ outcome ($P < 0.01$) but gives a better perspective of the influence of direction. It is clear that the ruminal pH in the CY and YY groups drifted less than the YC group, and tended to drift less than the CC group providing more evidence to the stabilization hypothesis.

As expected, there was an effect of day on the Δ in all rumen pH variables ($P < 0.01$). Figures 4 and 5 illustrate the general direction of the change over the transition. For each figure, the basal value for each variable is represented by the y-base of

0. Deviations from 0 indicate the direction and units change from each of the listed basal values. [Figure 4](#) shows the effect of day on the maximum, minimum, variance, and range which shows days that were most affected corresponded to the STEP2 diet through the first week of the finisher diet. Interestingly a second assault during the last 7 d of measurement reveals changes ($P < 0.05$) for these variables which demonstrate that even after adaptation to a diet external factors may cause rumen disturbances. In this situation, the external factor was moving the cattle through the facilities on day 100 (day 44 of the 50-d transition period) to collect ultrasound and biometric measurements. This single event caused significant disturbance for several days and provided considerable evidence to elucidate the effect that movement and stress have on ruminal pH of finishing steers. [Figure 5](#) displays drift of the mean ruminal pH and the upper and lower amplitude across the mean. Again the days with the greatest change from baseline are during the STEP2 and the first week of the finisher diet with a second assault in the last week of measurements ($P < 0.05$). Over the transition, the drift in low_amp is 0.1 pH unit on average lower ($P < 0.05$) than the baseline value, whereas the up_amp drifts nearly twice as far from its baseline ($P < 0.05$) causing an overall increase in mean ruminal pH ($P < 0.05$). It is suspected that this change in up_amp is due to an increasing bunk visit interval over time as dietary density increases and potentially greater time spent ruminating as steers grow and generate greater buffering capability. Another potential reason could be

that steers had greater water intake. However, that information was not measured in this study.

In summary, the findings of the drift analysis, specifically the main effects of treatment, offered a different perspective of the effect of supplemental ADY during dietary transition from the preliminary analysis. It also empowered the case for measuring deviations within subject rather than raw or transformed data and holding on to arbitrary pH thresholds for meaning. The drift analysis reveals that the addition of ADY during the dietary transition may help stabilize daily range and variation of ruminal pH during the transition from a low to high energy diet.

Liver and Lungs Scores

Liver and lung analysis of the finished steers is shown in [Table 6](#). Liver abscess frequency was 19.6%, but liver abscess prevalence and abscess severity were not different among treatment groups ($P \geq 0.34$). Although there was no difference between treatment groups, it is still interesting to note that the CC group experienced the greatest prevalence and most severe abscesses and the CY group experienced the fewest abscesses and least severe of the groups. This was surprising considering that the CY group experienced greater acidosis bout prevalence. This led to the investigation of the relationship between acidosis and liver abscesses detailed in the next section. There were no treatment differences in the distribution of lung scores all of which were a score of 3 or less ($P = 0.66$).

Table 6. Effects of treatment on liver and lung characteristics of finished beef steers

Items ¹	Treatment ²				SEM	P-value
	CC	CY	YC	YY		
N	29	31	29	28		
Abscess prevalence, %						
No abscess	69.0	87.1	82.8	82.1		0.35
Abscessed	31.0	12.9	17.2	17.9		0.34
A	17.2	9.7	6.9	10.7		
A+	13.8	3.2	10.3	7.1		
Lungs score, %						0.67
1	20.7	38.7	51.7	32.1		
2	65.5	54.8	34.5	50.0		
3	13.8	6.5	13.8	17.9		
4	0.0	0.0	0.0	0.0		
5	0.0	0.0	0.0	0.0		

¹Items are postmortem liver scores [modified method by [Brown et al. \(1975\)](#)] and lung scores [as described by [Schneider et al. \(2009\)](#)] expressed as a percentage within each TRT group.

²Treatments are CC = control, no ADY fed throughout the transition; YY = yeast fed throughout the entire transition; CY = control fed during the grower diet and transitioned onto diets containing yeast; YC = yeast fed during the grower diet and transitioned onto diets without yeast.

Figure 6. Mosaic displays represent the frequency of days experiencing bouts (DEB) of acidosis and their relationship to feedlot performance traits DMI, ADG, and G:F by quartile rank. Cell colors represent the number of DEB of acidosis during the 50 d monitored over dietary transition; Gold = 0 d or never experienced a bout of acidosis; Green = experienced 1 to 10 d of acidosis; Pink = experienced 11 to 20 d of acidosis; Purple = experienced greater than 21 d of acidosis and cell height represents the probability of a subject within a column to be designated in one of the colored groupings. Cell width represents the probability of steers being within the designated quartile for these respective performance traits within a column. Highest = 1st–25th percentile; High = 26th–50th percentile; Low = 51st–75th percentile; or Lowest = 76th–100th percentile.

Relationship of Feeding Performance, Acidosis Bouts, and Liver Abscesses

There has been considerable speculation (Owens et al., 1998; Nagaraja and Lechtenberg, 2007) that periodic bouts of ruminal acidosis may result in

Figure 7. Distribution of liver abscess severity by percentile rank within performance traits DMI, ADG, and G:F. Liver abscess scores are categorized on the Elanco scoring system (Brown et al., 1975). Colors represent y-axis liver score values of 0 = green, A = pink, and A+ = purple. Column width and performance trait status are based on $n = 117$ subjects and their rank within performance trait quartiles. Cell height is the probability of a subject portraying respective liver abscess traits within the column.

liver abscesses. It also stands to reason that any liver damage will decrease overall metabolic efficiency and thus hinder growth and feeding performance. In a χ^2 analysis, feeding performance traits DMI, ADG, or G:F from our companion paper were used to detect any relationships with bouts of acidosis and liver abscess prevalence and severity. Steers were assigned a categorical status label based on their relative position within the population

quartiles for DMI, ADG, and G:F. Steers ranking in the top 25%, 26% to 50%, 51% to 75%, and 75% to 100% of the population were labeled *highest*, *high*, *low*, and *lowest*, respectively, for each feed performance trait. Only steers equipped with rumen boluses ($n = 63$) were used in assessments which included acidosis bout assessment but their original population rank within a feed performance trait was retained and not scaled to the bolus population. Since acidosis bout occurrence displayed a Poisson distribution, labels were assigned for meaningful interpretation rather than the distribution in which steers were grouped by the number of days experiencing bouts (DEB) of 0, 1 to 10, 11 to 20, or >20 d out of the 50-d measurement period. Although this separation resulted in unequal group sizes, it provided practical meaning for observation.

Feeding performance and acidosis bouts. Feedlot performance traits and DEB relationships are illustrated in the panels of mosaic plots in Figure 6. There was no relationship between DMI status and DEB ($P = 0.80$; Figure 6a). However, there was a numeric relationship between ADG status and DEB where steers ranking in the top 50th percentile (high or highest) experienced fewer days of acidosis than those in the lower 50th percentile (low or lowest) and no steers in the top 50th percentile experienced greater than 21 d of acidosis ($P = 0.11$; Figure 6b). Similarly, there was a tendency for a relationship

between G:F status and DEB in which those steers with greatest feed efficiency had fewer DEB than those with the lowest feed efficiency ($P = 0.06$). This finding is consistent with suggestions of repeated bouts of acidosis having negative impacts on performance due to decreased short-chain fatty acid absorption (Schwaiger et al., 2013).

Feeding performance and liver abscesses. There was a numeric relationship between DMI status and liver abscess severity ($P = 0.13$; Figure 7a). Steers ranking lowest for DMI had numerically greater A+ liver scores than steers with greatest DMI. There was a significant relationship between ADG status and liver abscess severity ($P = 0.04$). Steers with the greatest ADG had fewer and less severe liver abscess scores than steers ranked below them. It could be that the presence and severity of liver abscesses contributed to the lower performance of steers which is supported by earlier research (Brink et al., 1990). Although the relationship of G:F status and liver abscesses was not significant ($P = 0.35$), the mosaic plot shows a similar trend in the pattern of occurrence and severity as the ADG status outcome where those steers with the highest G:F had numerically fewer abscesses.

Acidosis bouts and liver abscesses. There was no relationship between DEB and liver abscess prevalence ($P = 0.98$) or severity ($P = 0.90$; Figure 8).

Figure 8. Distribution of liver abscess score by days experiencing bouts (DEB) of acidosis. Liver abscess scores are categorized on the Elanco scoring system (Brown et al., 1975). Colors represent y-axis liver score values of 0 = green, A = red, and A+ = blue. The column width of DEB is based on $n = 64$ subjects and their associated DEB grouping. Cell height is the probability of a subject portraying respective liver abscess traits within the column.

This conflicts with the expected outcome and also general assumptions of chronic bouts of acidosis predisposing cattle to an increased probability of rumenitis, rumen lesions, and consequently liver abscesses (Nagaraja and Chengappa, 1998). Although the postmortem rumen was not examined for lesions or keratinization, these findings showed that steers which never experienced a defined bout of acidosis during the transition still had a 10% abscess occurrence (2 of 19 steers). Even more interesting, 4 steers with the most extreme number of DEB (21, 28, 39, and 42 d of 50 d, respectively) yielded no liver abscesses whatsoever. Although bouts experienced during the entire feeding period are not available, some have suggested that the transition phase sets the tone for the remaining days on feed (Dohme et al., 2008). Thus, evidence may only be provided that there is not necessarily a linear relationship between DEB during the dietary transition and liver abscess prevalence or severity if any relationship at all.

There is evidence to suggest that at the current dosage (3×10^{10} CFU/d) supplementation of the ADY *S. cerevisiae* strain used in this study may aid in the stabilization of ruminal pH characteristics during the dietary transition from low- to high-concentrate diets as evidenced in the drift analysis. However, beyond the direct action in the rumen, it was no evidence to suggest that ADY effects were sufficient to improve the animal performance or affect liver health status. Further research should address different ADY strains and the potential for dose-dependent effects (in the context of CFU/d) as it has been found that feeding ADY at 6×10^{10} CFU/d can improve dry matter digestibility and metabolizable energy of the diet to finishing steers (Crossland et al., 2018).

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