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Short Communication: feeding behaviors are not correlated with area under the curve for reticulorumen pH below 5.8 and 5.6 in finishing steers

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Abstract

Persistent low rumen pH (<5.8 to 5.6) is the most researched sign of Subacute Ruminal Acidosis (**SARA**), a disorder in cattle caused by consumption of a high-concentrate diet. Animals may ruminate less and eat forages to slow acid accumulation, but there are no other easily detectable signs of SARA. Our objective was to evaluate whether feeding behavior is correlated to daily time spent below reticulorumen pH 5.8 and 5.6. We predicted that the severity of daily fluctuation in pH below 5.8 would be negatively correlated to daily intake, the number of visits to the feed bin, and time spent eating, as decreases in these variables are indicative of sickness behavior. These aspects of feeding behavior are moderately, positively correlated to each other ($r \geq 0.3$), thus do not represent 3 independent tests of our hypothesis, but rather, create an overall picture of feeding behavior. Eighteen steers were fed a high-concentrate finishing ration ad-libitum, with delivery twice daily into automated feed bins that measured feeding behavior. Wireless boluses measured reticulorumen pH in 10-min intervals continuously for 11.5 ± 0.9 d (mean ± SD). The mean daily reticulorumen pH was 6.1 ± 0.2, the mean daily maximum pH was 6.7 ± 0.1, and the mean daily minimum pH was 5.5 ± 0.2 (mean ± SD). The area under the curve (**AUC**) for pH below 5.8 and 5.6 for each 24-h day was calculated for each animal (AUC: 75.2 ± 15.5 and 30.3 ± 7.4 pH × min/24 h, respectively, mean ± SE). Repeated measures correlation analyses investigated the relationship between AUC and each of the behavioral variables. There was no correlation between time spent eating (74.0 ± 3.0 min/24 h, mean ± SE) or visits to the feed (27.0 ± 2.4 no./24 h) and AUC ($r \geq -0.072$; $P \geq 0.34$). A weak negative correlation existed between the dry matter intake (10.0 ± 0.2 kg/24 h) and AUC < pH 5.6 ($r = -0.164$; $P = 0.03$), but not for AUC < pH 5.8 ($r = -0.122$, $P = 0.10$). The same analyses were conducted for daily AUC and the feeding behaviors on the following day to capture a delayed behavioral response, but no associations were detected ($P \geq 0.12$). The feeding behaviors measured alone were not adequate to describe the severity of reticulorumen pH depression in finishing cattle. Individual variation in tolerance to low pH, adequate time to adapt to the finishing ration, and/or selection pressures for weight gain may have contributed to the lack of a defined sickness response to SARA.

Lay Summary

Finishing steers consume a diet high in easily digestible carbohydrates that can cause pH depression in the rumen. If this depression is persistent, it can lead to a digestive disorder called Subacute Ruminal Acidosis (**SARA**) that causes systemic health problems. In general, sick cattle will reduce intake and activity, so theoretically, sickness behavior should be a reliable predictor of SARA. The objective of this experiment was to calculate the severity of SARA experienced by finishing steers on a daily basis and correlate this information with changes in behavior over the following 24 to 48 h. We predicted that cattle would eat less, spend less time eating, and visit the feed less as SARA became more severe. Time spent eating and visits to the feed were not correlated with the severity of pH depression, and intake showed only a weak negative association. These findings support previous studies demonstrating that feeding behavior is not a reliable predictor of SARA in finishing steers.

Key words: acidosis, beef, behavior, cattle, finishing, sickness

Abbreviations: AUC, area under the curve; BW, body weight; DM, dry matter; DOF, days on feed; RFID, radio frequency identification; SARA, subacute ruminal acidosis; TMR, total mixed ration

Introduction

Subacute ruminal acidosis (**SARA**) is a digestive disorder that can result from the rapid digestion of starch-containing concentrates in the finishing ration, producing a buildup of volatile fatty acids in the rumen (Steele et al., 2016). To maintain microbial and digestive function, the healthy ruminal pH range for cattle is thought to be 5.8 to 6.5 (Nagaraja and Titgemeyer, 2007). A prolonged and severe drop in pH below 5.0 represents the acute and potentially fatal form of the disease, while SARA is typically defined as a sustained pH depression below 5.6 to 5.8 (Plaizier et al., 2022). The latter can lead to systemic health problems, including, but not limited to, inflammation (Zebeli and Metzler-Zebeli, 2012), rumenitis (Nagaraja and Lechtenberg, 2007), and liver abscesses (Plaizier et al., 2009). The high proportion of concentrates (≥76%; USDA, 2013), and low amount of physically effective forage fed in the finishing ration can cause an increase in ruminal acidity and a risk of SARA (González et al., 2012). For example, a 2014 study of 13,183 beef carcasses in the United States found that 30% exhibited liver abscesses (Rezac et al., 2014).

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When observed at the feedyard lot level, liver abscesses were identified in 0% to 95.5% of cattle and their prevalence overall is increasing across years (Grimes et al., 2024). Tucker et al. (2015) identified high-concentrate feeding and its effects on digestive health and behavior as areas where future research is needed to improve beef cattle welfare.

General sickness behavior is characterized by an increase in resting, and reductions in physical activity and time spent eating (Hart, 1988), although there is variability in how cattle respond to the specific problem of SARA behaviorally, if at all. For example, some beef cattle reduce intake while others do not (González et al., 2012). Early lactation dairy cattle ruminate less (436 vs. 533 min/d; mean) following an acidosis challenge (DeVries et al., 2009). Contrary to what would be expected with the generalized sickness response, those same cows visited the feed bunk more often in the 24 h after the challenge. However, they did reduce their meal size in the 24 h after the challenge (DeVries et al., 2009). Both dairy and beef cattle alter their feed sorting behavior to ameliorate the negative effects of SARA when challenged, favoring more physically effective particles over smaller grain components (DeVries et al., 2009, 2014a). A grain-induced acidosis challenge also reduced time spent eating in dairy cattle but had no effect on intake (Li et al., 2011; Silberberg et al., 2024). Wagner et al. (2020) used machine learning models to detect changes in behavior of dairy cows experiencing a SARA challenge with limited success, citing the need for larger data sets to account for individual variation. The signs of SARA are thought to be more severe when caused by experimental induction than natural occurrence due to the altered composition of challenge diets (Plaizier et al., 2022), which further complicates any attempt to use these changes in behavior to diagnose the disorder.

Changes in behavior caused by naturally occurring SARA are less well documented as comprehensive sampling requires continuous monitoring of rumen pH and behavior, both historically costly and laborious. Recent advances in remote sensing technologies have allowed for more efficient data collection on both fronts, and yet, few studies have addressed the relationship between feeding behavior and naturally occurring SARA using continuous monitoring techniques. For example, chop length and inoculation of barley silage with esterase-producing bacteria influenced both feeding behavior and ruminal pH parameters in finishing steers, however, no relationship with SARA could be inferred because the disorder was observed across all treatments (Addah et al., 2015). In a different approach, there were no differences in dry matter intake (**DMI**) between early lactation dairy cows categorized as high or low risk for SARA based on the area under the curve (**AUC**) for pH below 5.8 (Coon et al., 2019). Heirbaut et al. (2022) recommend that instead of classifying cattle as high or low risk for SARA, a more accurate predictor of the onset of illness would be the intra-animal changes in behavior in relation to pH depression. An advantage of studying intra-animal changes is the ability to capture a delayed behavioral response that may occur in the hours and days following a bout of naturally occurring SARA (Oetzel, 2007). Dairy cattle change their feeding behavior following an acidosis challenge relative to baseline measures, increasing their feeding time on day 1 postchallenge before recovering on day 2 (DeVries et al., 2009). Capturing similar changes during and after naturally occurring SARA would require continuous monitoring of both pH and feeding behavior and statistical analyses that account for day-to-day variation in both parameters at the animal level.

The objective was to investigate if feeding behavior is correlated to the severity of SARA experienced by finishing cattle adapted to a high-concentrate diet using continuous pH and feeding behavior monitoring. We predicted that cattle would reduce their daily intake, time spent feeding, and number of visits to the feed within 24 h in response to the severity and duration of reticulorumen pH depression. We also examined, post hoc, these relationships with reticulorumen pH and the behavioral responses the next day (24 to 48 h later)."

Materials and Methods

Animals and housing

All procedures were approved by the University of California Davis Institutional Animal Care and Use Committee (Protocol #21195). The experiment was conducted from November to December 2021. All animals were administered a Revalor-S implant to improve ADG and F:G efficiency in late August 2021. Eighteen Angus-cross steers (11 mo and 475 ± 3 kg, 49 ± 16 DOF; mean ± SD) were housed in group pens (30 m^2/animal) at the University of California Davis feedlot facility in October 2021 before being enrolled in the study. The pens were bedded with rice hulls that were scraped and replaced weekly. Animals were fed a finishing total mixed ration (**TMR**; Coon and Tucker, 2024a) into automated feed bins (Insentec B.V., Marknesse, Netherlands) twice daily at 0800 h and 1530 h and had ad-libitum access to water. Animals accessed the automated feed bins with an associated RFID ear-tag.

As part of a larger experiment (Coon and Tucker, 2024a), animals were moved to 1 of 2 experimental pens in cohorts of 4 (60 m^2/animal), each pen had 8 automated feed bins and 4 unbedded rubber mats on the ground in the lying area. The cohorts were composed of 4 animals, but not all animals in each group were included in the analyses presented here. This is because some animals in the larger experiment had access to additional forage and we chose to exclude those cattle from this study. In total, there were 28 steers distributed across 7 groups of 4 animals each, of which only 18 animals were included in the analyses presented here. The heaviest animals were enrolled first to balance weight gain throughout the finishing period. Approximately 1 wk before enrollment in the larger study, cattle were administered a wireless telemetry bolus (smaXtec pH Bolus, smaXtec animal care GmbH, Graz, Austria) that measured reticulorumen pH at 10-min intervals. Starting on the first day of enrollment and continuing throughout the study, animals were locked in the back half of the pen at 0700 h for 1 h and again at 1500 h for 30 min, preventing them from accessing the feed bins while feed was distributed. The amount of feed was adjusted daily, such that it was 115% of the previous day's intake for each animal to ensure feed was provided ad libitum.

Feed sampling and analysis

Once per wk, a fresh feed sample of the TMR was collected and frozen immediately at −20 °C until further analysis. Samples were sent to Cumberland Valley Analytical Services Inc. (Maugansville, MD) for analysis of DM (135 °C; AOAC International, 2000: method 930.15), ash (535 °C; AOAC International, 2000: method 942.05), ADF (AOAC International, 2000: method 973.18), NDF with heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991), and CP (N × 6.25; AOAC International, 2000: method 990.03; Leco FP-528 Nitrogen Analyzer, Leco, St. Joseph, MI).

Statistical analyses

Time spent in the experimental pen differed by animal due to the conditions of the larger experiment, leading to 11.5 ± 0.9 d (mean ± SD) of data collection per animal. Based on the distribution of intake, an outlier threshold of less than 5 kg DM per day was identified; 1 animal was removed from analyses based on this. Absolute values for area below a pH threshold of 5.8 and 5.6 (AUC < pH 5.8, 5.6) were calculated using methods described in Coon et al. (2018).

Same day analyses

Repeated measures correlation analyses were conducted between the daily AUC values and the daily intake, number of visits, and time spent eating from the same day as the pH measures. Repeated measures correlation analyses were also conducted between each of the feeding behaviors: daily intake, number of visits, and time spent eating in a pairwise manner to evaluate collinearity. The rmcorr function in the rmcorr package of R (version 0.5.4) was used to conduct the analyses with a confidence level of 0.95, using animal ID as a random effect. Statistical significance was defined as $P < 0.05$, and tendencies were reported if $P < 0.10$. These analyses included 207 d of data total.

Next day analyses

To capture the association between AUC on one day and feeding behavior the following day, repeated measures correlation analyses were also conducted between the daily AUC values and the daily intake, number of visits, and time spent eating on the subsequent 24 h. The last 24-h period for each animal was excluded from analyses as there were no "Next Day" data, resulting in 189 days of data total.

Results

The data (Coon and Tucker, 2025a) and RMarkdown files, including the means, standard errors, and confidence intervals for all raw data and correlation analyses (Coon and Tucker, 2025b), can all be found online in the Dryad repository.

Same day results

The mean daily intake, time spent eating from and visits to the primary bin on the same day are reported in Table 1. The daily mean reticulorumen pH, as well as the mean maximum and minimum pH values are reported in Table 1. The mean daily time spent below pH 5.8 and 5.6, mean daily AUC < pH 5.8, AUC < pH 5.6, and mean daily AUC < pH 5.8/DMI and AUC < pH 5.6/DMI can also be found in Table 1.

The daily number of visits to the feed bin was not correlated with AUC < pH 5.8 or AUC < pH 5.6 (r = -0.018 and –0.047, respectively, $P \geq 0.53$). Similarly, daily time spent eating in minutes was not correlated with AUC < pH 5.8 or AUC < pH 5.6 (r = 0.002 and –0.072, respectively, $P \geq 0.34$). DMI was not correlated with AUC < pH 5.8 (r = –0.122, P = 0.10; Figure 1A), but was negatively correlated with AUC < pH 5.6 (r = -0.164, P = 0.03; Figure 1B).

The daily number of visits to the feed bin was positively correlated with both the daily time spent eating in minutes and the DMI (r = 0.494 and r = 0.300, respectively, $P < 0.01$).

Table 1. Feeding behaviors and reticulorumen pH variables for finishing steers fed a high-concentrate diet presented as mean ± SE on either the same day as pH measures or the next 24 h

Item	Same day	Next day
Feeding behavior		
Dry matter intake, kg/24 h	10.0 ± 0.2	10.0 ± 0.2
Total time spent eating, min/24 h	74.0 ± 3.0	73.3 ± 2.9
Visits to the feed bin, #/24 h	27.0 ± 2.4	27.1 ± 2.4
Reticulorumen pH		
Reticulorumen pH/24 h	6.1 ± 0.0	n/a
Maximum reticulorumen pH/24 h	6.7 ± 0.0	n/a
Minimum reticulorumen pH/24 h	5.5 ± 0.1	n/a
pH < 5.8		
Time below reticulorumen pH 5.8, min/24 h	298.6 ± 50.9	n/a
Area under the curve[1] pH < 5.8, pH × min/24 h	75.2 ± 15.5	n/a
AUC pH < 5.8/dry matter intake, DMI[2]	7.8 ± 1.5	n/a
pH < 5.6		n/a
Time below reticulorumen pH 5.6, min/24 h	152.3 ± 32.4	n/a
AUC[1] pH < 5.6, pH × min/24 h	30.3 ± 7.4	n/a
AUC pH < 5.6/DMI[3]	3.2 ± 0.7	n/a

[1]AUC = area under curve.
[2]AUC/DMI = area under curve pH < 5.8 (pH × min/24 h) divided by DMI (kg/24 h). The AUC and DMI are taken from same day measures.
[3]AUC/DMI = area under curve pH < 5.6 (pH × min/24 h) divided by DMI (kg/24 h). The AUC and DMI are taken from same day measures.

Time spent eating was also positively correlated to DMI (r = 0.559, $P < 0.01$).

Next day results

The mean daily intake, time spent eating from and visits to the primary bin on the next day are reported in Table 1. The daily number of visits to the feed bin was not correlated to AUC < pH 5.8 and AUC < pH 5.6 on the previous day (r = 0.113 and r = 0.070, respectively, $P \geq 0.15$). The same was true for daily time spent eating in minutes, and AUC < pH 5.8 and AUC < pH 5.6 on the previous day (r = 0.062 and r = –0.008, respectively, $P \geq 0.43$). Finally, DMI was not correlated to AUC < pH 5.8 (r = -0.071, P = 0.37; Figure 1C) or to AUC < pH 5.6 on the previous day (r = –0.123, P = 0.12; Figure 1D).

Discussion

There was minimal correlation between reticulorumen pH depression and feeding behavior in the concurrent 24-h period and no correlations in the subsequent 24 h in finishing steers fed a high-concentrate diet. Despite mean time spent below reticulorumen pH 5.8 surpassing 5 h/d, the number of visits to the feed bin per day and the daily time spent eating were not correlated with AUC < pH 5.8 or AUC < pH 5.6. There was a weak negative correlation between DMI and AUC < pH 5.6 on the same day, although no other correlations were detected for DMI and AUC for either pH threshold on the same or next day. Behaviors on the same day were correlated to one another, so the analyses between feeding behaviors and pH are not independent. Aside from intake,

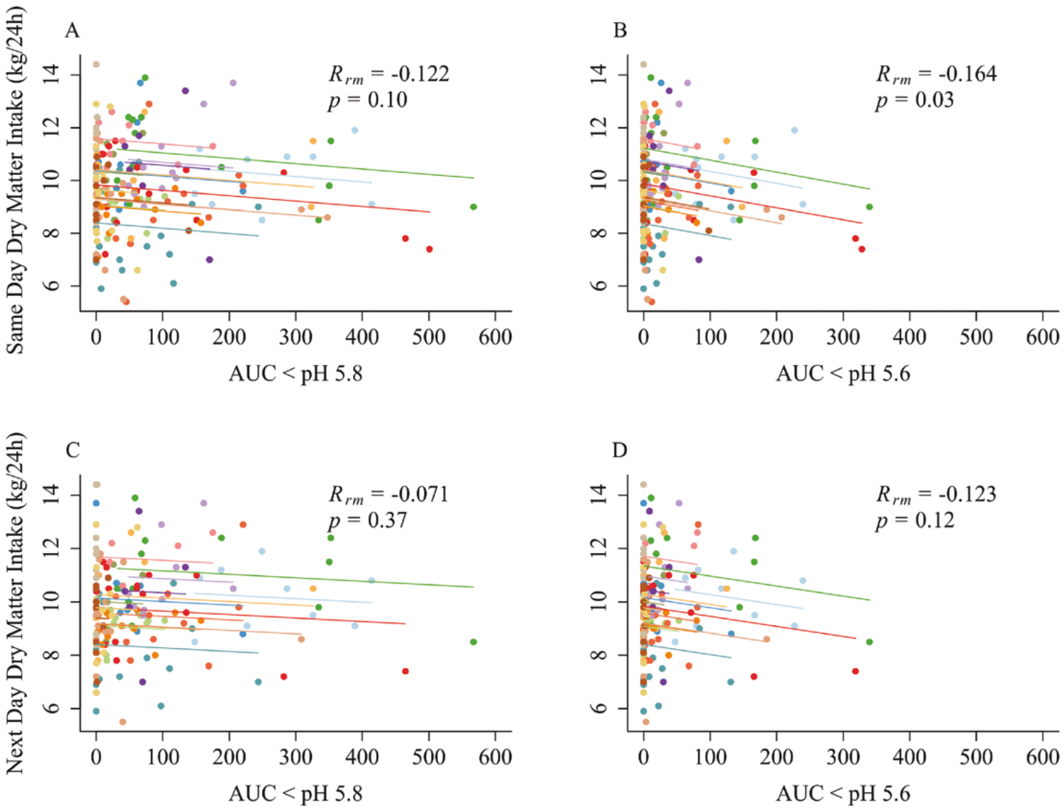

Figure 1. Repeated measures correlation between (A) AUC for reticulorumen pH below 5.8 and daily DMI in kg on the same day, (B) AUC for reticulorumen pH below 5.6 and DMI on the same day, (C) AUC for reticulorumen pH below 5.8 and DMI on the next day, and (D) AUC for reticulorumen pH below 5.6 and DMI on the next day for finishing steers fed a high-concentrate ration. Distinct colors represent individual steers.

there does not appear to be evidence that feeding behaviors, including time spent eating and visits to the feed, can be used as indicators of SARA in this dataset.

Chronic, low reticulorumen pH (<5.8; based on time below this threshold) was widespread in this experiment, but feeding behavior patterns were comparable to other feedlot studies. The descriptive pH parameters (mean, max, and min) were similar to those observed by Llonch et al. (2020), who used the same boluses in beef heifers. However, the daily time spent below the diagnostic thresholds for SARA was greater in the present experiment than Llonch et al. (2020), which may be due to differences in the feeding schedules and diet composition. To further emphasize the complex relationship between feeding management and reticulorumen pH, an earlier experiment using smaXtec boluses in finishing steers reported daily times spent between pH 5.0-5.6 that were over twice the mean daily time below pH 5.6 in our study (Crossland et al., 2018). However, intake and time spent eating were comparable to previous research in finishing cattle (Llonch et al., 2020; Pereira et al., 2023). The daily number of visits to the feed bin also reflects observations of finishing cattle using the Insentec feeding system (Winders et al., 2022; Coon and Tucker, 2024b). These findings demonstrate that the present study is representative of typical experimental conditions for finishing cattle despite widespread SARA in the dataset.

An explanation for the lack of correlation between feeding behavior and AUC for reticulorumen pH could be individual variation in the ability to tolerate severe pH depression. While we might have expected that sickness behaviors like a reduction in time spent eating would increase as AUC worsened, there is research to suggest that cattle vary in their tolerance of low pH. For example, finishing steers with abscessed livers did not differ in the time spent below reticulorumen pH 5.6 compared with finishing steers with healthy livers at slaughter (Theurer et al., 2021). This could indicate that animals with healthy livers better tolerated low pH, although the severity of pH depression (AUC) was not reported. In addition, there are other measures of SARA that were not included in our study, such as ruminal motility, indicators of inflammation, and fecal consistency (Plaizier et al., 2022), that would create a fuller picture of what each steer experienced. Another way this question could be addressed would be to look within an individual's patterns of rumen pH and ask if changes that are relatively large for that animal better correspond with his changes in feeding behavior or other indicators of SARA.

Another contributing factor to the lack of correlation between feeding behavior and severity of SARA experienced, could be that all animals were adapted to the finishing ration and were on average 49 ± 16 DOF (± SD; range 25 to 70 DOF) before data collection began. Dairy cattle provided with 34 d to adapt to a high-concentrate ration augmented their feeding behavior to sort in favor of longer, forage particles to ameliorate low pH during an acidosis challenge to a greater extent than cattle with only 8 d to adapt (DeVries et al., 2014b). Feeding sorting was not measured in the current experiment, but might explain why other feeding behaviors did not change with SARA severity if animals were altering diet composition to ameliorate low pH. Cattle experiencing subsequent acidosis challenges exhibit behavioral adaptations like an initial increase in feeding frequency and a reduction in meal size that eventually disappear, potentially because of physiological changes in response to periods of repeated low ruminal pH (DeVries et al., 2009; Penner et al., 2011; González et al., 2012). Additionally, cattle change their daily intake patterns during the transition from an all-roughage diet to a finishing ration (González et al., 2012), but the present study began a minimum of 25 d after the animals had been successfully stepped up to the high-concentrate diet, suggesting there was sufficient time for the feeding behavior patterns to stabilize. Finally, the incidence, prevalence, and severity of SARA increases as the finishing period progresses (Castillo-Lopez et al., 2014), so one might expect to see greater changes in feeding behavior given that the data were collected well into the finishing period. However, the current study did not follow animals continuously throughout the finishing period, and our correlation results do not reflect long-term feeding behavior and acidosis patterns.

Another idea that has received little attention is the role that appetite-stimulating implants and selection for growth have on the sickness response to chronic low pH. All cattle were administered a Revalor-S implant approximately 2 mo before data collection began. This implant stimulates an increase in intake (Hermesmeyer et al., 2000) that may have superseded negative effects of SARA on feeding behavior. As predicted for sickness behavior, intake on the same day tended to be negatively correlated with AUC, but the association was weak and there were no correlations between AUC and the other feeding behaviors. Since it is predicted that sickness would result in reduced activity and intake, it is possible that the implant may have minimized a drop in feeding behavior frequency as the severity of SARA increased. Furthermore, beef cattle have been bred for increased growth rate and feed efficiency, thus consuming more in a shorter time period (Terry et al., 2021). This selection pressure may have masked sickness behavior by driving high intake regardless of the negative effects of chronic low pH. However, there is plenty of research demonstrating that dairy cattle bred for high production exhibit sickness behavior and that finishing animals experiencing acidosis reduce intake (González et al., 2012; Dittrich et al., 2019), making this explanation less plausible. Similarly, beef cattle from the same source population readily showed sickness responses to BRD (Toaff-Rosenstein and Tucker, 2018), including a drop in time spent at the feedbunk. More research is needed to identify the internal factors associated with the onset of sickness behavior due to SARA in finishing cattle.

In conclusion, correlation analyses between feeding behavior and the severity of SARA in finishing cattle detected a tendency for a weak negative relationship between same day intake and AUC in this dataset. Other measures of sickness behavior, including reductions in the number of visits to the feed and time spent eating were not correlated with chronic low pH. While mean daily AUC < pH 5.8 and pH 5.6 values were indicative of SARA, cattle showed variation in their tolerance of low reticulorumen pH, with some animals maintaining their feeding amount and frequency while others did not. Given that these animals were nearly 50 DOF, on average, with time before data collection began to adapt to the high-concentrate ration, it is possible that chronic low reticulorumen pH is not the only instigator of sickness behavior resulting from SARA. Other systemic measures, such as inflammation, may be more reflective of the severity of illness experienced by the animal than simply chronic low reticulorumen pH and have a greater influence on the occurrence of sickness behaviors. To summarize our findings, a reduction in feeding behaviors as predictive sickness indicators was not correlated to SARA in finishing cattle adapted to a high-concentrate ration.

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Author Contributions

Rachael Coon (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing—original draft), and Cassandra Tucker (Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing—review & editing)

Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

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