EFFECT OF INCREASING DIETARY ENERGY CONSUMPTION ON INTAKE, DIGESTION, AND RUMINAL FERMENTATION IN LIMIT-FED STEERS

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ABSTRACT

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Effects of increasing dietary energy consumption on intake, digestion, and ruminal fermentation in limit-fed cattle were determined using 16 ruminally cannulated steers (359 kg ± 44 BW). All steers were fed a constant level of wheat straw (0.56% of BW) and one of four levels of concentrate (0.69, 0.88, 1.06, and 1.25% of BW) such that steers were fed 70, 85, 100, and 115% of NRC predicted NEm requirements in a one period, randomized complete block study. The concentrate portion of the ration consisted of dry-rolled corn (45%), dried distillers' grains (42%) and a premix (13%). Diets and feeding levels were consistent with a companion mature cow project. The trial was 17 d long with 11 d for adaptation, 5 d to determine intake and digestion, and a 1 d ruminal fermentation profile. Dry matter intake increased linearly ($P < 0.01$) as per the design of the project from 3.70 kg/d for 70% to 4.19, 4.66, and 5.22 for 85, 100, and 115%, respectively. Digestion of DM increased linearly ($P = 0.03$) from 64 to 74% for treatments 70 and 115%, respectively. There were no significant differences for NDF and ADF digestion ($P > 0.20$). Digestion of GE increased linearly from 65% to 70, 67, and 75% for treatments 70, 85, 100, and 115%, respectively (P = 0.03). Correspondingly, digestible energy intake increased ($P < 0.01$) linearly from 9.6 Mcal/d for 70% to 15.6 Mcal/d for 115%. Mean ruminal pH decreased quadratically ($P < 0.01$) with increasing energy intake. Similar mean pH values were observed

for 70, 85, and100%; 6.34, 6.38, and 6.36, respectively, and there was a decrease to 6.25 for 115%. No time × treatment interaction was observed (*P* = 0.17) for ruminal pH. The lowest ruminal pH was 6.15 and 5.95 at h 6 for 85 and 115%, respectively, whereas lowest ruminal pH for 70% was 6.05 at h 9, and 100% was 6.12 at h 12. There was a treatment × hour interaction (*P* < 0.05) for acetate to propionate ratio resulting from changes over time not a re-ranking of treatments. Mean acetate to propionate ratios decreased quadratically (*P* = 0.02) and averaged 3.28, 3.36, 3.02, and 2.98 for treatments 70, 85, 100, and 115%, respectively. Increasing concentrate provision increased diet digestion and energy consumption without producing changes in ruminal fermentation that could possibly impact long-term ruminal health.

CHAPTER I

LITERARY REVIEW

Introduction

World demand for meat protein is expected to increase as the global population grows and emerging economies experience increased median income. However, there is limited access to pasture and grazing lands to raise the cattle required to meet the growing global demand for beef; therefore, systems that raise cattle to provide more meat protein per unit of land while using cost effective methods is required. Competition for resources in a limited environment has driven an increase in cattle numbers, but efficiency is needed to maintain production (Thornton 2010). Improved efficiency would make the beef industry more sustainable and resilient to challenges such as drought and land fragmentation. Sustainable intensification of beef production systems increases the amount of meat protein produced, increases the efficiency of feed resource utilization, and increases system resiliency.

Reducing intake through limit feeding is strategy to improve system efficiency that affects digestion and ruminal fermentation (pH and volatile fatty acid (VFA) concentrations). Acetate, propionate, and butyrate are three VFAs that can be measured in ruminal fluid. Acetate is made in higher proportions when fermenting fiber while propionate is a gluconeogenic VFA that's production is associated with starch fermentation. Starch is broken down more easily than fibrous feeds which increases VFA concentration, but high amounts of starch can overwhelm the rumen and decrease fiber digestion. Measuring these nutrients and factors while comparing them to intake will provide a broad view of the effects of increased concentrate.

Limit-fed systems seek to provide concentrates and roughages in different proportions to maximize efficiency. Concentrates or grains are nutrient dense and high energy feeds, while roughages such as grasses and hay are higher in fiber and lower in energy. Concentrate is primarily used to finish cattle and is popular in feedlot settings. Value of a feed or ration can be assessed, with the goal being to feed less and the cow or steer to gain more per calorie of gross energy. In a study breaking down the value of a calorie, intake reduction was correlated with efficiency when feeding in specified proportions. This reduction would mean weight gain and finishing with less calories consumed, making the cost decrease. With beef production systems improved with lower cost and more efficient cattle, sustainability becomes a feasible option (Wickersham 2013).

Discussion

More efficient feed conversion rates and digestion of feed has been researched in a number of trials. Murphy et al. (1994) used 8 ruminally cannulated steers in a 2 × 2 factorial to determine the effects on intake of all-concentrate diets and corn processing. Diets provided equal protein, vitamin and mineral intake. In the study, four time periods occurred in the trial. Each steer was fed 4.35 kg of dry matter (DM) each day during the first period. This represented 70% of NRC requirements for maintenance. Steers were fed either whole-shelled or dry-rolled corn during this first period. For period two steers were fed 6.21 kg to resemble ad libitum feeding, with the same processed grain being fed. Period 3 and 4 used 4.35 kg and 6.21 kg of dry matter intake, respectively. The same steers were used and fed whole-shelled if previously fed dry-rolled, and dry-rolled if previously fed whole-shelled corn (Murphy et al., 1994). The study was able to show how processing affected digestion and intake by comparing the same steers against their own results. Ruminal contents were sampled for pH, and VFA. Sampling was done using techniques of Raun and Burroughs from their studies with intact lambs. Briefly, a suction strainer is inserted into the rumen and fluid can be withdrawn directly, through a rumen fistula. This method did not affect VFA ratio values but there were slightly lower total VFA concentrations and higher pH (Raun 1962). When this method was used for comparative trials, the same method will be consistent enough for comparative results in experiments. Fecal grab samples and feed samples were collected and dried for analysis of DM, OM, N and starch. Digestion of DM and OM demonstrated a grain processing × intake interaction. The high intake dry-rolled corn was 4 % lower in digestibility but low intake dry-rolled corn was 8% higher in digestibility. Starch dry matter digestion was 85% for the low intake dry-rolled diet and 80% for the high intake dry-rolled diet. The Low and high intake whole-shelled diets were 79% and 83%, respectively. There was an intake × processing interaction with dry-rolled corn more readily available to process. Starch digestibility was not affected by processing at high intake levels (Murphy et al., 1994). Overall, processed corn and low intake diets increased DM digestion.

For the high energy dry-rolled corn diets, acetate concentration was lower and propionate concentration was higher compared to the low energy diets. Butyrate concentration increased for dry-rolled corn compared to whole-shelled corn. Ruminal pH was measured to be lower at hours 2, 3, 4, 6, and 9 in dry-rolled corn compared to whole-shelled corn. Fermentation was suspected to be faster for dry-rolled corn and accounted for the decrease in pH. The dry-rolled corn also increased ruminal VFA concentrations, more for the low intake treatment due to decreased ruminal volume (Murphy 1994). In Klinger's, et al. (2007), study with sixteen crossbred steers in confinement, there were two treatments randomly assigned. The high-grain diet consisted of 1.94 Mcal of NEm/kg and 1.27 Mcal NEg/kg, and the high forage diet consisted of 1.57 Mcal NEm/kg and 0.97 Mcal NEg/kg. Feeding the high grain diet resulted in 31% less fecal output (*P*

< 0.05). Steers fed the high-grain diet spend less time ruminating and eating, which could improve efficiency of digestion (Klinger 2007).In Felix's, et al. (2011), study with 144 Angus-cross steers a 2 × 2 factorial arrangement was used with steers blocked by BW into eight pens (2011). Steers were fed one of four treatments: 65% dried distillers' grains (DDG) to gain 0.9 kg of BW/day, 65% DDG fed to gain 1.4 kg of BW/day, 65% corn fed to gain 0.9 kg of BW/day, or 65% corn fed to gain 1.4 kg of BW/day. The remaining fraction of each diet was 15% corn silage and 20% supplement for each steer. Fecal grab samples were used to determine digestion of DM, OM, acid detergent fiber (ADF), and neutral detergent fiber (NDF). Samples were collected on day 52 during the growing phase before and after feeding. DDG diets had lower DM and NDF values (P < 0.02) than corn based diets, and higher nitrogen digestion. Average daily gain (ADG) was highest for steers fed to gain 0.9 kg of BW/day, and did not differ between sources of nutrients for finishing steers, although for growing steers corn based diets did have greater ADG. For finishing steers, those fed to gain 0.9 kg BW/d gained 14% faster than those fed to gain 1.4 kg BW/d, and were lighter starting the finishing phase and more efficient ($P = 0.03$). The limit-fed steers fed to gain lower amounts demonstrated improved efficiency (Felix, 2011).

In Trubenbach's study with 32 crossbred cows, arranged in a 2 × 2 factorial cows were fed either a low energy (1.96 Mcal ME/kg) or high energy (2.54 Mcal ME/kg) diet at either 80% NRC net energy requirements or 120% of NRC net energy requirements. Cows were fed in confinement. Body weight was greater for the high energy diet and did not differ between the 80% and 120% intake levels ($P = 0.08$). Retained energy was higher for the high energy diet at the 120% intake level ($P < 0.1$). The birth weight and adjusted 205 day weaning weight was not affected from the treatments ($P = 0.22$). Increasing dietary energy density decreased maintenance requirements 28%, which greatly improves efficiency of the cow-calf system. The limit-fed system used improved efficiency more notably for the high energy diet compared to the low energy diet (Trubenbach 2014).

Conclusion

Beef cattle can be limit-fed to manage the growing demand of meat protein through improved efficiency and digestibility. In Murphy's study, low intake diets and processed corns improved efficiency and digestion. The pH and VFA concentrations responded accordingly (2014). In Klinger's study, steers fed a high grain diet were also more efficient and hypothesized to ruminate less often. Compared to forages, concentrate is easier to digest and process with more nutrient availability as well (2007). In Felix's study with growing and finishing steers, the diet fed to gain less had significantly improved digestion, although in the different stages of the project steers were slightly more efficient with corn or DDG. Growing steers may affect the project differently and have improved efficiency when limit-fed more strictly (2011). In Trubenbach's study with beef cows, the high energy diet provided more available energy and nutrients to the cows. High energy diets had improved efficiency when using a limit-fed system. Feeding over intake was shown to contribute to this efficiency as well (2014). This study can be compared to steers for an overall picture of the beef industry. Cows and steers seem to respond to limit-fed diets similarly, with improved efficiency in high energy, nutrient dense rations in most cases.

CHAPTER II

MATERIALS AND METHODS

The experimental protocol was approved by the Institutional Animal Care and Use Committee at Texas A&M University (AUP 2014-0003).

We determined the effects of dietary energy consumption on digestion and ruminal fermentation in limit-fed cattle. A set of 16 ruminally cannulated Angus × Hereford (359 kg ± 44 BW) steers were used in a randomized complete block experiment. Steers were fed at one of four levels 70%, 85%, 100% and 115% of maintenance energy requirements. Level of intake was determined amounts determined using metabolic body weight (MBW) and corresponded with a previously conducted cow project. Wheat straw was fed at 26.06 g/kg MBW for each treatment, regard. Concentrate was fed at 49.4, 57.9, 40.6, and 32.0 g/ kg MBW for 100%, 115%, 85% and 70% respectively.

The experimental period was 17d and all steers were housed in a climate controlled barn with free access to water. Prior to starting steers were fasted to determine shrunken BW. Shrunk BW was used for all calculations. After being weighed the steers were penned and fed for the first day of the trial (the morning of day one). Steers were fed every morning at 0530 for consistency, and the barn routinely cleaned in mornings and evenings. From days 1 to 11 steers were adapted to their specific treatment. From days 12 to 15 samples of the concentrate and wheat straw were collected for analysis. They were weighed in a brown bag and put into a forced-air, drying oven at 60 degrees C for 96 h. The drying oven removed moisture from the straw and grain. To get the partial dry matter they were weighed again after allowing the samples to air equilibrate overnight or for 24 h. From days 13 to 16 fecal grab samples were collected every 8 hours for analysis, to compare with collected feed samples. Fecal samples showed what was not digested in each steer. Each day the times of collection shifted two hours forward. This accounted for diurnal variation, or the natural fluctuations that can occur in the feces each day. Each sample collected was taken and added to a larger bucket in an even layer. The layers composed the composite sample and were kept in a freezer as collections were added.

Samples from the rumen were collected h 0 (prior to feeding) and at 2, 4, 6, 9, 12, and 18 h after feeding. A suction strainer was inserted into the rumen, and fluid was collected from three areas of the rumen for a representative sample. Samples were used to determine the VFA content using collection techniques similar to Raun and Burroughs' study with intact lambs (1962). Each time the rumen fluid was collected the pH values of the rumen was determined. Before putting the vials in the freezer at -20 degrees the portable pH probe was placed in each vial and the corresponding pH recorded. Acidity increases when there was more concentrate digested by the microbes and more activity in the rumen.

Samples of rumen fluid were filled in designated vials labelled VFA. There were rumen fluid vials for each steer and for each time of collection, marked h 0, h 2, h 4, h 6, h 9, h 12, and h 18. Each sample was 10 mL total, with VFA samples containing 1 mL 1 N HCl and 9 mL rumen fluid. The VFA labelled samples were stored at -20 degrees C and later spun down in a centrifuge to be sent to Kansas State University for laboratory analysis.

Feed and fecal samples were ground through a 1-mm screen in a Wiley Mill, and a composite sample was dried at 105 degrees C in the forced-air, drying oven for 24 hours. After determining DM the samples were combusted at 450 degrees C for 8 hours to determine organic matter. The acid detergent fiber and neutral detergent fiber values were determined with the ANKOM fiber system. Acid detergent insoluble ash (ADIA) was determined by ashing the ADF residue, which determined total fecal production and ruminal passage as a marker. Feed and fecal samples were placed in a bomb calorimeter to measure gross heat and total gross calories. ADIA was used in calculations for digestibility. Fecal production was calculated by amount of ADIA consumed/concentration of ADIA in feces.

CHAPTER III

RESULTS

Nutrient Digestion and Fecal Production

Treatments fed concentrate at varied NRC requirement levels with treatments at 70%, 85%, 100% and 115% of NEm requirements. Total DM intake, OM intake, NDF, and ADF were linearly significant due to the structure of the treatments ($P < 0.01$). DM digestion was linearly significant ($P = 0.03$) with 70% at 64.9%, 85% at 70.0, 100% at 67.4 and 115% at 74.2%. Diets higher in concentrate were correlated with higher digestion values. OM digestibility was highest for the treatment fed at 115% NEm requirements, at 76.5%, and linearly decreased to 69.95, 72.11, and 68.02 for treatments at 100%, 85% and 70% respectively ($P = 0.03$). NDF and ADF digestibility did not vary significantly between treatments ($P > 0.22$). Gross energy (GE) intake was linearly significant with the 115% treatment being the highest at 20.869 Mcal and treatments 100%, 85% and 70% being 18.571, 16.662, and 14.659 Mcal respectively ($P < 0.01$). Digestible energy (DE) intake was linearly significant following the same trend ($P < 0.01$). GE digestibility was linearly significant with treatments fed at 70%, 85%, 100% and 115% at 65.71, 70.58, 67.85 and 75.10 respectively ($P = 0.03$). Diets higher in concentrate were correlated with higher amounts of GE intake and DE intake.

Ruminal Analysis and Evaluation

The pH for the trial was lowest for the 115% diet at 6.25 and quadratically increased to 6.36, 6.38, and 6.34 for treatments 100%, 85% and 70% ($P < 0.01$). Total VFA was not significant between treatment groups ($P = 0.63$). The acetate to propionate ratio (A: P) followed a quadratic trend and was lower in the 115% diet at 2.89 and highest in the 85% diet at 3.37 ($P = 0.02$).

Treatments higher in concentrate produced more propionate and diets higher in forage produced more acetate. Acetate showed quadratic significance ($P < 0.05$) with values of 66.84, 66.91, 64.61, and 64.26 for treatments 115%, 100%, 85%, and 70% respectively. Propionate showed quadratic significance ($P < 0.05$) with values of 20.52, 20.21, 22.08, and 22.63 for treatments 115%, 100%, 85% and 70% respectively.

Table 1. Effects of levels of concentrate offered on intake and digestion in limit-fed steers.

		Treatment						
Item	115	100	85	70	**SEM**	**Linear**	**Quadratic**	**Cubic**
No. of Observations	4	4	4	4				
Total DM Intake	5.23	4.66	4.19	3.70		<0.01	<0.01	0.56
Total OM Intake	4.85	4.32	3.89	3.43	0.12	<0.01	<0.01	0.56
Total NDF Intake	2.34	2.16	2.04	1.91	0.06	<0.01	<0.01	0.52
Total ADF Intake	1.30	1.23	1.19	1.14	0.03	<0.01	<0.01	0.49
DM Digestibility	74.20	67.37	69.95	64.90	2.94	0.03	0.17	0.13
OM Digestibility	76.50	69.95	72.11	68.02	2.91	0.03	0.16	0.14
NDF Digestibility	67.40	61.69	64.69	62.00	3.22	0.23	0.61	0.19
ADF Digestibility	55.43	51.00	55.22	54.81	3.19	0.83	0.46	0.23
GE Intake	20869	18571	16662	14659	501.73	<0.01	<0.01	0.57
GE Digestibility	75.10	67.85	70.58	65.71	2.99	0.03	0.16	0.11
DE Intake	15671	12591	11755	9638	585.16	<0.01	<0.01	0.03

Table 2. Effects of levels of concentrate on pH and VFA concentration in limit-fed steers.

	Treatment							
Item	115	100	85	70	**SEM**	**Linear**	**Quadratic**	**Cubic**
pH	6.25	6.36	6.38	6.34	0.04	0.04	<0.01	0.17
Total VFA	88.28	88.73	88.15	91.18	4.03	0.63	0.76	0.78
Molar Percentages								
Acetate	64.26	64.61	66.91	66.84	0.92	0.02	0.01	0.30
Propionate	22.63	22.08	20.21	20.52	0.95	0.06	0.04	0.41
Isobutyrate	0.84	0.87	0.82	0.79	0.04	0.32	0.28	0.68
Butyrate	10.00	10.15	10.05	10.08	0.42	0.93	0.99	0.83
Isovalerate	1.39	1.41	1.26	1.06	0.14	0.08	0.10	0.84
Valerate	0.89	0.88	0.75	0.70	0.04	0.00	0.00	0.27
A:P Ratio	2.89	3.02	3.37	3.28	0.16	0.04	0.02	0.37

CHAPTER IV

CONCLUSION

Digestion increased as the level of concentrate increased Dry matter intake, organic matter intake, and digestibility was greater for energy dense diets with more concentrate. Limit-fed diets with high amounts of concentrate, allow steers to digest larger amounts. The more feed and concentrate available provide more nutrients for the steer to utilize. Using this knowledge in the industry could improve production efficiency and weight gain efficiency. The implications for beef cattle producers and finishers would be more cost effective feeding procedures to raise more efficient cattle, which in turn helps meet demand from the world for meat protein.

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