COMPARISON OF FAT SOURCES ON DIGESTION AND RUMINAL

BIOHYDROGENATION IN CATTLE CONSUMING A FEEDLOT

RATION

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JESSICA RAE BABER

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ABSTRACT

Comparison of Fat Sources on Digestion and Ruminal Biohydrogenation in Cattle Consuming a Feedlot Ration. (May 2014)

Jessica Rae Baber
Department of Animal Science
Department of Agricultural Economics
Texas A&M University

Research Advisor: Dr. Tryon Wickersham
Department of Animal Science

Supplemental fat is predominantly fed in feedlots to increase the energy value of the ration. Feedlots utilize supplemental fat to replace energy from grains because of its lower cost per unit of DE. Our objective was to compare the effects of four supplemental fats (animal fat, VOP, interphase and phos) on digestion and biohydrogenation of the ration, the fatty acid profile reaching the duodenum, and on the profile of absorbed fatty acids. Four ruminally and duodenally cannulated Angus steers were used in a 4×4 Latin square. Diet was fed ad libitum at 0700 each day. Periods were 12 d with d1 through 7 for adaptation to the diet, d 8 through 11 was for determination of intake and digestion, and d 12 determined ruminal fermentation. Acid detergent insoluble ash was used as an external marker for duodenal and fecal output determination. Intake of all nutrients did not differ ($P \geq 0.08$) between treatments. Ruminal digestion of OM and NDF were greater in IP than AF and VOP ($P \leq 0.05$). Ether extract digestion appeared to have occurred in the rumen suggesting marker recovery problems at the duodenum, as digestion of EE is not expected. Total tract fatty acid digestion was similar between all treatments ($P \geq 0.16$), and biohydrogenation in the rumen did not differ between treatments ($P \geq 0.05$).

CHAPTER I

LITERATURE REVIEW

Introduction

Fat supplementation can provide more energy in the diet, which allows the animal to deposit more and increase efficiency of gain. Thus, fat supplementation allows for increased animal performance in feedlots (Zinn, 1989b; Plascencia et al., 1999; Vander Pol et al., 2009). The feedlot industry must continually combat rising input costs, particularly feed costs. Rising costs have led many to find alternative sources of feed for cattle. In feedlot diets, grains tend to make up most of the diet. High concentrate diets are used to increase dietary energy, but concentrates used as an energy source can be expensive. Supplementing fat as the energy component of the diet is beneficial by reducing feed costs and lowers DMI.

Feeding supplemental fat in feedlot diets increases ADG of steers which leads to increased G:F in steers if intake does not change (Brandt and Anderson, 1990). Depending on fat source, marbling on carcasses has either increased or been similar to control diets when fed to feedlot steers (Zinn, 1989b; Brandt and Anderson, 1990). Although fat supplementation seems to be beneficial for productive efficiency, the amount of fat added to the diet can have negative effects on rumen fermentation of forage, leading to decreases in production efficiencies. Finding an amount of fat to add to feedlot diets is key since nutrient digestibilities tend to decrease as more fat is added. Fiber digestion has decreased in many trials studying fat supplementation (Zinn, 1989a; Zinn et al., 2000; Plascencia et al., 2003), while others show fat supplementation has not affected fiber digestion (Plascencia et al., 1999; Montgomery et al., 2008). However, total starch

digestion has not been affected by adding fat to feedlot diets. While energy in the diet increases, lipid digestion decreases from increased fat supplementation (Zinn, 1989a).

Discussion

Fat is commonly fed to finishing cattle. Feeding fat to animals is beneficial when energy requirements of the animal are high as fat has 2.25 times more energy than carbohydrates. Fats are classified as two main types, saturated and unsaturated. Fatty acids can be fed as saturated, monounsaturated, or polyunsaturated. Also, they may be free fatty acids or esterified to a glycerol backbone. In diets fed to ruminants, added fats may be protected from the rumen environment through protein coatings. In the rumen, the unsaturated fats become saturated through biohydrogenation, which breaks double bonds into single bonds by adding hydrogen (Byers and Schelling, 1988). Some of the more popular fat sources used in feedlots are yellow grease, tallow, and corn oil. In 2010, inedible tallow and yellow grease totaled over 6 billion pounds produced in the United States, of which just less than 2 billion pounds went into animal feed products (United States Census Bureau, 2010). Yellow grease is usually favored over tallow because tallow requires facilities that can heat up the fat before mixing into the rations whereas yellow grease is liquid at room temperature and easily included into rations.

Fats, especially unsaturated fats, are toxic to microbes in the rumen. Unsaturated fats tend to change the fluidity of the membranes in microorganisms, killing them. Thus, rumen microbes have the ability to hydrolyze esterified fats to free fatty acids. Once this occurs, fatty acids are hydrogenated from polyunsaturated and unsaturated to saturated fatty acids in a process called biohydrogentation. In high grain diets, such as feedlot diets, this hydrogenation is less complete

than when fed high forage diets. Feeding high levels of polyunsaturated oils can decrease hydrogenation because the levels fed are higher than the ability of the rumen microbes to hydrogenate the oils (Byers and Schelling, 1988). Traditionally, added fats are not supplemented at more than 5% of the diet to minimize the toxic effects.

Nutrient digestion and the effect of fat source was studied with five Holstein steers (Montgomery et al., 2008). The diet consisted mainly of steam-flaked corn and sources of fat used in this study were tallow, corn oil, corn germ and flax oil. Steers were allowed ad libitum access to diet and water. Ruminal digestibility of starch was 86.2 (corn germ) to 90.5% (tallow) when fat was supplemented at 4% compared to the control, at 91.5%. Corn germ had the most starch flowing from the rumen to duodenum (446 g/d), almost 200 g more than control (250 g/d; (Montgomery et al., 2008). Zinn et al. (1989a) reported similar ruminal starch digestibilities of 90.3, 90.3 and 90.4% for 0, 4, and 8% supplemental fat, respectively. This study used six crossbred steers to determine the effect of level of fat supplementation on digestion. Steam-rolled barley was used as the basis for the restricted diet fed (1.8% BW). The same study compared yellow grease and blended-animal fat. There was a difference of 2% in ruminal starch digestion with greater starch digestion in steers fed yellow grease than the blended-animal fat treatment (Zinn, 1989a). The interaction of calcium and supplemental fat was studied for effects on nutrient digestion (Zinn and Shen, 1996). The diet fed was based on steam-flaked barley and was restricted to 1.8% BW/d. When a diet of 41% starch similar to Zinn (1989) was fed, ruminal starch digestion was 90.0 and 88.4% for 0 and 5% yellow grease supplementation (Zinn and Shen, 1996). Plascencia et al. (1999) fed 4% added fat with increasing amounts of free fatty acids (15-42%) and a control diet with no added fat. Plascencia et al. (1999) reported ruminal starch digestion tended to

linearly decrease as free fatty acids in the supplement increased. However, these differences were small as the 0% fat diet had 87.7% ruminal starch digestion, whereas the 15% free fatty acid treatment had 85.6% ruminal starch digestion.

Overall fat supplementation did not effect total tract starch digestion. The level of supplementation on total starch digestion is depicted in Figure 1, which demonstrates fat supplementation does not change digestibility of starch. When intake was restricted to 1.8% BW/d and fat supplementation increased from 0% to 8%, total tract starch digestion was between 99.2 and 99.4% (Zinn, 1989a). Plascencia (1999) observed similar results when studying the effects of increasing free fatty acids in a 4% added fat diet. As free fatty acids in a diet increased from 0 to 42% of the diet, total tract starch digestion was around 98.8%. When comparing main effects of the two sources, total tract starch digestion was 99.2 and 99.3% for yellow grease and blended animal-vegetable fat, respectively. Montgomery (2008) fed a diet containing about 60% starch and 4% added fat. Though the diet was higher in starch than the amount fed in Zinn's (1989) study, 60% compared to 37%, the total tract digestibilities were similar, 99.6% and 99.3%. As stated above, there tended to be differences in ruminal starch digestion between the control and treatments, but total tract digestibilities were not different. Therefore, the small and large intestines digested and absorbed the increased amount of starch leaving the rumen. Montgomery et al. (2008) used tallow, corn oil, corn germ, and flax oil. When comparing the animal source (tallow) to the plant sources (corn oil, corn germ, and flax) of supplemental fat, total tract digestibility was not changed, 99.6% and 99.7% respectively. Zinn et al. (1989a) also compared yellow grease and blended animal-vegetable fat as supplemental fat sources. Once again, as there was a difference in ruminal starch digestion between the two sources, as discussed

earlier, but total tract starch digestion did not differ in accordance with Montgomery et al. (2008).

Feed was restricted to 2% BW/d in a study comparing the degree of ruminal biohydrogenation of fat (Zinn et al., 2000). Biohydrogenation takes place in the rumen by microbes. This study fed a formaldehyde-protein protected fat at varying levels to prevent the rumen microbes from changing the structure of the fatty acids. Low biohydrogenation (LBH) had the most formaldehyde-protein protected fat and high biohydrogenation (HBH) consisted of yellow grease. Medium biohydrogenation (MBH) contained a mixture of the two previous treatments. Microbes were able to easily access the HBH treatment for biohydrogenation and had the least access to LBH. This study found adding 4% fat to a finishing diet decreased ruminal starch digestion by 5%. When comparing the 2% added fat to 6% added fat diets, total tract starch digestion significantly decreased from 99% to 98.6%. However total starch digestion was about 98.6% when the degree of biohydrogenation changed from LBH (54%) to HBH (75%). In a study previously mentioned observing the interaction of calcium and fat supplementation, total tract starch digestion was 99.5 and 99.4% for 0 and 5% fat supplementation, respectively (Zinn and Shen, 1996). Effects of body weight and level of fat supplementation on fatty acid digestibilities has been considered (Plascencia et al., 2003). While fatty acid digestion was the primary focus of the study, other nutrient digestibilities were determined as well. Four diets were compared increasing in level of fat supplementation (0, 3, 6, 9%). Level of fat supplementation did not effect total starch digestion. Body weight did not change total digestibility of starch at any of the fat supplementation levels (Plascencia et al., 2003).

Although starch digestion has primarily been unaffected by fat supplementation, fiber digestion has been inconsistently reported. Fat supplementation has been shown to decrease ruminal fiber digestion (Zinn, 1989a; Plascencia et al., 2003; Figure 3). There are a few mechanisms by which dietary fat can reduce fiber digestion. Physical coating of the fiber with fat can reduce digestion and the toxic effects of fat on rumen microbes will reduce fermentation of fiber. When supplementing yellow grease at 0, 4 and 8% intervals of added fat, ruminal ADF digestion decreased from 27.3% to 6.7% (Zinn, 1989a). Plascencia et al. (2003) supplemented fat to steers of different weights to investigate the relationship between body weight and fat supplementation. Ruminal fiber digestion decreased when fed a diet with 15% NDF and intake was restricted to 2.0% BW/d for lightweight (175 kg) and heavyweight (300 kg) steers. Yellow grease was supplemented at 0, 3, 6, and 9% added fat. Ruminal NDF digestion linearly decreased from 46.6% to 27.5% as fat supplementation increased for each weight class of steers. Degrees of biohydrogenation were compared in a study where steers were fed restricted intake of 2.0% BW/d (Zinn et al., 2000). Ruminal NDF digestion decreased from LBH to MBH, 46.3% to 29.3% respectively. Fiber in the LBH diet was likely more easily accessible and therefore digestible. This diet contained the most protein protection which allowed the microbes to access fiber without the toxic coating. High biohydrogenation had 3% greater ruminal NDF digestion than MBH. Plascencia et al. (1999) found ruminal ADF digestion to not be affected by the level of free fatty acids in feed. Also, ruminal ADF digestion percentages (5.9-19.1%) were similar to Zinn's (1989) findings (6.7-27.3%) when both studies used restricted intake between 1.8-2.3% BW/d and fed alfalfa and sudangrass hay for fiber source. Interestingly, the control fed at 0% added fat was similar to the 15% free fatty acid diet for ruminal ADF digestion (Plascencia et al., 1999).

Source of fat supplementation did not effect fiber digestion when feeding a diet containing 13% NDF according to Montgomery et al. (2008). When comparing fat sources, ruminal NDF digestion was consistently around 45%. Total tract NDF digestion was higher at 55% for all sources. When NDF digestibilities for corn germ and corn oil were compared together, corn germ was significantly higher (66.4%) than corn oil (53.1%). A study was done to compare forage levels and fat supplementation and their effects on digestion (Zinn and Plascencia, 1996). Alfalfa was fed as the forage at 10% and 30%, and yellow grease was fed at 0% and 6% added fat. There was not a significant interaction between forage and level of fat supplemented for ruminal ADF digestion. Digestibilities for ruminal ADF ranged between 32% and 42% and fat supplementation did not affect ruminal ADF digestion at either forage level. Tallow, yellow grease, and griddle grease were compared to a no added fat treatment in a study to determine magnesium influences (Ramirez and Zinn, 2000). Ruminal NDF digestion decreased by at least 10% when fat was supplemented at 4%.

Method of incorporating supplemental fat has been thought to change performance and intake of finishing steers (Zinn and Plascencia, 2004). Tallow was incorporated into the diet 3 different ways at 3 different levels of supplementation (3, 6, and 9%). Interactions were found between level and method of supplementation for ADG and intake (Zinn and Plascencia, 2004). Intake decreased linearly as fat supplementation level increased from 3% to 9%. Consistent with these results, Krehbiel et al. (1995a) observed DMI to decrease from 9.3 to 8.83 kg/d when fat supplementation in the form of tallow increased from 0 to 4% (Krehbiel et al., 1995a). However,

Zinn et al. (1989b) found DMI did not change when supplementation as yellow grease increased from 0 to 8%, but 8% supplementation had the highest intake at 6.42 kg/d (Zinn, 1989b).

Although ADG was not affected by level of fat supplementation in Krehbiel et al. (1995a), G:F increased from 0.139 to 0.154 due to decreased intake. Brandt and Anderson (1990) observed similar findings when comparing fat sources supplemented at 3.5%. Soybean oil, tallow, and yellow grease saw increased ADG compared to the control of no added fat by at least 0.08 kg/d. In this study, intake was not affected by fat supplementation, but intake of steers fed tallow (8.67 kg/d) was lower than steers fed yellow grease (9.13 kg/d). Fat supplementation increased G:F from 0.160 to 0.174, but the source of fat did not change gain to feed (Brandt and Anderson, 1990). In another trial, Brandt and Anderson (1990) observed increases in ADG between control, soybean soapstock (SBSS), SBSS/tallow mixture, and tallow from 1.77 to 1.83 kg/d. However, when the control was compared to yellow grease supplement, there were not differences in ADG, but DMI decreased from 9.83 (control) to 9.22 kg/d (yellow grease). During a grain adaptation and subsequent finishing period, performance of finishing steers was observed (Krehbiel et al., 1995b). Average daily gain decreased from 1.77 to 1.33 kg/d as level of fat supplementation increased from 0 to 8% during the 129 d finishing period and DMI decreased from 10.78 to 9.45 kg/d as fat supplementation increased. Accordingly, G:F decreased from 0.164 to 0.142 (Krehbiel et al., 1995b). This indicates the decrease in DMI was not enough to overcome the decreased ADG observed. Steers were fed a high concentrate diet (92.5%) because the study was looking at subacute acidosis in feedlot cattle. Performance of these steers could have been decreased because of acidosis and not necessarily the fat supplement. As mentioned earlier, Zinn et al. (1989b) found DMI was similar across fat supplementation levels. However, G:F linearly

increased from 0.133 to 0.156 as level of supplementation increased. This is mainly due to linear increase of ADG (0.83 to 1.02 kg/d; Figure 2). Zinn et al. (1989b) also studied the effect of source of fat supplementation on performance and found yellow grease and blended animal-vegetable fat did not differ significantly for ADG, 0.996 and 0.944 kg/d, and DMI, 6.41 and 6.19 kg/d. Similarly, G:F was not significantly affected by the source of fat. When fed mainly dry-rolled grain sorghum, tallow supplementation at 4% did not change DMI, ADG or G:F (Huffman et al., 1992). Average daily gain was decreased by 0.25 kg/d (1.38 to 1.13 kg/d) when supplementation increased from 0 to 5% added fat in a study involving corn oil in finishing rations for heifers (Vander Pol et al., 2009). However in the same study, tallow was used as the supplemental fat source at 0, 1.3 and 2.6% of the diet. Average daily gain did not differ between levels, 2.24, 2.21 and 2.29 kg/d for 0, 1.3 and 2.6%, respectively (Vander Pol et al., 2009). Zinn and Shen (1996) found DMI to decrease (0.53 kg/d) when fat level increased from 0 to 5%, which led to an increase in G:F by 0.01.

Ruminal biohydrogenation of fat was studied in a feedlot setting on performance of steers (Zinn et al., 2000). Average daily gain (1.56 and 1.45 kg/d) and DMI (8.41 and 8.77 kg/d) did not differ between fat treatments and control or between susceptibility to ruminal biohydrogenation (Zinn et al., 2000). However, G:F tended to differ between control and supplemental fat treatments, 0.165 (control) and 0.182, 0.177 and 0.180 (LBH, MBH, and HBH). The effect of amount of free fatty acid in feedlot diets on performance in finishing steers was studied in a 144 d project by Plascencia et al. (1999). As free fatty acids in the diet containing 5% fat supplementation overall increased in intervals of 15, 28.5 and 42%, G:F was increased from

0.151 to 0.159. Again, this is caused by a larger increase in ADG than the slight increase in DMI as free fatty acid content increased in treatments.

Fatty acid digestion was also observed in Plascencia et al. (1999). Fatty acid digestion of C18:0 was depressed 15% when 5% fat was added to finishing diets. Total fatty acid digestion was decreased when fat supplementation was incorporated at 8% because of decreased C18:0 digestion. Supplemental fats are high in C18 fatty acids. When these unsaturated C18 fatty acids entered the rumen, microbes saturated the double bonds making the duodenal chyme high in C18:0. Similarly, Zinn et al. (1989) observed a 10% decrease in small intestine lipid digestion as supplementation of yellow grease increased from 0 to 8%. This was probably due to increasing amounts of lipid leaving the abomasum, 166, 326 and 481 g/d for 0, 4, and 8% fat treatments. Also, when diets were supplemented at 6% yellow grease, postruminal C18:0 digestion decreased from 77 to 50%, which accounts for the 16% depression of total fatty acid digestion (Zinn, 1992). However, postruminal digestion of C14:0 increased from 34 to 62%. Interestingly, when the microbes' ability to hydrogenate fat increases, the postruminal C18:0 digestion decreases from 87% (LBH) to 77% (HBH). This could indicate the small intestine has a great C18:0 supply, resulting from biohydrogenation, than it can absorb. There was a linear decrease in posturminal total fatty acid digestion when going from LBH to HBH. Also, Zinn et al. (2000) found unsaturated C18 fatty acids have greater postruminal fatty acid digestion in diets with added fat than the control.

One of the main reasons to include fat in feedlot diets is to increase energy density. Zinn (1989a) fed diets with increasing amounts of gross energy from supplemental fat (23.4 to 26.4 Mcal/d).

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However, gross energy in fecal excretions increased (4.01 to 5.58 Mcal/d) with increasing amounts of supplemental fat. This makes the gross energy used in the body similar for all diets. Increased energy content in feces may be associated with either the decreased fatty acid digestion or the decreased fiber digestion observed when the level of fat supplementation increases. Zinn (1989a) also studied how the source of fat affects nutrient digestion. Gross energy was similar for yellow grease and blended animal-vegetable fat, 25.6 and 25.7 Mcal/d, respectively. While fecal excretion of gross energy was not significantly different. Yellow grease had a greater amount of gross energy, 0.23 Mcal/d more, than the other source.

Conclusion

While ADG has been found to increase when supplemented with fat, the amount of fat included in the diets should be considered. The harsh effects of supplemental fat on digestive characteristics of nutrients will eventually decrease the efficiency of the animal. Fiber digestion is decreased when dietary fat increased, but this can change depending on how the diet is prepared and the rumen characteristics. Total tract starch digestion does not change due to increase fat supplementation or the source of fat. This suggests that the detrimental effects from fat to the rumen only effects the fiber fermenting bacteria. Including levels of supplemental fat at low levels does not harm digestibilities of fiber as much as at higher levels, and the low levels of inclusion will increase ADG and G:F. The source of fat, level of free fatty acids, and biohydrogenation levels do not seem to be detrimental to nutrient digestion or animal performance.

CHAPTER II

MATERIALS AND METHODS

The experimental protocol was approved by the Institutional Animal Care and Use Committee at Texas A&M University.

Four Angus steers fitted with ruminal and duodenal cannulas were used in a 4×4 Latin square design experiment. Steers were housed in an enclosed barn in individual pens and had ad libitum access to water and commercial trace mineral blocks. Four treatments were compared: 1) animal fat (AF), 2) VOP, 3) Interphase/Kappa (IP), and 4) Phos (PHOS). Four experimental 12 d periods were used, each consisting of 6 d for adaptation, 5 d for intake and digestion measurements, and 1 d for sampling rumen fluid for ruminal pH, VFA, and NH_3 measurements. Diets were fed daily at 0730 and were offered ad libitum consumption (Table 1). On d 7 through 10 diet samples were obtained before feeding. Feed refusals were collected and sub-sampled before feeding on d 7 through 10. Feed and feed refusals were dried at 55°C for 96 h then weighed for partial dry matter (PDM) and frozen at -20°C.

Chromic Oxide (10g/d) was hand mixed into the diet prior to feeding on d 1 through 11 to estimate duodenal flow and fecal output. N^{15} isotope was hand mixed into the diet on d 4 through 11 to estimate microbial flow. On d 8 through 11, duodenal and fecal samples were collected 3 times daily and immediately frozen at -20°C. Duodenal and fecal samples were collected every 8 h with sample time advancing 2 h each day so samples were obtained at 2 h intervals in a 24 h period over a 4 d collection period. Approximately 500 g of whole ruminal contents was

collected once daily on d 8 through 11 for rumen bacteria. Ruminal contents were immediately blended for 5 minutes in a Waring blender with 500 mL of 0.9% saline solution. Blended ruminal contents were strained through 2 layers of cheesecloth and the strained liquid was frozen at -20°C. Collection times advanced 6 h each day thus samples were obtained at 6 h intervals in a 24 h period over a 4 d collection period. On d 12, a suction strainer (Raun and Burroughs, 1962; 19 mm diameter, 1.5 mm mesh) was used to collect rumen fluid samples prior to feeding (0 h) and 3, 6, 9, 12, and 18 h after feeding. A portable pH meter was used to measure the pH of each sample immediately after each sampling time. Subsamples of the rumen fluid were prepared for later determination of VFA and NH_3 and frozen at -20°C. Before freezing, 8 mL of rumen fluid was combined with 2 mL of 25% *m*-phosphoric acid for VFA analysis, and 9 mL of rumen fluid was combined with 1 mL of 1 *N* HCl for NH_3 analysis. At h 4 after feeding on d 12, blood samples were obtained from the jugular vein of each steer with 15 mL heparinized tubes, and was placed on ice immediately. Blood samples were centrifuged at $5000 \times g$ for 15 min. Blood plasma was frozen at -20°C.

Feed, orts, and fecal samples were dried at 55°C in a forced-air oven for 96 h, air-equilibrated, then weighed to determine partial DM. Duodenal samples were lyophilized. Feed, orts, duodenal, and fecal samples were ground in a Wiley mill to pass a 1-mm screen. Feed, orts, and fecal samples were composited by steers across days within period. Chromium concentrations of feed, orts, duodenal, and fecal samples were determined by SDK labs. Feed, orts, duodenal, and fecal samples were dried at 105°C in a forced-air oven for 24 h to determine DM then ashed for 8 h at 450°C to determine OM. Nitrogen was measured using the Elementar rapid N cube (Elementar, Hanua, Germany) and CP was calculated as N × 6.25. Feed, orts, duodenal, and fecal samples

will be analyzed for NDF and ADF using an Ankom Fiber Analyzer with sodium sulfite and amylase omitted and without correction for residual ash (Ankom Technology Corp., Macedon, NY).

Rumen fluid samples were thawed and centrifuged at $20,000 \times g$ for 20 minutes. Volatile fatty acid concentrations were measured using a gas chromatograph with methods described by Vanzant and Cochran (1994). Ammonia N concentrations were measured using a UV-vis with colorimetric procedures described by Broderick and Kang (1980). Samples of ruminal contents were thawed to isolate ruminal bacteria. Thawed samples were centrifuged at $500 \times g$ for 20 min to remove feed particles in the samples. Supernatants were centrifuged at $20000 \times g$ for 20 min to pellet the bacteria. Bacteria pellets were re-suspended in 0.9% NaCl solution and centrifuged at $20000 \times g$ for 20 min. The bacteria pellet samples were frozen then lyophilized. After samples were lyophilized, the dried bacteria were analyzed for DM, OM, N, and N^{15}.

Samples of feed, orts, duodenal, and feces were sent to SDK labs (Hutchinson, KS) for analysis of total starch, acid hydrolysis, ether extract, and fatty acid composition by gas chromatography. Samples were also sent off for analysis of chromium.

Calculations

Acid detergent insoluble ash was used as digestion markers to estimate digestibility. Duodenal and fecal output was calculated as amount of ADIA (g/d) consumed divided by the concentration of ADIA in the duodenal chyme and feces (g/g of DM). Nutrient digestibilities were calculated by the following formula: [1-(output of nutrient/intake of nutrient)] $\times$ 100. The amount of N of

microbial origin was determined by dividing duodenal N^{15} isotope flow by the measured

microbial N^{15} isotope:N ratio. Organic matter truly fermented in the rumen was determined by

subtracting microbial OM from total OM reaching the duodenum.

Table 1. Nutrient composition of experimental diets fed to steers

Item	AF[1]	VOP	IP[2]	PHOS
OM, %	94.1	93.5	93.2	93.6
CP, %	12.8	12.7	14.0	12.8
NDF, %	35.6	36.1	36.6	36.0
ADF, %	22.5	22.1	22.8	22.3
Starch, %	28.8	28.7	26.4	27.3
Ether Extract, (**EE**) %	6.3	6.0	5.7	6.3
Acid Hydrolysis, (**AH**) %	7.3	6.7	7.0	7.1

[1]AF = animal fat
[2]IP = interphase

CHAPTER III

RESULTS

Nutrient Intake and Digestion

Intake of all nutrients was similar between treatments ($P \geq 0.08$; Table 2). Ruminal digestion of OM and NDF was greater for IP than VOP and AF ($P \leq 0.05$) and tended ($P \leq 0.08$) to be greater for IP than PHOS, 66.01 and 54.64%, respectively (Table 3). Ruminal digestibility of ADF was greater for IP than VOP ($P \leq 0.05$). Ruminal starch digestion was greater for IP than all other treatments ($P \leq 0.01$). There was a tendency ($P = 0.08$) for PHOS to have greater ruminal starch digestion than VOP, 70.7 and 63.8%, respectively. All treatments had positive EE and AH ruminal digestibilities, there were expected to be negative due to microbial lipid synthesis. This data suggests problems with marker recovery. Ruminal AH digestion was greater in steers supplemented with IP than VOP ($P \leq 0.05$), and tended ($P = 0.07$) to be greater for IP than AF. Duodenal flow of OM, NDF, ADF, starch and AH were greater for AF and VOP than IP ($P \leq 0$ .05). Duodenal flow of ether extract was less for IP than AF, 0.34 kg/d and 0.50 kg/d, respectively ($P \leq 0.05$).

Starch flow tended ($P = 0.08$) to be greater for PHOS (0.79 kg/d) than VOP (1.07 kg/d). Ether extract flow to the duodenum tended ($P = 0.09$) to be less for IP than VOP, 0.34 and 0.45 kg/d, respectively. Total digestion of OM tended ($P \leq 0.10$) to be greater for IP than AF and PHOS, and IP was greater than VOP ($P \leq 0.05$) for total OM digestion. Total digestion of NDF tended ($P = 0.08$) to be greater for IP than VOP, 46.97 and 26.57%, respectively. Total digestibility of ADF was greater for IP than VOP ($P \leq 0.05$), while total ADF digestion tended to be less for

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VOP than AF ($P = 0.09$). However, total starch digestion was greatest in VOP than IP, 97.93 and 94.14%, respectively ($P \leq 0.05$). Also, PHOS tended ($P = 0.09$) to be lower in total starch digestion than VOP. Total digestion of EE was similar for all treatments ($P \geq 0.16$), and total AH digestion was greater for IP than VOP ($P \leq 0.05$). Fecal excretion of OM, NDF, ADF, starch, and EE were similar for all treatments ($P \geq 0.07$). Fecal excretion of AH was greater for VOP than IP, 0.29 and 0.19 kg/d, respectively ($P \leq 0.05$).

Fatty Acid Intake and Digestion

Animal fat resulted in greater intake of C16:0, C17:0, C18:0 compared to other fat sources ($P \leq$ 0.05; Table 4). All treatments differed in amounts of C18:3 ($P \leq 0.05$), and all had greatest intake of C18:2. Intake of C18:1 and C18:2 were greater in AF and IP than VOP and PHOS ($P \leq 0.05$). Intake of C18:0 was less than C18:1 and C18:2 in all treatments. Duodenal flow of C18:0, C18:1 and C18:2 were similar between treatments (Table 5). Although intake of C18:0 was low, duodenal flow of C18:0 was greatest for all treatments because of the movement from C18:1 and C18:2 to C18:0. C18 biohydrogenation did not differ between treatments ($P \geq 0.05$) and ranged from 78.31% to 91.89%.

Ruminal Characteristics

Effects of fat supplementation on ruminal fermentation characteristics are reported in Table 7. PHOS had a greater percentage of acetate than AF ($P \leq 0.05$), while AF had a greater percentage of propionate ($P < 0.05$). Molar percentage of acetate tended to be lower for AF than IP ($P \leq$ 0.05). There tended to be greater molar percentage of butyrate for PHOS than AF, 13.86 and 10.99%, respectively. Ruminal pH tended ($P = 0.10$) to be greater for PHOS than VOP, while

other comparisons between treatments were similar ($P \geq 0.14$). Ruminal ammonia did not differ

significantly between treatments ($P \geq 0.19$).

Table 2. Effect of fat supplementation on intake and nutrient flow in cattle consuming a finishing ration (Marker = ADIA)

Item	Treatment[1]				SEM	Contrast *P*-value[2]					
	AF	VOP	IP	PHOS		AF-IP	AF-PHOS	AF-VOP	IP-PHOS	IP-VOP	PHOS-VOP
No. of observations	4	4	3	4							
Intake, kg/d											
OM	9.28	9.01	8.70	8.84	0.42	0.25	0.31	0.51	0.76	0.52	0.69
NDF	3.45	3.38	3.27	3.31	0.21	0.46	0.50	0.76	0.88	0.63	0.71
ADF	2.15	1.97	1.94	1.99	0.14	0.17	0.22	0.18	0.72	0.82	0.89
Starch	2.89	2.87	2.71	2.69	0.20	0.44	0.32	0.91	0.90	0.50	0.37
EE	0.63	0.59	0.54	0.60	0.36	0.08	0.48	0.33	0.20	0.28	0.76
AH	0.73	0.65	0.68	0.67	0.41	0.44	0.29	0.16	0.82	0.54	0.66
Flow to duodenum, kg/d											
OM	4.73	4.67	3.07	3.98	0.37	0.02	0.15	0.89	0.12	0.02	0.18
NDF	1.95	1.90	1.36	1.72	0.16	0.03	0.27	0.77	0.13	0.05	0.39
ADF	1.43	1.43	1.04	1.23	0.09	0.02	0.11	0.95	0.15	0.02	0.10
Starch	1.02	1.07	0.32	0.79	0.16	<0.01	0.13	0.70	0.02	<0.01	0.08
EE	0.50	0.45	0.34	0.42	0.04	0.03	0.19	0.37	0.17	0.09	0.60
AH	0.53	0.51	0.37	0.47	0.04	0.03	0.25	0.61	0.11	0.05	0.49
Fecal excretion, kg/d											
OM	2.69	2.96	1.98	2.53	0.32	0.15	0.70	0.52	0.25	0.07	0.32
NDF	1.65	1.69	1.27	1.59	0.21	0.22	0.81	0.86	0.29	0.18	0.68
ADF	1.29	1.46	1.05	1.29	0.19	0.36	0.99	0.44	0.35	0.14	0.45
Starch	0.29	0.35	0.16	0.23	0.06	0.66	0.49	0.20	0.31	0.13	0.50
EE	0.06	0.09	0.06	0.08	0.01	0.29	0.87	0.42	0.24	0.11	0.52
AH	0.24	0.29	0.17	0.25	0.05	0.13	0.42	0.38	0.34	0.04	0.13

[1]AF = animal fat; IP = Interphase/Kappa

[2]AF-IP = animal fat vs. interphase/kappa; AF-PHOS = animal fat vs. PHOS; AF-VOP = animal fat vs. VOP; IP-PHOS = interphase/kappa vs. PHOS; IP-VOP = interphase/kappa vs. VOP; PHOS-VOP = PHOS vs. VOP

Table 3. Effect of fat supplementation on site and extent of nutrient digestion in steers (Marker = ADIA)

Item	Treatment[1]				SEM	Contrast P-value[2]					
	AF	VOP	IP	PHOS		AF-IP	AF-PHOS	AF-VOP	IP-PHOS	IP-VOP	PHOS-VOP
No. of observations	4	4	3	4							
Ruminal digestion, %											
OM	48.91	48.72	66.01	54.63	4.0	0.02	0.24	0.97	0.06	0.02	0.23
NDF	43.11	44.70	60.13	46.89	4.0	0.02	0.39	0.77	0.08	0.04	0.56
ADF	32.98	27.08	47.94	37.60	6.0	0.12	0.55	0.45	0.25	0.05	0.20
Starch	65.52	63.78	89.00	70.67	5.0	<0.01	0.16	0.60	<0.01	<0.01	0.08
EE	19.48	23.38	38.40	29.01	8.0	0.13	0.36	0.66	0.41	0.23	0.61
AH	25.05	21.77	46.06	28.35	7.0	0.07	0.71	0.71	0.11	0.05	0.47
Total tract digestion, %											
OM	71.02	67.32	77.84	71.74	2.0	0.08	0.81	0.24	0.10	0.02	0.17
NDF	52.11	50.25	62.54	52.89	4.0	0.12	0.88	0.73	0.15	0.08	0.62
ADF	39.77	26.57	46.97	36.43	5.0	0.35	0.61	0.09	0.19	0.03	0.18
Starch	90.29	97.93	94.14	91.53	2.0	0.11	0.51	0.23	0.24	0.03	0.09
EE	89.70	85.56	89.97	87.76	2.1	0.93	0.47	0.16	0.46	0.17	0.42
AH	66.72	55.39	75.24	63.36	7.0	0.33	0.65	0.16	0.19	0.05	0.30

[1]AF = animal fat; IP = Interphase/Kappa

[2]AF-IP = animal fat vs. interphase/kappa; AF-PHOS = animal fat vs. PHOS; AF-VOP = animal fat vs. VOP; IP-PHOS = interphase/kappa vs. PHOS; IP-VOP = interphase/kappa vs. VOP; PHOS-VOP = PHOS vs. VOP

Table 4. Effect of fat supplementation on fatty acid intake in steers

Item	Treatment[1]				SEM
	AF	VOP	IP	PHOS	
No. of observations	4	4	3	4	
Intake, g/d					
C14:0	3.18[b]	0.38[a]	1.23	0.00[a]	0.81
C14:1	0.00	0.00	0.36	0.00	0.16
C15:0	0.00	0.15	0.00	0.00	0.09
C15:1	0.00	0.00	0.00	0.00	0.00
C16:0	106.41[b]	78.55[a]	75.51[a]	70.16[a]	8.38
C16:1	0.95[b]	0.00[a]	0.03[a]	0.00[a]	0.21
C17:0	0.49	0.15	0.36	0.00	0.24
C18:0	36.18[b]	15.82[a]	17.01[a]	15.15[a]	4.18
C18:1	182.94[a]	115.03[b]	131.03[a]	119.54[b]	13.70
C18:2	230.81[a]	301.04[b]	246.67[a]	316.74[b]	18.01
C18:3	2.24[a]	11.78[b]	7.04[c]	14.06[d]	0.69
C20:0	0.68	0.45[b]	1.06[a]	0.48	0.17
C20:1	1.85[a]	0.16[b]	0.97[c]	0.19[b]	0.22
C20:2	1.06[a]	0.00[b]	0.22	0.00[b]	0.37
C20:3	0.00	0.00	0.00	0.00	0.37
C22:0	0.21[a]	1.56[b]	1.43[b]	2.14[c]	0.24
C22:1	1.16	1.02	1.13	1.75	0.33
C22:2	0.00	0.00	0.00	0.00	0.00
C24:0	0.55[a]	1.41	1.31	1.84[b]	0.38
C24:1	0.00	0.00	0.00	0.00	0.08

[1]AF = animal fat; IP = Interphase/Kappa. Means within a row with different superscripts differ (P < 0.05).

Table 5. Effect of fat supplementation on fatty acid profile reaching the duodenum and biohydrogenation in steers

Item	Treatment[1]				SEM
	AF	VOP	IP	PHOS	
No. of observations	4	4	3	4	
Flow to duodenum, g/d					
C14:0	1.54[a]	0.74	0.34[b]	0.40[b]	0.30
C14:1	0.59	0.21	0.34	0.20	0.26
C15:0	1.10	1.13	1.48	1.16	0.19
C15:1	0.00	0.00	0.00	0.00	0.00
C16:0	94.14[a]	66.74[b]	51.05[b]	56.73[b]	5.94
C16:1	0.00	0.00	0.00	0.00	0.00
C17:0	1.50[a]	0.68[b]	0.31[b]	0.85	0.25
C18:0	333.93	335.65	208.06	328.31	45.96
C18:1	29.55	17.75	45.14	11.98	19.07
C18:2	19.57	16.60	13.09	14.50	4.10
C18:3	0.00	0.66	0.59	0.00	0.45
C20:0	5.13[a]	3.17[b]	2.85[b]	2.72[b]	0.40
C20:1	1.98	0.55	1.39	0.40	0.73
C20:2	0.91[a]	0.33	0.00[b]	0.00[b]	0.33
C20:3	0.37	0.00	0.00	0.00	0.16
C22:0	1.39	1.66	1.55	1.69	0.23
C22:1	1.10	0.63	0.52	0.60	0.35
C22:2	0.00	0.00	0.00	0.00	0.00
C24:0	1.89	2.25	1.58	2.23	0.26
C24:1	3.90[a]	2.14[b]	0.92[b]	1.89[b]	0.61
C18 biohydrogenation, %	85.53	89.98	78.31	91.89	6.42

[1]AF = animal fat; IP = Interphase/Kappa. Means within a row with different superscripts differ (P < 0.05).

Table 6. Effect of fat supplementation on fecal fatty acid profile in steers

Item	Treatment[1]				
	AF	VOP	IP	PHOS	SEM
No. of observations	4	4	3	4	
Fecal Excretion, g/d					
C14:0	0.48	0.50	0.55	0.52	0.92
C14:1	0.51	0.59	0.72	0.56	0.16
C15:0	0.31	0.59	0.72	0.56	0.16
C15:1	0.04	0.00	0.10	0.05	0.06
C16:0	10.32	12.09	8.36	10.41	1.72
C16:1	0.05	0.00	0.07	0.05	0.06
C17:0	0.06	0.04	0.10	0.06	0.06
C18:0	28.97	43.38	21.74	36.68	8.60
C18:1	11.23	12.94	11.44	1.29	2.04
C18:2	8.60	10.49	8.45	8.45	1.76
C18:3	0.00	0.00	0.00	0.06	0.04
C20:0	1.04	1.22	0.77	1.21	0.28
C20:1	0.59	0.63	0.57	0.85	0.19
C20:2	0.38	0.29	0.36	0.49	0.15
C20:3	0.20	0.35	0.29	0.37	0.16
C22:0	0.45	0.72	0.54	0.81	0.20
C22:1	0.60	0.80	0.70	0.86	0.16
C22:2	0.00	0.19	0.18	0.00	0.10
C24:0	0.63	1.01	0.76	1.00	0.23
C24:1	0.65	0.87	0.79	1.02	0.22

[1]AF = animal fat; IP = Interphase/Kappa. Means within a row with different superscripts differ ($P < 0.05$).

Table 7. Effect of fat supplementation on ruminal fermentation characteristics

Item	Treatment[1]				SEM	Contrast, *P*-value[2]					
	AF	VOP	IP	PHOS		AF-VOP	AF-IP	AF-PHOS	VOP-IP	VOP-PHOS	IP-PHOS
No. of Observations	4	4	3	4							
Total VFA, m*M*	144.0	147.8	146.7	139.7	8.85	0.62	0.76	0.58	0.90	0.31	0.44
Molar percentages											
Acetate	52.76	53.61	54.50	54.34	1.81	0.26	0.06	0.04	0.36	0.33	0.94
Propionate	32.08	30.82	28.83	27.45	2.58	0.46	0.13	0.03	0.32	0.09	0.48
Butyrate	10.99	11.44	12.88	13.86	1.28	0.73	0.24	0.07	0.35	0.11	0.52
Valerate	1.92	2.06	1.82	2.00	0.34	0.63	0.77	0.79	0.49	0.83	0.61
Isovalerate	1.36	1.26	1.06	1.40	0.19	0.66	0.27	0.87	0.45	0.56	0.23
Isobutyrate	0.89	0.81	0.88	0.94	0.09	0.46	0.92	0.65	0.57	0.26	0.61
Ruminal pH	5.81	5.79	5.83	5.94	0.10	0.78	0.86	0.14	0.68	0.10	0.24
No. of Observations	3	3	2	3							
Ammonia, m*M*	5.10	7.74	6.32	5.92	0.92	0.50	0.19	0.35	0.35	0.73	0.47

[1]AF = animal fat; IP = Interphase/Kappa

[2]AF-IP = animal fat vs. interphase/kappa; AF-PHOS = animal fat vs. PHOS; AF-VOP = animal fat vs. VOP; IP-PHOS = interphase/kappa vs. PHOS; IP-VOP = interphase/kappa vs. VOP; PHOS-VOP = PHOS vs. VOP

CHAPTER IV

DISCUSSION

Sources of supplemental fats were fed at 4% DM in a finishing ration and intake of DM, OM, starch and N was similar across all sources of fat. We observed greater ruminal NDF digestion in steers supplemented IP than AF or VOP and greater ruminal ADF digestion for IP than VOP. Ruminal NDF digestion was similar to observations reported by Montgomery et al. (2008). Other studies have reported ruminal ADF and NDF digestion to be much lower (Zinn, 1989; Plascencia et al., 1999; Plascencia et al., 2003). Zinn (1989a) reported fiber digestion to differ with varying fat sources. Blended animal-vegetable fat had lower fiber digestion (8%) than yellow grease (17.2%; Zinn, 1989). These findings were much lower than the findings in our study. Our diet consisted of 22% ADF whereas Zinn (1989a) fed a diet of 12% ADF. Lower fiber digestion could have been due to a larger proportion of fat to fiber, making the forage in the Zinn (1989a) study coated with greater amounts of fat. Ruminal starch digestibilities were greater for IP than any other fat source in our study. In contrast, Montgomery et al. (2008) did not see changes in ruminal starch digestion between fat sources, which is similar to the findings by Zinn (1989a). However ruminal starch digestion was lower for yellow grease than griddle grease when sources were fed at 4% added fat (Plascencia et al., 1999).

Total tract digestibility of OM was greater for IP than VOP. Overall, total OM digestion (67-77%) was lower than what has been found in other studies (80-85%; (Zinn, 1989; Zinn et al., 2000; Montgomery et al., 2008). Total starch digestion was similar to values observed in other studies (Zinn, 1989). While there were large differences between our findings and other studies

(Zinn, 1989; Plascencia et al., 1999; Plascencia et al., 2003) for ruminal fiber digestion, there were not as large of differences in total tract fiber digestion. Our treatments were all similar in total fat digestion and this corresponds other findings (Plascencia et al., 1999; Plascencia et al., 2003).

In the rumen, fat usually appears making the flow of chyme to the duodenum higher in fat than the diet fed. However, our data indicates a disappearance of fat in the rumen. This observation is likely attributable to failing to collect a representative sample of digesta flowing to the duodenum. Most studies find a net appearance of fat when leaving the abomasum (Zinn et al., 2000; Plascencia et al., 2003; Montgomery et al., 2008), but some have shown a small disappearance of fatty acids after leaving the abomasum (Plascencia et al., 1999). The differences seen in fatty acid profile are due to the treatments being from different fat sources.

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