GRAIN ADAPTATION AND SOURCE IMPACT ON EATING BEHAVIOR AND PERFORMANCE OF FEEDLOT STEERS

By

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Title of Study: GRAIN ADAPTATION AND SOURCE IMPACT ON EATING BEHAVIOR AND PERFORMANCE OF FEEDLOT STEERS

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Abstract: A feedlot experiment was conducted to evaluate the effect of replacing steam-processed corn (SPC) with steam-flaked wheat (SFW) in feedlot rations. In experiment 1, 152 crossbred steers (321 ± 2.7 kg BW) were blocked by weight and randomly assigned to 1 of 4 treatments with 8 pens per treatment. Treatments contained varying levels of SFW (0, 20, 40, 60; CON, SFW20, SFW40, SFW60) were fed for 175d. All diets contained DDGS 20% of diet DM. In experiment 2, 6 ruminally cannulated steers (BW 395 ± 12 kg) were used to determine the *in situ* DM digestibility (ISDMD) of a fresh sample of: 1) dry-rolled corn (DRC); 2) SFW obtained immediately after flaking (SFW-F); 3) SFW obtained after drying through a vacuum air lift (SFW-D); 4) steam-flaked corn (SFC) obtained from a commercial feed yard (SFC); 5) composited sample of SPC fed throughout Exp. 1 (SPC). In Exp. 1 no differences in BW ($P = 0.74$) or ADG ($P = 0.45$) were observed. SFW60 had the lowest DMI ($P = 0.05$). A positive linear relationship in G:F ($P = 0.03$), YG ($P = 0.01$) and wheat inclusion. Cost of gain can be maintained if wheat price/27 kg is $0.18 to $0.76 greater than 25 kg of corn. In Exp. 2 there was no difference between SFW-E and and SFW-F ($P = 0.99$) and SFP had lower ISDMD than SFC at all time points ($P < 0.01$). Steam-flaked wheat can effectively be fed to feedlot cattle, but further research is needed to determine optimum dietary inclusion and when SFW is competitively priced to SPC. Two hundred and twenty-three steers (initial BW= 556.5 ± 4.2 kg) were adapted to an 90.75% concentrate diet using 4 diets to analyze feeding behavior during adaptation to a finishing diet in both winter and summer. Four step diets contained 22.3, 34.8, 42.8, 49.8, and 57.5% DRC, DM basis. Diet volume, energy, and DMI were calculated per meal and per d. Dry matter intake was greatest in FIN (P < 0.0001), and energy intake per d was greatest in FIN ($P < 0.0001$). Energy intake per meal was greatest in STEP4 and FIN ($P < 0.0001$). Increase in eating rate was likely due to less ensalivation needed in low forage diets. Data suggests that cattle consumed to physical fill in STEP1 and STEP2 and consumed to chemostatic fill in STEP3, STEP4 and FIN. Previous water restriction, animal size (> 550 kg), and previous nutrition (54.8% wet corn gluten feed for 160d) may have increased caloric capacity.

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CHAPTER I

INTRODUCTION

The use of wheat as grain in feedlot diets has grown over the last 20 years (Galyean and Gleghorn, 2001; Samuelson et al., 2015; Vasconcelos and Galyean, 2007). Previous research (Owens et al., 1997; Zinn 1992) has shown that feeding wheat in feedlot diets will result in similar performance to feeding corn. Zinn (1992) determined that the NEg value of steam-flaked wheat (SFW) is 97% that of steam-flaked corn (SFC). Limited published research (Huck et al., 1998; Kreikemeier et al., 1987; Stock et al., 1987) exists investigating positive associative effects of feeding multiple grains in a finishing diet. When feeding multiple grains advantages in growth performance may occur due to improvements in grain fermentation, digestibility, and N metabolism. However, no previous research has been done with feeding a combination of SFC and steam-flaked wheat (SFW). With high production costs in the beef production system, accurate estimates of growth performance using different feedstuffs is vital. Growth performance of cattle fed SFC and SFW will be used to determine which grain is more economical at a given price and inclusion in the diet. Depending on the corn and wheat price in certain regions, opportunity may occur to feed wheat if it provides similar growth performance. Variation in climate and rainfall in certain regions may limit cereal grain production. Daryanto et al. (2016) found that during a 40% reduction in water supply.

corn will lose 39.3% of its yield while wheat will only lose 20.2% Therefore, wheat may be a feasible alternative in areas and periods of limited water supply.

Adaptation to the finishing diet is an important facet of feedlot nutrition. As ruminants, cattle are adapted to consuming diets high in fiber. Consumption of a high grain diet requires cattle to adapt to the new feed source to prevent acidosis. The adaptation is needed: 1) for the rumen microbial community to adjust to a new substrate, and 2) for ruminant animals to adapt their feeding behavior from a gut-fill to a chemostatic fill mechanism. Previous research (Fulton et al., 1979; Gaylean and Defoor, 2003) indicates that DMI will decrease as roughage is removed from the diet. In addition, meals will become smaller as cattle change their regulation of feeding behavior from a gut-fill to a chemostatic mechanism (Fulton et al., 1979). The feeding of corn by-products has become commonplace in many North American feedlot diets (Klopfenstein et al., 2008) and receiving diets contain higher levels of corn by-product (Samuelson et al., 2015). Further research is needed to understand how varying levels of roughage and corn by-product during grain adaptation contribute to changes in feeding behavior. Lastly, existing databases investigating changes eating behavior during in grain adaptation have been collected with a small number of animals in metabolism trials (Fulton et al., 1979; González et al., 2012). New data with larger pens are needed to understand how cattle change their feeding behavior when given large amounts of starch in a pen environment. The objectives of the experiments presented herein include: 1) Examine the differences in feedlot performance and carcass characteristics between steers fed SFW or steam-processed corn (SPC). In addition, investigate possible associative effects on growth performance from feeding multiple flaked grains. Finally, both dried and fresh SFW and

SPC were used to test possible effects of drying immediately after flaking on DM and starch *in situ* digestibility, and 2) determine how individual animal feeding behavior changes during adaptation from a low energy, high forage diet to a high energy, high grain diet. Differences in DM, calories, and liters will be used to evaluate changes in mass, energy, and volume, respectively, consumed per meal. Changes in feed intake regulation will help determine when cattle have transitioned from physical to a chemostatic fill mechanism.

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CHAPTER II

REVIEW OF LITERATURE

FEEDING WHEAT TO FEEDLOT CATTLE

Wheat in feedlot diets

The feedlot sector of North American beef production is often characterized by the feeding of cereal grains. Of these grains corn is the most common, but variation price and availability provide opportunities for other grains to be fed. Wheat, barley, and milo are also used in feedlot diets. Wheat is characterized by its high digestibility and high fermentation in the rumen. Over the past 50 years of feedlot research, wheat has been established as a promising grain source in feedlot diets. This literature review analyzes growth performance and metabolism research trials evaluating wheat compared to other grains and the use of different grain processing methods with wheat to maximize performance.

The 2015 Texas Tech Feedlot Survey (Samuelson et. al., 2015) surveyed 49 consulting feedlot nutritionists regarding their current nutritional recommendations and common management practices by their clients. In the survey 43.5% of respondents said their clients use wheat as a secondary grain in receiving diets and 50% said their clients used wheat as a secondary grain in finishing diets. An upward trend has been shown in wheat usage in feedlot diets since 2000 when the first Texas Tech Survey was done. In the 2000 survey 25% of respondents said their clients used wheat as a secondary grain, which was less than milo use. In the 2007 survey Vasconcelos and Galyean (2007) 37% of feedlot clients used wheat as a secondary grain while only 31% used milo (Samuelson, et al. 2015).

Wheat composition

Various wheat varieties include hard red winter, hard red summer, durum and soft wheat. Wheat is classified based on hardness, or resistance to fracture. Moisture, protein, starch, and endosperm matrix all have a direct effect on wheat hardness. However, if hard and soft wheat varieties are processed to a similar degree they have a similar feeding value based on OM digestibility (Yang, et al., 2014). Each of the varieties are higher in protein than other grains such as corn or barley, but more soft varieties are used for processing into flour and other products for human consumption (Lardy and Dhuyvetter 2016). Due to its more digestible starch protein matrix and seed coat, wheat has a faster rate of degradation in the rumen, making it more likely to induce acidosis. As a result of its high fermentation, wheat, especially rolled wheat, is rarely included at more than 50% of the diet (Yang et al., 2014).

Feeding multiple grains

Feeding a combination of grains may improve feedlot performance. Stock et al., (1987) evaluated feeding various combinations of HMC, DRC, or dry rolled grain sorghum (DRGS). In general, a mixture of grains resulted in a positive associative effect on digestibility and feed efficiency. Feeding a combination of HMC and DRC in a 75:25

mixture resulted in the greatest G:F ratio. In addition, feeding a combination of HMC and DRGS resulted in a 4.2% greater feed efficiency over diets containing exclusively HMC or DRGS. DRGS, like DRC, has a slower fermentation than HMC. The inclusion of HMC improved the digestibility of the DRGS due to a greater microbial population. In addition, the inclusion of the less fermentable DRGS helped limit acidosis caused by HMC (Stock et al., 1987).

Grain processing

In a review, Owens et al., (1997) compiled data from 605 feeding trials that fed different grains and processing methods. They observed no difference between corn and wheat in observed, body weight adjusted, and NRC (1996) ME values. Dry rolling and steam flaking corn and wheat resulted in similar feed efficiencies (G:F) DRC (0.152) and DRW (0.152). Flaking grains were also similar SFC (0.170) and SFW (0.169). ME values were also similar between SFC (3.73 Mcal/kg DM) and SFW (3.64 Mcal/kg DM). There were differences in optimum roughage source. DRC, HMC, and SFC diets were best used with alfalfa while wheat diets with corn silage resulted in better performance.

In a metabolism trial at the University of Nebraska-Lincoln, Fulton et al., (1979) used four cannulated steers in a crossover design to compare differences in rumen fermentation of coarse rolled wheat (DRW) and corn (DRC). During this study calves were adapted to high concentrate using step diets containing, 35, 55, 75, and 90% concentrate. While consuming the DRW diet, calves had a much lower DMI ($P<0.01$) than the DRC diet, 6.60 kg vs 9.51 kg, respectively. In addition calves consuming the DRW had lower mean ruminal pH (5.48 +- 0.04 vs 5.58 +- .04) than those on DRC, respectively. Rumen lactate production was also greater and faster in the DRW diets in the 35 and 55% concentrate diets. The greater amount of organic acids stimulated satiety at a lower intake in the DRW diets. In addition, cattle consuming DRC had a typical feeding pattern which resulted from a large intake after feeding, and several small meals throughout the day following that event. The cattle on the DRW diets ate more throughout the day in more frequent, smaller meals, indicating greater acid load and/or energy content. An important aspect of this trial was that DRW has faster fermentation than DRC, and no other grain processing was used.

Steam flaking is the most common method of grain processing in North American feedlot diets. In a survey, feedlot consulting nutritionists indicated that steam flaking was the primary method of grain processing used by 65% their clients (Samuelson et. al., 2015). Corn processing is an important aspect of feedlot nutrition in order to maximize the digestibility and nutrient utilization of the animal. High starch grains are commonly fed as an energy source and grain processing is done to maximize the digestibility of the starch. The most common methods of grain processing are steam flaking, dry rolling, or ensiling grains at a higher moisture content.

The seed coat must be broken by mechanical means in order to expose the protein and starch matrix for microbial digestion. If grain is not processed the only breaking of the seed coat that will occur is by the animal during mastication. The seed coat is a normal protective layer of the grain to prevent damage from insects, moisture, and fungal infection. The breaking of the seed coat during processing exposes the starch granules so they can be soaked with moisture and heated (Rowe et. al., 1999). There are other factors of the grain which will also affect the starch digestibility including the endosperm, ratio of non-starch polysaccharides, the protein matrix, and the characteristics of the starch (Rowe et al., 1999).

The primary goal of steam flaking is gelatinization of the starch granules. During this process moisture and high temperatures disrupt the starch matrix by expanding the starch granules. The increased temperature allows for greater moisture uptake by the starch granules (Zinn et al., 2002). There are several advantages to steam flaking. After the starch is soaked in the steam chamber, the starch will then be more digestible in the rumen. However, the greater amount of digestibility is not only attributed to the starch. The crushing of the seed coat and endosperm also makes the other parts of seed, such as the protein, more digestible. As a result there is an increase in small intestine digestibility without a dramatic increase in ruminal digestion.

In Table 2.1 data adapted from Huntington (1997) summarizes the different digestibilities of wheat and corn after undergoing various forms of grain processing. Wheat has the most rapid starch digestion in the rumen, twice the rate of barely, and almost 4 times the rate of corn (Herrera-Saldana et al., 1990). Yang et al., (2014) when feeding high levels of wheat and barley advised using a greater amount of time to adapt cattle to more fermentable diets containing wheat.

The increase in feed efficiency associated with feeding steam flaked grain is a result of the amount of digestible nutrients available in the small intestine. This allows more energy to be absorbed as glucose from starch which is more energetically efficient than forming glucose from VFA’s via gluconeogenesis, the most common form of energy utilization in ruminants. Specific nutrients such as glucose can also be made available to the animal instead of organic acids which are a byproduct of microbial fermentation. Lastly, the risk of acidosis from extensive starch digestion in the hindgut is reduced. The colon is another site of microbial fermentation, and a large amount of undigested starch passing into the cecum could result in acidosis in the cecum. Due to greater digestion of starch in the rumen and small intestine this limits the risk of acidosis due to hindgut fermentation (Rowe et al., 1999).

After traveling through the steam chest and rollers, commercial mills will let the flaked grain either fall onto a pile directly or be moved onto a conveyor. From a pile the corn will often be loaded onto a feed truck via a front-end loader. Another common method is for the flaked grain to travel via a vacuum air lift onto and conveyor and into overhead bins. From these overhead bin the corn will be loaded into a batch mixer. There has been speculation whether the post-processing treatment could have an impact on the starch availability of the flaked grain and cause retrogradation. Retrogradation is the loss of gelatinization and solubility of the starch (Zinn and Barrajas 1997). This results in re-association of starch into a crystalline matrix and a loss of moisture (Rooney and Pflugfelder 1986).

To investigate the effect of drying, 10 ruminally and duodenally cannulated Holstein steers were fed a diet with either fresh SFC (SFC-F) or dried SFC (SFC-D). The SFC-F was flaked every weekday and the SFC-D was flaked in one batch and put on a concrete pad for 5 d and turned periodically to stimulate drying. There were no effects on ruminal pH but VFA concentration tended to be 8.3% greater ($P < 0.10$) for SFC-F. Proportion of propionate was greater for SFC-F (26.0 vs 23.7%) ($P < 0.10$). There was no difference in DM, OM, starch or ADF either in ruminal or total tract digestibility. From these results it was concluded that the feeding value of SFC was not affected by drying (Zinn and Barrajas 1997).

In another trial, SFC was sampled immediately after being rolled. SFC was either put directly into a container to simulate a leg conveyor (LEG) or immediately cooled to 37°C to simulate an air lift (AIR). There was a difference in starch availability, 0.522 vs 0.313, for AIR and LEG, respectively ($P<0.001$). However, there was no difference in IVDMD after 36 h of incubation. Authors had more confidence in the IVDMD than the starch availability and concluded that these two methods of grain transport within a mill had no effect on feeding value (McMeniman and Galyean 2006).

More intense grain processing will result in thinner, more degradable grain. It is assumed that this will predispose cattle to acidosis. However, research has shown that a combination of minimal roughage inclusion and more intensely processed grain can still be used. In 2015 survey the average bulk density of flaked wheat was 0.42 kg/L (32.6 lb/bu) which was greater than the average recommended bulk density of corn 0.35 kg/L (27 lb/bu) (Samuelson, et al. 2015). This is likely due to the bulk density of wheat (0.77 kg/L) which is usually greater than that of corn (0.72 kg/L) (Anjum and Walker, 1991). Hales et al., (2010) evaluated the extent of flake density and roughage levels. Corn was steam flaked to a density of either 335 g/L (26 lb/bu) or 386 g/L (30 lb/bu) and roughage was included at either 6 or 10%. The lower bulk density resulted in the highest G:F with supposed minimal effect on metabolic health. In conjunction a feeding behavior study was conducted. A lesser amount of the 335g/L flaked diet was consumed in the first 6 h, indicating that feed intake was more spread out in the first part of the day by higher energy, heavily processed SFC (Hales, et al., 2010).

Another less common method of grain processing is tempering in combination with dry rolling. Tempering is done by adding moisture to the grain and allowing to soak for approximately 60 minutes before being rolled (Zinn et al., 1998). Zinn et al., (1998) compared tempered rolled corn with a DRC control and SFC. Tempering improved ADG 9% and G:F 5% over DRC ($P < 0.10$). This new method of grain processing improved NE content of the diet 6% ($P < 0.01$). Surfactants may also be used which help increase water penetration. Zinn et al., (1998) investigated increasing levels of surfactant were also applied with the tempering. Surfactant linearly increased microbial efficiency ($P < 0.05$). However, this process was still inferior to SFC as dietary NE values were 6% greater in SFC over tempered corn. Wang, et. al, (2003) found that surfactants in combination with tempering improved G:F (P<0.05). Previous research has also shown that surfactants can improve rumen fermentation (Wang et al., 2000), and linearly increase microbial efficiency (Zinn et al., 1998). Steam flaking corn requires a steam chest, rolls, and a boiler to provide the steam. Tempering requires much less equipment and may be a more economic method of grain processing depending on the size of the feeding operation.

Quality control of grain processing is an important factor affecting the digestibility and subsequent performance of grains. Zinn et al., (2002) reviewed previous quality standards of steam flaking grain that have been determined from research trials.

Often the reference values for energy content of flaked grains are less than the observed advantages in growth of the animal. This is due to the fact that many of those references for energy value were based on advantages in starch digestion. However, the advantages in digestion also effect the fiber and protein portions of the grain (Zinn et al., 1994). Increases in total tract digestibility of SFC result from increases in both ruminal and post ruminal digestion. The greater intestinal digestion of starch results in less starch available in the cecum. A greater pH is maintained in the cecum, and cellulolytic bacteria are able to better digest fiber resulting in greater fiber digestibility (Zinn et al., 2002).

It was originally hypothesized that the greater intestinal digestibility of starch in SFC was a result of greater pancreatic secretions stimulated by greater microbial protein passage into the duodenum. Owens et al., (1986) and Zinn et al. (1995) fed greater amounts of protein to stimulate pancreatic enzymes. However, they concluded that this did not increase the digestibility. Rather, the form of the protein matrix surrounding the starch would affect the digestibility and consequently the availability of the starch. Both the heat and mechanical breakdown of the protein matrix during flaking increased the amylolytic process of flaked grains. This effect is seen more in SFC than SFW due to the chemical differences in the protein matrix (Zinn et al., 2002).

The availability of the starch is primarily affected by flake density, often measured in g/L or lb/bu. Adding moisture or "tempering" the grain before entering the steam chamber allows for greater saturation of the starch, and a smaller steam chest can be used. In a feeding trial, Sindt, et al., (2006) added moisture so that SFC was either 18% or 36% moisture. The wetter SFC was more durable and resulted in less fines, but heifers in the feeding trial had lower performance. Furthermore, addition of a surfactant to help accelerate moisture uptake before flaking had no effect on starch availability (Sindt, et al. 2006). The most reliable indicator of optimum grain processing is the concentration of starch in the feces (Zinn et al., 2002) There is a strong relationship between percent of fecal starch and total tract starch digestion (R^2=0.95) Starch content of the feces should be between 2 and 3% for optimum flaking denstiy (Zinn 1994) (Zinn et al., 2002).

Steam-flaked corn vs. steam-flaked wheat

Steam flaking grain results in better feed efficiency by decreasing intake, but maintaining ADG. On average there is a 10% improvement in feed efficiency for SFC and SFW over a dry rolled control. In addition, the ME content of the diet will be improved by 15% and 13% for corn and wheat, respectively (Owens, et al., 1997).

As steam flaking became more common, SFC and SFW were evaluated in a 121-d comparative slaughter trial (Zinn 1992). Different sources of dietary fat (cottonseed oil soapstock and yellow grease) were compared with inclusion of SFC or SFW. Ten steers were slaughtered at random at the beginning of the trial. Using specific gravity, carcass composition of fat, water, and protein was determined. At slaughter the specific gravity of each carcass was determined to calculate the proportion of fat, and protein and thereby determine the overall retained energy from the diet. In conjunction with the performance trial, four rumenally and duodenally cannulated Holstein steers were used in a digestibility trial. Samples from the rumen and duodenum were taken for four consecutive days after a 2 week diet adaptation to test for digestibility of DM, OM, starch, NDF, fatty acids, and dietary N (Zinn 1992).

There were no grain x fat inclusion interactions. The SFW that was fed had greater DM (87.0 vs 83.0%), N (2.47 vs 1.47), density (0.36 vs 0.30 kg/L, and lower starch (65.0 vs 72.3 %) and amyglucosidase reactive starch (11.2 vs 12.5%). The author made an important distinction between ruminally digestible and amyglucosidase reactive starch. Amyglucosidase is an enzyme that will hydrolyze bonds between glucose molecules of starch, but will not hydrolyze insoluble starch.

The NE value of SFW was 96% the value of SFC. Using carcass growth characteristics SFW had a NEm of 2.28 Mcal/kg and an NEg of 1.58 Mcal/kg relative to SFC with NEm of 2.38 Mcal/kg and NEg 1.67 Mcal/kg. NEm and NEg were 3.5 and 4.4% higher for SFC, respectively. Daily gain and feed conversion had a tendency to favor SFC diets. In the cannulated steer trial both SFC and SFW had high rumen digestibility of starch with a mean of 91.1%. SFW had a greater passage of microbial N to the small intestine ($P < 0.05$). There was no difference in OM, ADF, or starch in ruminal or post ruminal digestibility. This indicates that flaking both grains likely resulted in similar advantages in digestibility for non-starch components. There was greater (5.7%) total tract N digestibility for SFW ($P < 0.05$) (Zinn 1992).

In other research Martin et al. (1986) fed a 12% forage diet comparing SFW and SFC and determined that SFW had 99% the ME of SFC. Garret et al. (1968) fed SFC and SFW at 64 and 84% of the diet. Both grains at each level resulted in similar growth performance.

Steam-flaked wheat – flake density and roughage inclusion

Kreikemeier, et al., (1990) conducted a feeding trial to evaluate different roughage levels with 0, 5, 10, or 15% roughage with SFW. The roughage source was a 50:50 mixture of alfalfa and corn silage. Given that corn silage is only 50% roughage, the effective fiber treatments were more accurately 0, 3.75, 7.5, and 11.25%. Wheat was flaked to 582 g/L (43 lb/bu) for all diets. There was a linear increase in DMI with increase in roughage inclusion. There was as quadratic response with ADG, G:F, and HCW ($P<0.05$). Observed NEm values were similar to predicted values for 5, 10, and 15% roughage, but lower than predicted for 0% roughage. No tylosin was fed, and as a result over 60% of the livers were condemned in this trial (Krekemeier et al., 1990).

In conjunction with the feeding trial, six ruminally cannulated steers were fed the same diets in a metabolism trial. Cattle were fed at either 2x or 3x maintenance. Defaunation (loss of ruminal protozoa) became a problem because of the high level of grain and rapid fermentation. As a result, after each period diet changes occurred, rumen evacuation was done, and rumen fluid from donor steers replaced the digesta in each rumen.

Rate of starch digestion (%/h) increased with increased roughage content. In the 0% roughage diet there were lower amounts of VFA. There was a linear effect of roughage on ruminal passage (%/h). There was also greater intake and starch in ruminal digesta with increasing roughage. Most of this was attributed to greater substrate availability and microbial growth. Microbial population was also analyzed. There was a dramatic decrease in protozoa population with increased feed intake. Total and amylolytic bacterial populations doubled with increased feed intake. This was largely due to greater amounts of substrate and less predation from protozoa. An *in situ* trial was also done comparing SFW and DRW and roughage inclusion. There was a linear increase in starch digestion (%/h) with increased roughage, and DRW had greater starch digestion than SFW, 21.3 and 6.1%, respectively (Kreikemeier et al., 1990).

Steam flaking wheat results in better performance than dry rolling wheat, and allows for a greater inclusion of wheat in the diet. Zinn (1994) compared DRW to 2 thicknesses of flaked wheat. In a performance trial 72 steers were fed one of three treatments: DRW was rolled to a density of 0.52 kg/L (40 lb/bu), coarse SFW (SFW-C) was flaked to a density of 0.39 kg/L (30 lb/bu) and thin SFW (SFW-T) was flaked to a density of 0.30 kg/L (23 lb/bu). A metabolism trial was also performed with 12 ruminally and duodenally cannulated steers.

There were no performance advantages from making the flake thinner. There was a 13.5% improvement in ADG ($P < 0.10$) and 8.8% improvement in G:F ($P < 0.05$) in SFW over DRW. The NEm of SFW was 5% greater than DRW. Backfat thickness was greater in SFW ($P<0.10$) relative to DRW. There was also a tendency for SFW calves to have more liver abscesses. Observed NEg values for DRW, SRW-C, and SRW-T were 1.50, 1.57, and 1.59 Mcal/kg, respectively. In the metabolism trial steam flaking decreased N degradation in the rumen by 27% ($P < 0.05$) and increased post ruminal N digestion by 11% ($P<0.05$) (Kreikemeier 1990). Previous research (Hale et al., 1970 and Arnett 1972) had shown no improvement in performance in flaking wheat vs rolling wheat. However, in these studies wheat was less than 50% of the diet. Bris, et al., (1966) and Hale, et al., (1973) showed that both ADG and DMI were increased in SFW relative to DRW.

Conclusion

Grain processing is an important step in feed preparation of feedlot diets. Dry rolling, high moisture ensiling, steam flaking, and tempering can all be used with the various sources of grain to increase the utilization by the animal. Different grains respond more favorably to certain grain processing methods better than others. It has been shown repeatedly that SFW and SFC are similar in total tract digestibility, and when fed will result in similar DMI, ADG, and G:F.

However, much of the previous research with rolled and steam flaked wheat was performed 20 or more years ago. New research is needed to investigate the use of wheat in feedlot diets with modern ingredients especially corn by-product. In addition, current data is needed to analyze the economics of feeding wheat relative to corn using modern commodity prices. In addition previous research has investigated the feeding of a combination of grains. However, the author could find no previous trials investigating the feeding of multiple flaked grains. In a future with high volatility in grain markets, the opportunity may arise for feedyards, especially those with multiple steam flakers, to feed a grain such as wheat in conjunction with corn to lower feed costs. Data is needed to estimated expected differences in performance with multiple flaked grains.

ADAPTATION TO FEEDLOT DIETS

Cattle in their natural environment will consume large amounts of forage in large, infrequent meals. Due to this natural ability to consume large amounts of plant material, cattle must be adapted to eating grain. Grain adaptation is a common practice in feedlots across the Midwest and the Southern Plains. Best management practices must be used to limit the risk of acidosis and digestive upset during this change in primary substrate. Heavy emphasis is put on ration formulation during the feedlot stage of beef production, and particular attention is paid to the grain that is used and the adaptation program used to acclimate cattle to that grain. This literature review summarizes the physiology behind rumen acidosis, the physiological changes experienced by ruminants during grain acclimation, and how different grain adaptation programs have been used to avoid acidosis.

Acidosis

Theories on acidosis have been developed by many scientists over the years. One theory is that acidosis is only caused and determined by the pH of the rumen (Forbes and Bario, 1992). As fermentation causes an accumulation of organic acids in the rumen, rumen pH begins to decline. An overload of acid then causes homeostatic mechanisms to limit acid production and remove the acid produced as quickly as possible. A similar theory by Owens et al. (1998) hypothesizes that acidosis is caused by an increase in osmolality due to accumulation of organic acids and glucose. This occurs when acid production is greater than absorption. The change in osmolality will cause an increase in fluid flowing into the rumen, decreasing absorption of VFA (Owens et al., 1998).

A third theory is based on organic acids absorbed into the bloodstream. As organic acids accumulate in the rumen they are absorbed into the bloodstream. After transport to other tissues, especially the liver, these organic acids undergo both oxidation and gluconeogenesis. The organic acids (volatile fatty acids, alpha keto acids, amino acids) and glucose are all absorbed and can be oxidized through the citric acid cycle and the electron transport chain. These processes produce energy. In addition, these molecules can enter gluconeogenic pathways to be synthesized into macromolecules. Eventually, these two biochemical processes become saturated sending a negative feedback to the central nervous system inducing changes in feeding intake (Allen et al., 2005).

A final theory focuses on endotoxins, histamines, and inflammation. While acidosis normally refers to reducing pH with a starch-based substrate, it is important to note that starch is not the only substrate that can induce acidosis. Studies at the University of Manitoba (Khafipour et al., 2009a,b) investigated subacute acidosis challenge in dairy cattle. One challenge study compared feeding alfalfa and alfalfa pellets. With utilizing the alfalfa pellets they were successful in inducing acidosis and decreasing ruminal pH below 5.5. Another study (Khafipour et al., 2009a) with similar design was done to induce acidosis using ground wheat and ground barley in both free and pelleted form. The dairy cows that were given the acidosis challenge in each study had a decrease in ruminal pH. However, the alfalfa challenge did not induce the same immune response due to lipopolysaccharide (Khafipour et al., 2009b). For this reason it is believed that acidosis induced from feeding grain will result in the greatest impact on the animal's health.

Changes in microbial environment and community

During adaptation to a high grain diet there is less forage available in the rumen. Cellulolytic bacteria such as *Butyrivibrio fibrisolvens* and *Fibrobacter succinogenes* struggle to proliferate due to a lack of substrate and poor environment. One of the organic acids that is produced is lactic acid. As starch intake increases, a greater amount of lactic acid is produced by *Stretococcus bovis* which thrives in a starch rich, low pH environment. *Megasphaera elsdenii* utilizes the lactate produced by *S. bovis,* and the end product of it's metabolism is propionate. The feeding of grain is more efficient because of the greater propionate production by the rumen microbes. Propionate will result in more glucose produced for the host animal from gluconeogenesis. However, if acid production is faster than absorption, rumen pH will continue to decline which will slow the growth of *M. elsdenii* and cellulolytic bacteria (Fernando et al., 2010). Regardless of grain adaptation method used, microbial adaptation will occur. However, diet formulation and exposure to a more fermentable diet will affect the dominance or lack thereof of lactate producing bacteria and lactate. Organic acid production will depend on the meal size as well as rate and extent of degradation by microbes. There is a balance that must be maintained between maximizing organic acid production without overloading the absorption and utilization potential of the animal (González et al., 2008).

Mechanisms of feed intake and satiety

Fulton et al. (1979b) infused NaOH into the rumen of calves undergoing an acidosis challenge. While keeping the pH above 5.75, they were able to maintain feed intake. This gives evidence to the chemostatic fill mechanism. When consuming a forage based diet, cattle will eat until tension receptors in the rumen give negative feedback to stop eating. Feeding diets with greater physical density and a greater proportion of grain relative to forage provides less stimulation of the rumen wall. As energy density of the diet increases a new mechanism of satiety must be used by the animal. Allen et al. (2005) proposed that the chemostatic mechanism is likely regulated by the metabolic potential of the animal. Feed intake is therefore regulated by the speed of absorption and metabolism of organic acids (Allen et al., 2005).

Saliva production is an important part of the animal’s individual ability to adapt to a high grain diet. Saliva has high concentration of NaOH which will help neutralize rumen pH. Saliva production depends on the forage content of the diet. As saliva production increases it allows for greater buffering of the rumen contents. Feedlot finishing rations have greater digestibility and have faster microbial degradation, however there is limited potential for saliva production to neutralize pH. In general, as starch and energy content of the diet increase there is a decrease in the size of meals and an increase in meal frequency. Due to less stimulation of the rumen wall, rumination decreases resulting in less salivation and buffering of acidic rumen contents. This combined with a change in fill mechanism results in a cattle consuming smaller, less frequent meals (González et al., 2012).

Feeding behavior

As previously mentioned, adaptation to a high-energy grain diet is in many ways an adaptation of the microbial community in the rumen. However, there is also a substantial adaptation that must take place in the animal. In a review, Gonzalez et al. (2012) stated that grain adaptation is affected by feeding behavior. Quantity and type of grain used, feed bunk management, feeding consistency, and feed additives will all have an impact on feeding behavior and subsequently adaptation to grain (Gonzalez et al., 2012).

Amount and type of grain

The type of grain used will impact feeding behavior, and a variety of grains have been used in feedlot diets. Grains such as wheat and barley have a faster fermentation while milo and corn have less rapid fermentation. In addition, more intense grain processing will result in more rapid fermentation. One of the first research trials to investigate grain type and changes of eating behavior and rumen pH was Fulton et al. (1979a). Four cannulated steers were adapted to a high concentrate diet using DRC and DRW. Rumen pH was monitored as well as individual animal intake using 4 step up diets with each fed for five days. Using the step diets the amount of concentrate was increased from 35% to 90%. Cattle fed DRC increased DMI while those fed DRW decreased DMI. The animals adapted to a higher grain diet in several ways. First, the amount of feed consumed in the first 2h after feeding decreased from 2.4 kg/h to 1.25 kg/h in the DRC and 2.40 kg/h to 0.35 kg/h in DRW. In each case DMI decreased on the 35 concentrate diet and increased until the 5th day of the 55 concentrate diet, before a drastic decrease in intake occurred on the first day of 75% concentrate. This same phenomenon occurred on the 5th day of 75% and 1st day of 90% concentrate. The amount and type of starch found in the grain will have a large impact on rumen digestibility and subsequently on rumen pH. Starch in wheat, unlike corn, is not bound in a protein matrix, making it more available for microbial breakdown. It was theorized that this difference in starch type had a profound effect on incidence of acidosis during adaptation (Fulton et al., 1979a).

In this experiment cattle decreased the rate of consumption throughout the day spreading out the starch load. Across the entire study, Fulton et al. (1979a), there was a wider range in rumen pH in the DRW (4.60 – 6.25) than the DRC (5.27-5.97). Over the entire period there was lower rumen pH for the DRW which was shown by a concentrate interaction. The highest amount of lactate in both diets occurred in the 35% concentrate diet while the lowest amount occurred at the 90% concentrate diet (Fulton et al., 1979a). This suggests that the microbial population had adapted to a high starch diet due to a lack of lactate accumulation. Fulton et al. (1979a) hypothesized that the microbial population adapts to the new substrate. The animal also decreases the rate of consumption throughout the day. However, when consumption rate, passage, absorption and changes in microbial population are not enough, the animal will decrease their intake to limit the amount of substrate available. This hypothesis was supported by the decrease in intake by the cattle fed DRW (Fulton et al., 1979a).

As animals continue to consume a high concentrate diet, there is evidence that changes in feeding behavior may revert back to eating patterns seen in a high roughage diet. Other physiological and microbial adaptations may occur as concentrate feeding continues. In recent research, (Dohme et al., 2008), dairy cattle were given a 1 d acidosis challenge by feeding greater amounts of steam rolled barley. The cattle were then backed down to the low barley diet after the acidosis challenge. The same acidosis challenge was repeated 2 more times at 14 d intervals. During each repetition of acidosis challenge, mean ruminal pH declined, number of meals decreased and meal size increased. This suggests that these cattle had adapted to the higher grain and were able to handle larger meals as eating behavior began to revert back to a high roughage intake pattern.

Physiological changes have also been observed (Penner et al., 2011). It has been noted that there is an increase in surface area in the digestive tract to allow for more absorption. Butyrate metabolism allows for adequate energy supply for rumen epithelium to increase surface area and accelerate absorption from the rumen wall (Penner et al., 2011).

Feed additives

Monensin is the primary feed additive that has an effect on feeding behavior. Monensin is an ionophore that changes the H+ ion concentration on the cell wall of gram negative bacteria. Gram negative bacteria in the rumen are primarily associated with lactate production which will drastically decrease rumen pH. Monensin gives a disadvantage to these by bacteria by producing an ion pore on the cell wall, allowing H+ ions to leak into the cell. The gram negative bacteria will expel energy to maintain H+ ion concentration on the cell wall. As a result, other bacteria proliferate resulting in an increase in propionate concentration (Gonzalez et al., 2008). A greater concentration of propionate stimulates satiety at a faster rate (Allen et al., 2005). This causes meal size to decrease and meal frequency to increase. Cattle consumed less meals (7.1 vs. 6.2 +- 0.5 meals/d) as well as meals smaller in size (2.2 vs. 3.7 kg/meal) in Monensin and control steers, respectively. This resulted in a slower eating rate throughout the day (0.23kg/h vs. 0.27kg/h +/-0.019/h) in Monensin vs. control fed steers. This assists in maintaining a more stable rumen environment and reduces acidosis risk (Erickson et al., 2003).

Sodium bicarbonate, a naturally occurring compound in ruminant saliva, is another feed additive. Gonzales et al. (2008) fed 12g and 50g/hd/d of sodium bicarbonate. They found that heifers fed 50g of sodium bicarbonate had the greatest meal size after bicarbonate feeding. The less severe depression in rumen pH allowed those animals to have greater meal intake after feed delivery (1.2 vs. 1.9 kg/meal) for the 12g and 50g of sodium bicarbonate, respectively (González et al., 2008).

Feed bunk management

There are three kinds of feed management commonly used. Slick bunk feeding is managed so that no feed remains in the bunk before new feed is delivered. Programmed feeding delivers feed based on body weight and desired performance. This reduces labor and feed wastage. In an *ad libitum* feeding program cattle always have access to feed (Gonzalez et al., 2012). *Ad libitum* feeding will increase feed intake, but feed wastage will increase. Relative to *ad libitum* feeding, programmed or slick bunk feeding may cause cattle to become meal eaters. This results in cattle consuming few, large meals throughout the day which may cause rumen pH fluctuations (Schwartzkopf-Genswein et al., 2003).

Feeding frequency also has an effect on eating behavior. Feeding multiple times a day allows for less severe drop and less variation in rumen pH. Feeding twice daily decreased rumen pH drop post-feeding and reduced overall pH fluctuation. However, two feedings a day also increased the acetate:propionate ratio, and cattle converted feed less efficiently (Soto-Navarro et al., 2000). Feeding multiple time times a day allows intake to be spread throughout the day. It also gives the opportunity for salvia production to peak when rumen pH is at its lowest (González et al., 2012).

Other factors that will influence feeding behavior include variation in weather and social interactions within a pen. Aggressive behavior will be observed as the amount of bunk space per animal decreases. Increasing the stocking rate of the pen will increase feeding rate because of competition with other cattle. This also increases the size of meal and subsequent drop in pH (Erickson et al., 2003).

Step-up programs

There are several methods of grain adaptation which have been adopted by the feedlot industry. According to the 2015 Texas Tech and New Mexico State feedlot nutritionist survey the most common method is the use of multiple step diets. Step diet programs use several diets with an increasing level of grain. According to the survey the most common grain adaptation method used is 4 step diets with each fed for 6d. Of the nutritionists surveyed, 56.3% stated that step diets were the most common method of grain adaptation used in the feedlots they consult for (Samuelson et al., 2015). In those diets the first step diet contains an average of 40.3% roughage The other most common method of grain adaption was the two ration blend which was used by 40.6% of the feedlots in the survey (Samuelson et al., 2015). A two ration blend involves a starter diet and a finishing diet. Over a set period of days there is a gradual decrease in the starter diet coinciding with an increase in the finishing diet. According to the 2015 survey, the average roughage content of the initial starter diet in a 2 ration blend is 38.8% with the average length of step up lasting 27 d (Samuelson et al, 2015).

Bevans et al. (2005) investigated the effect of rapid (RA) or gradual (GA) grain adaptation in 12 spayed, rumen cannulated heifers. The RA heifers were transitioned from a 40% concentrate diet to a to a 90% concentrate diet over 3 d using one 65% concentrate intermediate diet. The GA adaptation was done over 15 d using 5 intermediate diets. Rumen pH at 11 h post feeding of the 90% concentrate diet was lower in RA. Variance of hourly pH was greater in RA. In this study, there were some heifers on both treatments which began erratic feeding patterns after acidosis challenge. There were other heifers, however, who suffered little from acidosis and maintained steady feed intake (Bevans et al., 2005). Results from this study helped elucidate that even within grain adaptation program there is variability between animals (Bevans et al., 2005).

Holland et al. (2007) investigated the use of multiple adaptation programs on receiving calf health and performance. The cattle in this study were assigned to one of four treatments. Traditional (TRAD) cattle were fed a 64% concentrate diet starting at 1.5% of body weight. On days when the bunk was slick in the morning, the feed call was increased by 0.90 kg DM/hd until *ad libidum* feeding was achieved. On 8, 15, and 22 d the next step ration was fed at 72%, 80%, and 88% concentrate, respectively. After d 22 the 88% concentrate diet was program fed so that the steers gained 1.13 kg/hd/d. The Receiving (REC) treatment was fed the same as the TRAD, however those cattle were fed the 64% concentrate diet for 28 days prior to step up. Limited Maximum Intake (LMI) treatment was fed similar to the TRAD, however cattle were fed to 2.1, 2.3, and 2.5 times the maintenance energy requirement from d 0-7, 8-14, and 15-21, respectively. After d 22 steers were program fed similar to TRAD and REC. The Program-fed (PF) steers received the 88% concentrate diet on d 0. The diet was offered so that the same amount of metabolizable energy (ME) was offered as the 64% diet so that a 1.13 kg/hd/d ADG was achieved. The REC cattle had the greatest ADG, but these cattle had the lowest efficiency after being adapted to the finishing diet (Holland et al., 2007). In addition, the PF and TRAD had the greatest morbidity due to bovine respiratory disease (Holland et al., 2007). This study lends to the idea that there may be a tradeoff between health and performance when adapting cattle to grain. It is important to note that there was not a finishing performance portion of this study, so it is difficult to know how those calves would have performed over the entire feeding period.

Burken (2010) compared the traditional step up diets with a two ration blend in feedlot heifers. The four step up diets fed for 7 d each were compared to the two ration blend continuously changed over 28 d. There was no difference in DMI, ADG, and HCW, and a tendency was observed for marbling to be greater in the cattle fed the traditional step up ration (Burken 2010). Additionally there was also a tendency for greater daily DMI variation in the cattle fed the 2 ration blend. Overall there was no difference in feedlot performance or carcass characteristics (Burken, 2010). The 2 ration blend, however, could decrease the amount of forage needed by 21-28% (MacDonald et al., 2011). This would reduce the labor needed to process hay. In addition, feed loss or shrink would decrease with less forage being handled.

RAMP is a proprietary product by Cargill designed to replace the receiving ration in a feedlot. RAMP is used in grain adaptation programs as the receiving ration in a two ration blend. This helps reduce the need to grind forage for receiving rations and also reduces the number of rations needed to be fed. RAMP has been tested in several step up programs. Schneider et al. (2013b) adapted yearlings to a finisher diet using a 2-2 d transition (2 d 66% RAMP, 2 d 33% RAMP), 1-4 d transition (4 d 50% RAMP), and 3 d transition (1 d 75%, 1 d 50%, 1 d 25% RAMP). Two control gradual adaptation programs were done over 28 d, one replacing RAMP with a 25% Sweet Bran finishing diet, the other with a 47.5% Sweet Bran finishing ration. In the control step up, RAMP was fed at

5 intermediate levels in exchange for the finishing diet. Variation in DMI was lower for the 3 d transition than for the other treatments, but there were no other differences in feedlot performance or carcass characteristics (Schneider et al., 2013b). Contrary to previous research which has shown that faster adaptation increases the risk for acidosis, the lower variation in DMI may decrease the risk of acidosis. RAMP is relatively high in energy but has no starch content. It is believed that this high energy content helps adapt cattle to high energy finishing ration without including starch in the receiving diet (Schneider et al., 2013b).

Schneider et al. (2013c) again investigated grain adaptation using a more aggressive adaptation. Four STEP cattle were fed RAMP for 4 d, and then a 25:75, 50:50, and 75:25 mixture of RAMP and finishing diet for 6 d each before receiving 100% finishing diet on d 23. Two Step cattle received RAMP for 10 d, a 50:50 mixture of RAMP and finishing ration for 4 d, and then full finishing ration on d 15. 0 STEP cattle were fed RAMP for 10 d and 100% finishing ration on d 11. Adaptation method did not affect DMI, ADG, G:F, carcass traits, and incidence of liver abscesses. Intake variance during the transition period was greater for the cattle transitioned directly from RAMP to finisher ration. However, DMI variance was lower for 0 Step cattle during the finisher phase. It is important to note that in each of these trials cattle were first adapted to a finishing diet containing 47.5% Sweet Bran a branded wet corn gluten feed product. After 2 weeks of being fed this finishing diet, steers were fed a diet with 25% Sweet Bran until being shipped to a commercial abattoir. Further evaluating the feeding behavior of RAMP, Scheider et al. (2014) fed 60 yearling steers in Calan gates. The 0 Step and 4 Step treatments were compared to a traditional adaptation program using 4 Step rations. Zero

Step and 4 Step treatments had greater DMI compared to the traditional step up program (Schneider et al., 2014).

Schneider et al. (2013a) conducted a metabolism trial with RAMP to evaluate DMI, eating behavior and ruminal pH of ruminally fistulated steers. This study compared the 4 Step and 0 Step treatments described above from Schneider et al (2013c). Using suspended feed bunks, feed disappearance was monitored continuously and calves received *ad libitum* access to feed. Magnitude of pH change and ruminal variance were greater for 0 Step compared to 4 Step. Cattle adapted to 0 Step had greater time below pH 5.3 and 5.6. Eating time was greater for 0 Step but meals/day were not different between treatments. Because of the greater amount of eating time it was concluded that feeding RAMP would decrease acidosis by spreading out feed intake.

Conclusion

Adaptation to grain is an important period of the feedlot phase of beef production. The most critical aspect of grain adaptation is preventing opportunities for clinical and subclinical acidosis to occur. Acidosis can cause a decrease in feedlot performance, and is the costliest metabolic disorder in feedlot cattle. Prevention of acidosis is done by adapting both the feeding behavior of the animal and the rumen microbial population to a change in substrate. There are several methods of grain adaptation including using step diets and using a two ration blend. Recent research indicates that adaptation to grain can be improved by feeding starter diets high in energy and devoid in starch. Further research must be done to investigate how feeding behavior changes during adaptation to grain. In addition more research is needed to understand if initial roughage level or byproduct level has a greater effect on eating behavior during grain adaptation. In addition, changes meal size and calories per meal have not been adequately measured during grain adaptation. Lastly as feeding of corn byproduct has increased there is greater need to analyze daily feeding behavior using a step up program exchanging corn byproduct and roughage for grain.

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Table 2.1 Digestibility coefficients for different grains and processing methods

			Digestibility				
			Rumen	Postrumen			
Grain	Processing[a]	Starch intake, kg/d	% Intake	% Intake	% Entering	Total Tract, %	Citations[b]
Corn	DR	2.06	76.2	16.2	68.9	92.2	1 - 8
	SF	2.2	84.8	14.1	92.6	98.9	5 - 13
	SR	6.91	72.1	19	68.2	91.2	14
	HM	3.89	89.9	6.3	67.8	95.3	15
	G	10.65	49.5	44	86.5	93.5	16
Wheat	DR	2.94	88.3	9.9	85.4	98.2	17, 18
	SR	2.87	88.1	10	88.2	98.6	18

[a]DR = dry-rolled; SF = steam-flaked; HM = high moisture; G = ground; SR = steam-rolled.

[b]Citations: 1. Spicer et al. (1986); 2. Streeter et al. (1989); 3. Streeter and Mathis (1995); 4. Streeter et al. (1990b); 5. Zinn (1987); 6.Zinn (1988); 7. Zinn (1990a); 8. Zinn et al. (1995); 9. Zinn (1990b); 10. Zinn (1991); 11. Zinn (1993a); 12. Zinn (1993b); 13. Zinn and Borques (1993); 14. Oliveira et al. (1995); 15. Stock et al. (1987a); 16. McCarthy et al. (1989); 17. Axe et al. (1987); 18. McAllister et al. (1992b);

Adapted from Huntington, 1997

CHAPTER III

EFFECT OF REPLACING STEAM-PROCESSED CORN WITH STEAM-FLAKED WHEAT ON FEEDLOT PERFORMANCE, CARCASS CHARACTERISTICS, AND IN SITU DIGESTIBILITY OF STEERS IN FINISHING DIETS CONTAINING DRIED DISTILLERS GRAINS PLUS SOLUBLES

ABSTRACT: A feedlot experiment was conducted to evaluate the effect of replacing steam-processed corn (**SPC**) with steam-flaked wheat (**SFW**) in feedlot rations. In experiment 1, 152 crossbred steers (321 ± 2.7 kg BW) were allocated into 4 weight blocks and randomly assigned to 1 of 32 pens. Pens were randomly assigned to 1 of 4 treatments: Control (**CON**) diet containing SPC at 59.5% of diet DM; 19.5% SFW and 39.5% SPC (**SFW20)**; 39.5% SFW and 19.5% SPC (**SFW40)**; 59.5% SFW (**SFW60)**. All diets contained DDGS as 20% of diet DM. Steers were fed for 175 d and weighed every 28 d. During the final 35 d, steers were fed ractopamine hydrochloride. In experiment 2, 6 ruminally cannulated steers (BW 395 ± 12 kg) were used to determine the *in situ* DM digestibility (ISDMD) of a fresh sample of: 1) dry-rolled corn (**DRC**); 2) composited sample of SPC fed throughout Exp. 1 (**SPC**); 3) steam-flaked corn (SFC) obtained from a commercial feed yard in western Kansas (**SFC**); 4) SFW obtained immediately after flaking (**SFW-F**); 5) SFW obtained after drying through a vacuum air lift (**SFW-D**). In Exp. 1 no differences in final BW (P = 0.74) or ADG (P = 0.45) were observed. From d 1 to 84 a negative linear relationship between wheat inclusion and DMI ($P = 0.05$). From d 1 to 175, SFW60 had lower DMI ($P = 0.05$) than CON or SFW20. From d 1 to 84, a linear increase in G:F with greater SFW inclusion ($P < 0.01$) was detected. A positive linear relationship between G:F and wheat inclusion was also observed from d 1 to 175 ($P = 0.03$).

While there were differences in DMI, due to greater wheat prices used in the calculation ($233.90/metric ton DM SPC, $280.77/metric ton DM SFW), there was no difference ($P = 0.28$) in cost of gain (**COG).** Further analysis found that COG can be maintained if wheat price/27 kg is $0.18 to $0.76 greater than 25 kg of corn. Among carcass traits, there was a linear increase in LM area with increased SFW inclusion ($P = 0.01$). A linear decrease in YG ($P = 0.01$) was detected with increased wheat inclusion. In Exp. 2, there was no difference between SFW-D and SFW-F ($P = 0.99$) and SPC had lower ISDMD than SFC at all time points ($P < 0.01$). Steam-flaked wheat can effectively replace SPC in diets of feedlot cattle without impacting growth performance or carcass characteristics. Economics will be determined by the relationship of decreased DMI and ration cost change due to replacing SPC with SFW.

Key words: feedlot cattle, wheat, corn, grain processing, *in situ* digestibility

INTRODUCTION

The feedlot sector of North American beef production commonly feed cereal grains. In regions of North America, wheat is more abundant than corn. Over the past 50 years, wheat has been established as a promising grain source in feedlot diets. There has been an upward trend in wheat usage according to the Texas Tech and New Mexico State feedlot consulting nutritionist surveys. In 2000, 25% of respondents said their clients used wheat as a secondary grain (Galyean and Gleghorn, 2001). Reported use increased to 37% and 50% in the 2007 and 2015 surveys, respectively (Samuelson, et al., 2015; Vasconcelos and Galyean, 2007).

Improvements in feed efficiency associated with feeding steam-flaked grain is a result of the amount of digestible nutrients delivered to the small intestine. Grains such as barley, wheat, and oats have naturally high ruminal fermentation and do not benefit from steam-flaking in the same manner as corn (Rowe et al., 1999). Much of this difference is from variation in the grain's starch-protein matrix (Rowe et al., 1999). However, performance advantages still exist in SFW relative to dry-rolled wheat (DRW, Owens, et. al., 1997). Previous research has been done comparing SFW and SFC (Owens, et al., 1997; Zinn, 1992), but no recent data has been published testing growth performance with the grains in diets containing corn by-products that are currently commonly components of feedlot diets.

Due to potential economic impacts, quality control during and immediately after the flaking process has been investigated. After traveling through the steam chest and rollers, commercial mills will let the flaked grain either fall directly onto a pile, or be moved via vacuum air lift. Nutritionists question whether post-processing method could impact starch availability of flaked grain and cause retrogradation. Retrogradation is loss of and solubility of starch (Zinn and Barajas, 1997) and results in re-association of starch into a crystalline matrix and moisture loss (Rooney and Pflugfelder, 1986). McMeniman and Gaylean (2007) tested *in vitro* dry matter digestibility of grains subjected to both post-processing methods and found no difference in IVDMD.

The objective of this study was examine the differences in feedlot performance and carcass characteristics of steers fed steam-flaked wheat (SFW) replacing steam-processed corn (SPC) in diets containing industry-relevant levels corn by-product. In addition, *in situ* digestion of grains fed were compared to industry standard feedstuffs.

MATERIALS AND METHODS

Experiment 1

Use of steers in these experiments was approved by the Oklahoma State University Institutional Animal Care and Use Committee (ACUP AG-13-18). One hundred and fifty-two crossbred steers (BW 270.6 ± 2.5 kg) were received at the Willard Sparks Beef Research Center. Steer processing included metaphylaxis with tildipirosin at 1.0 mL/45 kg BW (Zuprevo; Merck Animal Health, Madison, NJ), an injectable antiparasitic doramectin at 1.1 mL/45 kg BW (Dectomax; Zoetis Parsippany, NJ), oral antiparasitic fendbendazole at 2.3 mL/45 kg BW (Safeguard; Merck Animal Health, Madison, NJ), viral (IBR, BVD, PI3, BRSV, *Mannheimia haemolytica*, and *Pasteurella multocida*, Titanium 5, Elanco Animal Health, Greenfield, IN) and bacterial (Clostridium chauvoei, septicum, novyi, sordellii, and perfringens Types C & D, Vision 7, Merck Animal Health) vaccinations and an individual ear tag (Temple Tag, Temple, TX).

After processing, calves were limit fed a receiving ration at 2.2% of BW (Table 3.1) for 65 d. On d -1 calves were individually weighed and were reduced by 4% to account for gut fill. Steers that received treatment for BRD (*n* =16) from d -65 to d -1 were allocated equally among treatments. On d0 steers were allocated to 1 of 4 weight blocks. The first 3 weight blocks contained 5 animals per pen (12.60 m x 4.65 m), while the fourth, heaviest weight block contained 4 animals per pen. Within block steers were randomly assigned to pen. Pens within block were randomly assigned to treatment with 2 pens per treatment in each block. Steers were provided *ad libitum* access to water using self-filling water tanks (Johnson Concrete Products, Hastings, NE) shared by adjacent pens. Each pen was partially covered by a shade from the bunk to the water tank (4.11 m x 4.65 m). On d 1, steers were individually weighed, implanted with 100 mg progesterone and 10 mg of estradiol benzoate (Component EC with Tylan, Elanco Animal Health), and sorted into treatment pens. Individual BW were collected on d 28, 56, 84, 112, 140 and 175. On d 84, calves received an implant with 200 mg trenbolone acetate (Component TE-200 with Tylan, Elanco Animal Health). On d 1, calves began an 18 d adaptation to experimental diets shown in Table 3.2. During adaptation feed was delivered 2 or 3 times a day, depending on the concentration of receiving ration and finishing ration delivered. Feed was delivered via a horizontal mixer (Rotomix 84, Dodge City, KS). Following d 28, calves were fed once a day between 0800 and 1000. A slick bunk protocol was implemented to ensure the last amount of feed in the bunk was consumed between 2400 and 0530. If feed was remaining in the bunk at 0600, the feed call for that day was reduced by twice the amount that was estimated to be remaining in the bunk. If feed remained in the bunk for two consecutive days, feed was removed, weighed, and DM was measured on a sample of the feed remaining. Ration and ingredient DM samples were collected 2 times per week. All DM's were analyzed using a forced air oven at 60°C (VWR Radnor, Pennsylvania). An average of the DM's from each week was used to calculate DMI. During each sampling, a fresh subsample was kept and frozen. Every 60 d, frozen samples were composited for analysis (Servitech Labs LLC., Dodge City, KS). Nutrient analysis of diets and grains can be found in Tables 3.3 and 3.4, respectively.

Steam-processed corn (Nesika Energy, Scandia, KS) was steamed at atmospheric pressure and 100°C for approximately 5 min, and then put through corrugated rollers. After being rolled, the SPC was placed on a concrete pad and air dried for 6 to 12 h before shipping. Steam flaked wheat (Dimmitt Flaking, Dimmitt, TX) was steamed for at atmospheric pressure and 100°C for approximately 30 min, then processed through a set of corrugated rollers, and cooled from 100 to 38°C in a vacuum lift. In treatment diets, SFW inclusions replaced SPC on a DM basis. Steam-processed corn was included in the control diet at 59.5% (**CON**). Treatment 2 contained 19.5% SFW (**SFW20**). Dietary treatment 3 contained 39.5% SFW (**SFW40**), and treatment 4 consisted of 59.5% SFW (**SFW60**), completely replacing SFC. On a DM basis, remaining dietary ingredients were dried distillers grains (20% **DDGS**), a mixture of molasses and corn steep (5%), prairie hay (10%), and pelleted supplement at 5.5% (Table 3.3).

Beginning on d 140 steers received 290 mg of ractopamine/hd (Optaflexx, Elanco Animal Health, Greenfield, IN) until d 175 when a final BW was taken. Steers were then sent to a commercial abattoir on d 175 (Cargill Meat Solutions, Dodge City, KS) and harvested on d 176. Hot carcass weight, longissimus muscle area (**LM**), backfat depth, liver score, quality grade **(QG)**, yield grade **(YG)**, and marbling were collected by West Texas A&M Beef Carcass Research Center. One carcass was condemned and was not included in the carcass data set.

In order to determine the economic difference of feeding SFW and SFC, the following costs were applied (Table 3.6): Wheat ($6.44/27 kg DM (1 bu)) and corn

(\$4.98/25 kg DM (1 bu)) prices were taken from weighted USDA average prices from 2011 to 2016 (USDA Economic Research Service, 2017). Graphical representation of yearly average trends for wheat and corn prices are found in Figure 3.1. Processing costs were considered to be \$6.23/t (metric ton DM) for steam-flaking (Macken, et. al., 2006) and \$3.52/t for steam processing resulting in \$233.90 and \$280.77/t, for SPC and SFW respectively. Supplement, prairie hay, molasses:steep blend, and DDGS costs were kept constant in all rations at \$355, \$97, \$441, and \$159/t, respectively. Yardage cost was calculated at \$0.45/hd per d, and cost of gain was calculated from the following equation:

$$\text{Cost of gain} = \frac{(\text{Total DMI (kg) x ration cost (\$/kg)}) + (\$0.45 \text{ x d})}{\text{Total BW gain (kg)}}$$

A new COG was calculated for each treatment using equivalent grain prices instead of USDA average for wheat and corn. From these data a linear regression was calculated to predict COG from level of SFW in the diet (0 to 59.5% of diet DM).

Using the following equations, the amount of dollars saved per kg of BW gain was calculated:

$$\text{\% Improvement in COG} = \frac{\text{COG with wheat inclusion - COG of CON}}{\text{COG of CON}}$$

$$\frac{\text{\$ saved}}{\text{kg gain}} = \text{\% Improvement in COG*COG with wheat inclusion}$$

$$\frac{\text{kg wheat consumed}}{\text{kg gain}} = \text{F:G*SFW inclusion}$$

$$\frac{\text{\$ saved}}{\text{kg wheat consumed}} = \left(\frac{\text{\$ saved}}{\text{kg gain}}\right) / \left(\frac{\text{kg wheat consumed}}{\text{kg gain}}\right)$$

$$\frac{\text{\$ saved}}{\text{bu wheat}} = \text{\$ saved * 27.22 kg/bu}$$

Experiment 2

An experiment was completed to compare the *in situ* dry matter disappearance (ISDMD) of SPC and SFW to other traditional processed grains in feedlot diets. All experimental procedures were done in accord with recommendations by Vanzant et al. (1998). A sample of SFC was obtained from a commercial feed yard in western Kansas (**SFC**) that was not dried. A composite of the SPC fed throughout the feeding experiment (**SPC**) was tested. In order to determine effects of drying on rumen fermentation characteristics, a fresh sample of SFW was obtained immediately after rolling (**SFW-F**) and a dried sample was obtained after drying through a vacuum air lift (**SFW-D**). Samples of SFW-F and SFW-D were obtained from 2 different loads during the feeding experiment. These were composited and used for the *in situ* analysis. These grain samples were compared to a DRC control (**CON**) procured commercially.

Six ruminally cannulated steers (395.2 ± 12 kg) were fed a common TMR (Table 3.5) at 110% of maintenance energy (NRC, 2000) requirement for 14 d before initiation of the experiment. Animals were fed at 0700 and 1400 daily and were given *ad libitum* access to water. Prior to initiation of the experiment, DM of each grain was determined from 3 samples dried at 55°C for 48 h. Empty 10 cm x 20 cm Dacron bags with 10 µm porosity (Ankom Technology Bar Diamond, Macedon, NY) were individually weighed. After determining mean DM of each treatment, 5.0 (± 0.025) g of DM was placed into each *in situ* bag. Bags were sealed using an impulse sealer (Model AIE-200, American Int'nl Electric, Industry, CA). Mesh laundry bags (38.1 cm x 45.7 cm) were filled with triplicate *in situ* bags of each treatment and triplicate blank *in situ* bags. Prior to insertion into the rumen, bags were subjected to a 20 min soak in tap water. All laundry bags except 0 h (blank) were inserted into the ventral sac of each represented steer in ascending h order (1, 3, 6, 9, 12, 18, 24, 48 h). After each incubation time point, bags from the corresponding h were gently hand rinsed a minimum of 5 times or until rinse water appeared clear, then hung on a clothes line to air dry for a minimum of 12 h. Bags were placed into a forced air oven set at 60 °C for 48 h and then weighed to determine DM disappearance (DMD).

Dry matter disappearance was calculated using the difference in dry sample weight before and after ruminal incubation after corrections for changes in blank bag weights. Fractions of digestible DM were calculated as: A fraction = DM digested during 20 min soak; C Fraction = DM remaining after 48 h incubation; B fraction = 100 - A fraction - C fraction.

Statistical analysis

In Exp. 1, data were analyzed using the PROC MIXED program in SAS 9.4 (SAS Inst., Cary, NC). Pen was the experimental unit and block was used as a random effect. Linear and quadratic models predicting response variables were calculated using the

REGRESSION procedure of SAS. Treatments means were compared when the *F*-statistic for treatment was significant, with least squares means separated using the least significant difference method. Percent of carcasses grading USDA choice or better and percent of carcasses with condemned livers was analyzed using the GLIMMIX program in SAS. Model included wheat inclusion (percent of the diet DM) as the independent variable and block as the random effect. For Exp. 2, data was analyzed using PROC GLM program of SAS. Animal was considered the experimental unit and each time point was analyzed separately. Tukey adjusted least square means for each treatment were separated using the least significant difference method. Differences for both experiments were considered statistically significant if $P < 0.05$.

RESULTS AND DISCUSSION

Experiment 1

Summary of results from the feeding experiment can be found in Table 3.7. A graphical representation of DMI during the experiment is found on Figure 3.2. No differences in BW ($P = 0.74$) or ADG ($P = 0.45$) from d 1 to 28, d 1 to 85, or d 1 to 175. Positive associative effects in ADG were observed (2.14% and 4.85%) from d 1 to 175 for SFW20 and SFW40, respectively. From d 1 to 28 CON had greater ($P < 0.01$) DMI than other treatments. From d 1 to 84, a negative linear relationship between wheat inclusion and DMI ($P = 0.05$) was detected. From d 1 to 175, SFW40 and SFW60 had the lowest DMI ($P = 0.05$). Positive associative effects in DMI from d 1 to 175 were observed in SFW20 and SFW40, 3.27 and 3.15%, respectively. From d 1 to 84 a positive linear increase in G:F with greater SFW inclusion ($P < 0.01$). A positive linear relationship was also observed in G:F from d 1 to 175 ($P = 0.03$). A positive associative effect (2.68%) in G:F was observed in SFW40 over the entire experiment. No differences in COG were observed d 1 to 28, d 1 to 85, or d 1 to 175 (P = 0.28).

Summary of carcass data can be found in Table 3.8. No differences were observed in HCW, dressing percent, 12 rib backfat, or percent of carcasses grading USDA choice or above. Longissimus muscle area increased linearly as SFW inclusion increased (P = 0.01). No statistical differences in marbling or percent of carcasses grading USDA choice or above were observed. A negative linear response in calculated YG with wheat inclusion (P = 0.01) was observed. Lastly, no differences in percent of carcasses with liver abscesses were detected among treatments.

The most consistent results from the experiment was a decrease in DMI as SFW was titrated into the diet and no differences in BW or ADG. Consequently feed conversion for SFW60 improved 6.7% over CON from d 0 to 175.

Cost of gain

Feed conversion data was used to calculate the highest price that can be paid for wheat to replace corn in the diet and maintain equivalent COG. Using G:F data from the experiment, the following equation was developed:

G:F = 0.1729 + 0.00022064*(SFW inclusion, % diet DM) *P* = 0.01

Assuming grain prices are equal, this regression used to calculate savings in COG per kg of SFW consumed. This was repeated at $2.50, $3.00, $3.50, $4.00, $4.50, and $5.00/25 kg corn. Linear trends in cost savings were used to generate the price of wheat that can be paid relative to corn and maintain COG. Summary of price estimates are found in Table 3.9 which is summarized by the following equation:

Wheat price $/27 kg = 1.08928 x (Corn Price $/25 kg) + 0.00102 x (Wheat Inclusion) + 0.2499, *P* < 0.01

At all price levels and all levels in the diet in the price that can be paid for wheat is greater than that of corn. At the intercept (wheat inclusion = 0) the price of wheat is \$0.18 to \$0.36 per 25 kg higher than corn. This is due to 7% greater in bushel weight of wheat. The price that can be paid for wheat relative to corn increases as wheat inclusion increases in the diet. This is due to the linear increase in G:F as the level of SFW increases in the diet.

Experiment 2

Results from the ISDMD are in Table 3.10 and Figure 3.3. Across all treatments DM digested during the initial soak (A fraction) was limited, with SFW-F having the greatest A fraction ($P < 0.01$). The B fraction was similar between SFW-D, SFW-F, and SFC, while SPC had the lowest B fraction. Lastly, SPC had the greatest C fraction while SFW-F, and SFW-D had the smallest ($P < 0.01$). At each time point SFW-F and SFW-D had greater disappearance than all other treatments ($P < 0.01$). At 3, 6, and 12 h SFC and SFW-D were not different. At all time points DRC and SPC had similar ISDMD, and were less than SFC, SFW-E and SFW-F. There was no difference in ISDMD SFW-F and SFW-E at any time point. At 48 h SPC had statistically lower ISDMD than SFW-E, SFW-F, and SFC and numerically lower digestibility than DRC.

Previous experiments have indicated that cattle fed SFW have similar performance relative to cattle fed SFC (Garret et al., 1968; Martin et al., 1986; Owens et al.,1997; Zinn, 1992). In the present experiment SFW resulted in lower DMI, similar ADG, and consequently greater G:F than SPC.

In a review, Owens et al. (1997) compiled data from 605 feeding experiments that fed different grains and used different processing methods. Owens et al. (1997) found no difference in BW adjusted or NRC (1996) metabolizable energy values between corn and wheat. Dry-rolled corn and dry-rolled wheat (**DRW**) resulted in similar feed efficiencies (0.152 and 0.152) respectively; SFC and SFW were also similar in G:F (0.170 and 0.169). Metabolizable energy values were similar between SFC and SFW, (3.73 and 3.64 Mcal/kg DM). Owens et al. (1997) reported an 11% increase in G:F for both corn and wheat when steam flaking was compared to dry rolling. Fulton, et al. (1979) found a decrease in DMI when steers were fed DRW relative to DRC. Kreikemeier et al. (1990) found that the rate of ruminal starch digestion was 3.5 times greater in DRW than SFW. These experiments indicate that steam-flaking corn improves G:F by increasing rumen and total tract digestibility. However, the advantage in performance when feeding SFW relative to DRW occurred by controlling the rate of fermentation by maintaining particle size.

It was originally hypothesized that the greater intestinal digestibility of starch for SFC over DRC was a result of greater pancreatic secretions stimulated by greater microbial protein passage into the duodenum (Magee 1961). Owens et al., (1986) and Zinn et al. (1995) fed greater amounts of protein to stimulate pancreatic enzymes. However, starch digestibility was not increased, and Owens et al., (1986) and Zinn et al. (1995) concluded that the form of the protein matrix surrounding the starch affects the digestibility of the protein and consequently the availability of the starch. Both the heat and mechanical breakdown during flaking increased small intestine digestibility of both the starch and protein. This improvement in digestibility is seen more in SFC than SFW due to the chemical differences in the protein matrix (Zinn et al., 2002).

Zinn (1992) conducted a 121 d comparative slaughter study to determine NE of SFC and SFW, and concluded SFW had 4% less NE than SFC. Steam-flaked wheat had a NEm and NEg of 2.28 and 1.58 Mcal/kg, respectively, while SFC had a NEm and NEg of 2.38 and 1.67 Mcal/kg. Calves fed SFC had a tendency to have greater ADG and G:F, but there were no differences in DMI.

Previous research has shown a positive associative effect from feeding multiple grains. have investigated feeding a combination of grains to maximize performance. In several feeding experiments DRC, high moisture corn **(HMC),** and dry rolled grain sorghum **(DRGS)** were fed in various combinations (Stock et al., 1987). Conversion was maximized when HMC made up the majority of the grain in the diet. Digestibility of DRGS was improved when included with a more fermentable grain source, likely due to a greater starch fermenting microbial population (Stock et al., 1987). When fed combinations of DRW and DRC cattle gained 4% faster and 4.4% more efficiently than average performance of 100% DRC or DRW (Kreikemeier et al., 1987). Huck et al. (1998) fed DRC, HMC, SFC, SFGS and combinations of SFGS:DRC and SFGS:HMC and found positive associative effects from feeding grain combinations. Feeding a slowly digestible grain source provides more starch to be fermented in the small intestine while combining with a grain that ferments rapidly in the rumen helps limit risk of ruminal acidosis (Huck et al., 1998). Bock et al. (1991) fed rapidly fermentable grains in multiple experiments (HMC:DRW and HMC:SFW) and observed positive associative effects. Another theory of the cause of the positive associative effects is that feeding combinations of grains differing in amino acid profile will shift the site of N digestion (Axe et al., 1987; Steeter et al., 1989), change ruminal N metabolism and affect the efficiency of ruminal microbial protein synthesis (Streeter et al., 1989). In the current study ISDMD results from Exp 2 indicate that the SFW fed in the experiment had a greater rate of fermentation than SPC. Therefore, the positive associative effect seen in DMI in SFW20 and SFW40 may have been the result of control of acidosis with the feeding of the less fermentable SPC. The positive associative effect in ADG in SFW40 was contributed to the associative effect on G:F. Due to the greater amount of CP in SFW and a difference in amino acid profile, there may have also been changes in rumen N metabolism and microbial protein synthesis contributing to the positive associative effect in ADG.

When feeding SFC and SFW to cannulated steers, average rumen digestibility of starch in both grains was 91.1% (Zinn, 1992). Steam-flaked wheat had a greater passage of microbial N to the small intestine and 5.7% greater total tract N digestibility than SFC (Zinn 1992). Because there was no difference in OM, ADF, or starch in ruminal or post ruminal digestibility, the author suggested that flaking both grains resulted in similar digestibility of non-starch components (Zinn, 1992). Further metabolism research is needed to investigate possible changes in VFA production, rumen pH, and rate of degradation.

Carcass data in the current experiment indicates that SFW can effectively replace SPC. The linear increase in YG can be explained by the linear relationship between percent wheat in the diet and LM area and numeric differences in backfat. Zinn (1992) found no difference in LM, fat thickness, marbling, or liver abscesses. Carcass specific gravity was also measured and no difference in percent water, protein, or fat was found in cattle fed SFC and SFW (Zinn 1992). The reason for differences in LM and YG in the current study are unclear given that there were no differences in ADG, BW, or HCW to justify differences in composition of growth.

Despite the high rate of rumen fermentation, no differences in liver abscesses between treatments. This indicates that feeding SFW did not appear to increase instances of rumenitis relative to corn. However, more research needs to be done to determine potential effects on ruminal metabolism.

With these improvements in cattle performance, SFW can effectively replace SPC while maintaining COG, depending on grain costs. Using the linear trend in G:F from the current experiment, cattle feeding operations can economically pay $0.17 to $0.76 more per 27 kg of wheat than corn before COG begins to increase. There are times of year and regions of the country where corn is in short supply and there is ample, economically priced wheat available. To illustrate time periods when wheat can be more economical than corn in a feedlot diet, price data from 5 cooperative grain elevators in western Kansas from December 2015 to August 2017 was collected. Data included base prices paid during each trading day. Average basis was calculated from prices of all the cooperatives. Prices were applied to the Chicago Mercantile Exchange price for each day. Price trends can be found in Figure 3.4. Using the data generated in Table 3.9, feeding wheat could have been economical when compared to feeding SPC from February 2016 to July 2017 in western Kansas.

While results of the feeding experiment indicate an improvement in performance of SFW over SPC, Exp. 2 explains some of those improvements. The ISDMD of the SPC fed during the experiment was similar to DRC, and had lower DMD than commercial SFC, SFW-F, and SFW-D at all time points. This indicates the SPC fed during the experiment did not receive adequate time in the steam chest. According to the average lab results from the grains fed in this experiment, the mean bulk density was 0.478 kg/L (37.1 pounds/bushel) and 0.483 kg/L (37.5 pounds/bushel) for both SPC and SFW, respectively. According to the 2015 feedlot nutritionist survey (Samuelson et al., 2015) the mean bulk density reported by nutritionists was 0.35 kg/L (27 pounds/bushel) and 0.42 kg/L (32 pounds/bushel) for SFC and SFW, respectively. This indicates that both the SPC and SFW fed were under processed during flaking. This was likely the reason for the low starch availability during the tests. The SPC was farther from the desired level of processing than the SFW.

Previous research investigated the effect of drying after processing on SFC was performed by Zinn and Barrajs (1997). Ten ruminally and duodenally cannulated Holstein steers were fed a diet with either fresh SFC (**SFC-F**) or dried SFC (**SFC-D**). Fresh SFC was flaked every weekday and SFC-D was flaked in 1 batch and put on a concrete pad for 5 d, and turned periodically to simulate drying. Ruminal pH did not differ, but VFA concentration tended to be 8.3% greater ($P < 0.10$) for steers fed SFC-F. Differences were not detected for DM, OM, starch or ADF for ruminal or total tract digestibility. These results concluded feeding value of SFC was not affected by drying (Zinn and Barrajas, 1997). Results from the current *in situ* experiment indicate that there was no difference in ISDMD between SFW-D and SFW-F. No difference in ISDMD was found between SFW immediately after flaking or after being moved through a vacuum air lift.

IMPLICATIONS

The feeding of SFW was shown to decrease DMI without an effect on ADG, resulting in overall increased feed conversion. Cost of gain estimates indicate that higher levels of wheat in the diet will result in higher COG, however this is price dependent. Equations predicting COG and G:F indicate that, depending on corn price and wheat inclusion, beef producers can afford to pay $0.49 to $0.77/27 kg (1 bu) of wheat over the price of 25 kg (1 bu) of corn and achieve similar or better COG. However, due to limited processing of the SPC fed, further research is needed before a nutritional recommendation can be made replacing SFC with SFW. Increases in LM area resulted in a linear decrease in calculated YG. There were however, no other statistical effects on carcass characteristics.

Differences in performance may have been due to inadequate time in the steam chest of the SPC. *In situ* DMD indicated that SPC fed had a lower rate of digestibility than commercially relevant SFC. Additional research is needed to compare SFW and SFC flaked at lower bulk densities. Air drying had no effect on ISDMD of SFW, and SFW had a greater rate of digestion than commercially relevant SFC.

Results indicate using a combination of flaked grains will not improve feedlot performance. Additional metabolism research is needed to determine if the inclusion of both grains in the diet improves overall digestibility, N metabolism, and prevention of acidosis.

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Table 3.1 Composition of receiving diet fed from d -65 through end of grain adaptation on d 18

Ingredient	% of diet DM
Dry Rolled Corn	10.00
Sweet Bran®[1]	54.80
Prairie hay	30.00
Dry Supplement[2]	5.20

[1]Sweet Bran® is a WCGF product by Cargill Corn Milling (Dalhart, TX).

[2]Supplement was formulated to provide: monensin (Rumensin 90) 28.3 mg/kg, tylosin (Tylan 40) 8.48 mg/kg (90% DM Basis, Elanco Animal Health, Greenfield, IN), fine ground corn 2.01%, limestone 1.57%, wheat midds 1.10%, urea 0.36%, magnesium oxide 0.05%, zinc sulfate 0.03%, salt 0.02%, Vitamin A 0.02%, cobalt sulfate 0.006%, manganous oxide 0.006%, Vitamin E 0.004%, and selenium 0.003%.

Table 3.2 Feeding program for adapting feedlot steers from the receiving diet to experimental diets

Day	Feeding 1, %[1]	Feeding 1 Ration[2]	Feeding 2, %[1]	Feeding 2 Ration[2]	Feeding 3, %[1]	Feeding 3 Ration[2]
1 - 2	45.0	REC	10.0	EXP	45.0	REC
3 - 4	40.0	REC	20.0	EXP	40.0	REC
5 - 6	40.0	REC	30.0	EXP	30.0	REC
7 - 8	40.0	REC	40.0	EXP	20.0	REC
9 - 10	50.0	REC			50.0	EXP
11 - 12	40.0	REC			60.0	EXP
13 - 14	40.0	EXP	40.0	REC	20.0	EXP
15 - 16	40.0	EXP	20.0	REC	40.0	EXP
17	45.0	EXP	10.0	REC	45.0	EXP
18	50.0	EXP			50.0	EXP

[1]Percentages represent the ratio of the total daily as-fed allotment delivered at that feeding.

[2]REC is the receiving diet in Table 3.1. EXP represents one of the treatment diets in Table 3.3

Table 3.3 Composition of dietary treatments and nutrient composition of finishing diets containing steam-processed corn, steam-flaked wheat, and 20% DDGS[1]

Ingredient, %	**CON**	**SFW20**	**SFW40**	**SFW60**
Steam-processed corn	59.50	39.80	19.70	-
Steam-flaked Wheat	-	19.70	39.80	59.50
DDGS	20.00	20.00	20.00	20.00
Cane molasses:Cornsteep	5.00	5.00	5.00	5.00
Prairie hay	10.00	10.00	10.00	10.00
Dry supplement[2]	5.50	5.50	5.50	5.50
Nutrient analysis				
NEm, Mcal/kg	2.09	2.08	1.96	1.97
NEg, Mcal/kg	1.42	1.42	1.32	1.31
TDN, %	87.48	84.68	80.73	80.65
CP, %	15.18	15.65	16.18	17.20
Ca, %	0.74	0.58	0.49	0.58
P, %	0.48	0.42	0.45	0.46
Mg, %	0.24	0.23	0.23	0.24
K, %	0.89	0.80	0.90	0.90
ADF, %	12.28	12.65	15.30	15.50
Crude fat, %	3.70	3.70	3.30	3.50

[1]Data represents the mean of 4 laboratory tests. Test 1 was a composite of d 1 to 28, test 2 a composite of d 29 -84, test 3 a composite of d 85 to 112, and test 4 a composite of d 113 – 175. Biweekly rations samples were composited for each laboratory composite.

[2]Supplement formulated to supply: 31.6 mg/kg monensin (Rumensin 90), 9.39 mg/kg tylosin (Tylan 40), 290 mg of ractopamine/hd/d (Optaflexx, 90% DM basis, Elanco Animal Health, Greenfield, IN), 2.1% fine ground corn, 1.56% limestone, 1.16% wheat midds, 0.36% Urea, 0.057% magnesium oxide, 0.034% zinc sulfate, 0.02% salt, 0.02% Vitamin A, 0.006% copper sulfate, 0.006% manganous oxide, 0.005% Vitamin E, and 0.003% selenium.

Table 3.4 Laboratory and tabular nutrient values of steam-processed corn (SPC) and steam-flaked wheat (SFW) fed during the feeding period

	SPC[1]		SFW	
Item	Experiment[2]	NRC[3]	Experiment[2]	NRC[3]
DM, %	85.15	80.70	84.23	82.96
Protein, %	9.63	8.48	14.25	14.42
Starch, %	71.85	76.24	64.85	64.87
Starch Availability, %	18.00	-	25.50	-
Ca, %	0.01	0.02	0.05	0.04
P, %	0.29	0.03	0.33	0.31
Mg, %	0.11	0.09	0.14	0.15
K,%	0.38	0.33	0.43	0.42
Density, kg/L	0.48	-	0.48	-
NEm, Mcal/kg	2.12	2.38	2.09	2.14
NEg, Mcal/ kg	1.46	1.67	1.43	1.47
Crude Fat, %	3.90	3.19	1.40	1.88

[1]SPC fed during the experiment is compared to steam-flaked corn (SFC) values in 2016 NASNRBC

[2]Data represents the mean of 4 laboratory tests. Test 1 was a composite of P1, test 2 a composite of P2 and 3, and test 3 a composite of P3 and 4, and test 4 a composite of P5 and P6.

[3]Data represents tabular values in the 2016 National Academies of Sciences Nutrient Requirements for Beef Cattle

Table 3.5 Composition of diet fed to cannulated steers during *in situ* experiment

Ingredient	% of diet DM
Prairie Hay	59.20
Dry Rolled Corn	28.09
DDGS	6.11
Molasses:Steep	2.59
Supplement[2]	4.00

[1]Diet was fed at approximately 1.31% BW to achieve 110% maintenance (NRC, 2000)

[2]Supplement was formulated to provide: monensin (Rumensin 90, 90% DM Basis, Elanco Animal Health, Greenfield, IN) 20.58 mg/kg, tylosin (Tylan 40) 6.17 mg/kg (90% DM Basis, Elanco Animal Health, Greenfield, IN), fine ground corn 1.54%, limestone 1.21%, wheat midds 0.84%, urea 0.28%, magnesium oxide 0.04%, zinc sulfate 0.02%, salt 0.02%, Vitamin A 0.01%, cobalt sulfate 0.005%, manganous oxide 0.005%, Vitamin E 0.003%, and selenium 0.002%.

Table 3.6 Prices used to calculate cost of gain to evaluate performance of feedlot steers fed finishing diets containing 20% dried distillers grains with solubles, steam-processed corn (SPC), steam-flaked wheat (SFW), or a combination of SPC and SFW

Ingredient	Price
Corn $/25 kg[1]	4.98
Wheat $/27 kg[1]	6.44
Yardage $/hd/d	0.45
	$/Metric ton DM
Steam Processed Corn	233.90
Steam Flaked Wheat	280.77
DDGS	159.22
Cane molasses:Corn steep liquor	440.92
Supplement	355.19
Prairie Hay	97.98
Steam-processing	3.52
Steam-flaking[2]	6.23

[1]Corn and wheat prices are based on weighted USDA average price per bushel from 2011-2016 (USDA ERS 2017).

[2]Derived from Macken, et al., (2006)

Table 3.7 Performance of steers fed finishing diets containing steam-processed corn (SPC), steam-flaked wheat (SFW), or a mixture of SPC:SFW in diets containing 20% dried distillers grains plus solubles

	Treatment[1]								
	CON	SFW20	SFW40	SFW60	SEM	Linear[4]	Quadratic[4]	Lack of Fit[4]	*P*-value[5]
BW, kg									
Initial	322.5	321.0	319.1	320.9	2.7	0.89	0.78	0.87	0.67
d 28	370.6	364.0	366.2	367.1	3.8	0.91	0.99	0.79	0.39
d 85	412.8	408.8	412.9	409.2	4.2	1.00	0.85	0.85	0.65
Final	606.7	610.3	618.2	610.9	10.5	0.78	0.76	0.81	0.74
ADG, kg									
1 - 28	1.72	1.54	1.68	1.65	0.08	0.86	0.26	0.13	0.16
1 - 84	1.59	1.62	1.68	1.60	0.47	0.66	0.21	0.30	0.25
1 - 175	1.62	1.65	1.71	1.66	0.53	0.43	0.35	0.49	0.45
Associative effect, %[6]		2.14	4.85						
DMI, kg									
1 - 28	7.63[a]	7.21[b]	7.23[b]	7.06[b]	0.11	0.15	0.65	0.60	<0.01
1 - 84	8.49[a]	8.36[ab]	8.17[b]	7.83[c]	0.15	0.05	0.64	0.93	<0.01
1 - 175	9.40[a]	9.46[a]	9.30[ab]	8.96[b]	0.19	0.21	0.43	0.95	0.05
Associative effect, %[6]		3.27	3.15						
G:F[2]									
1 - 28	0.226	0.214	0.233	0.234	0.010	0.15	0.39	0.23	0.24
1 - 84	0.188[c]	0.194[bc]	0.206[a]	0.204[b]	0.005	<0.01	0.43	0.44	<0.01
1 - 175	0.173[a]	0.175[a]	0.184[b]	0.185[b]	0.004	0.03	0.92	0.37	0.01
Associative effect, %[6]		- 0.13	2.68						
Cost of Gain, $/kg BW gain[3]									
1 - 28	1.026	1.124	1.059	1.077	0.11	0.51	0.30	0.24	0.32
1 - 84	1.212	1.228	1.199	1.256	0.04	0.40	0.51	0.40	0.33
1 - 175	1.317	1.355	1.337	1.380	0.04	0.23	0.92	0.37	0.28

[1]Treatments were due to type and inclusion of grain in the diet. CON = control diet with steam-processed corn (SPC) 59.5% diet DM basis; SFW20= steam-flaked wheat (SFW) 20% of the diet DM basis; SFW40 = SFW 40% of the diet DM basis; SFW60 = SFW 60% of the diet DM basis

[2]G:F was calculated as the total amount of BW gain divided by the total DMI for that period.

[3]Cost of gain was calculated by multiplying total DMI by the ration cost for that treatment. This numerator was then divided by the total gain during that period. Ration cost included Corn $4.97/25 kg, wheat $6.44/37 kg, grain processing costs were considered to be $6.23/t (metric ton DM) for steam-flaking (Macken, et. al., 2006) and $3.52/t for steam processing resulting in $233.90 and $280.77/t, for SPC and SFW respectively. Supplement, prairie hay, molasses:steep blend, and DDGS costs were kept constant in all rations at $355, $97, $441, and $159/t, respectively. Yardage cost was calculated at $0.45/hd per d, and cost of gain was calculated from the following equation: Cost of gain = ((Total DMI (kg) x ration cost ($/kg)) + ($0.45 x d))/ Total BW gain (kg)

[4]Linear and quadratic regressions were calculated using wheat inclusion (0-59.5%) to predict response from each variable. P-values indicate model significance. Bolded P-values were considered significant.

[5]Within row means without a common superscript differ ($P < 0.05$).

[6]Calculated as [(observed - expected)/expected] x 100

[7]Associative effect differed from zero ($P < 0.05$)

0

1

Table 3.8 Carcass characteristics of steers fed finishing diets containing steam-processed corn (SPC), steam-flaked wheat (SFW), or a mixture of SPC:SFW in diets containing 20% dried distillers grains plus solubles

	Treatment[1]								
	CON	SFW20	SFW40	SFW60	SEM	Linear[4]	Quadratic[4]	Lack of Fit[4]	*P*-value[5]
HCW	391.1	391.1	393.1	387.7	5.8	0.87	0.81	0.86	0.83
Dressing Percent[2]	64.6	65.3	64.5	64.1	1.5	0.80	0.76	0.82	0.91
12th rib fat, cm	1.3	1.2	1.0	1.2	0.1	0.21	0.23	0.38	0.20
LM area cm[2]	37.27[b]	37.27[b]	38.13[a]	39.72[a]	0.9	0.01	0.70	0.37	0.02
Marbling	430.4	439.1	401.6	428.4	22.7	0.60	0.56	0.06	0.40
Choice, % of carcasses	61.9	57.5	39.4	45.0	13.3	0.13	0.60	0.37	0.31
Calculated YG[4]	2.84[a]	2.77[a]	2.39[b]	2.41[b]	0.2	0.01	0.73	0.33	0.02
Liver Abscesses, % of carcasses	15.6	13.1	14.4	11.3	8.0	0.64	0.96	0.76	0.95

[a-b]Within row means without a common superscript differ ($P < 0.05$).

[1]Treatments were due to type and inclusion of grain in the diet. CON = control diet with steam-processed corn (SPC) 59.5% diet DM basis; SFW20= steam-flaked wheat (SFW) 20% of the diet DM basis; SFW40 = SFW 40% of the diet DM basis; SFW60 = SFW 60% of the diet DM basis

[2]Dressing Percent calculated as HCW divided by final BW

[3]400=Slight

[4]USDA yield grade (YG) calculated as 2.5 + (0.98425 × 12th rib fat, cm) + (0.2 × % KPH) + (0.00837 × HCW, kg) – (0.0496 × LM area, cm2) (formula derived from USDA, 1997).

[5]Linear and quadratic regressions were calculated using wheat inclusion (0-59.5%) to predict response from each variable. *P*-values indicate model significance.

[6]Overall F-Test

Table 3.9 Maximum price per 35 L (1 bu) of wheat relative to corn to maintain cost of gain

Corn Price/25 kg	$2.500	$3.000	$3.500	$4.000	$4.500	$5.000
Wheat Inclusion,%			Wheat Price/27 kg[1]			
0	$2.679	$3.214	$3.750	$4.286	$4.821	$5.357
5	$2.981	$3.527	$4.069	$4.619	$5.153	$5.695
10	$2.985	$3.531	$4.074	$4.624	$5.158	$5.700
15	$2.989	$3.536	$4.078	$4.629	$5.163	$5.706
20	$2.993	$3.540	$4.083	$4.634	$5.168	$5.711
25	$2.997	$3.544	$4.087	$4.639	$5.174	$5.717
30	$3.001	$3.549	$4.092	$4.644	$5.179	$5.723
35	$3.005	$3.553	$4.097	$4.650	$5.185	$5.729
40	$3.009	$3.558	$4.102	$4.655	$5.191	$5.735
45	$3.013	$3.562	$4.107	$4.661	$5.196	$5.741
50	$3.018	$3.567	$4.112	$4.666	$5.202	$5.747
55	$3.022	$3.572	$4.118	$4.672	$5.208	$5.754
60	$3.027	$3.577	$4.123	$4.678	$5.215	$5.761

[1]Prices indicate the highest price that can be paid for wheat relative to corn in order to maintain equivalent cost of gain. Estimates are based on advantages in cost of gain calculated from a linear regression of wheat inclusion to predict cost of gain and a linear regression of wheat inclusion to predict G:F.

Table 3.10 Nutrient composition and *in situ* digestibility of treatment grains from feeding experiment and industry standard feedstuffs[1]

Item	DRC	SPC	SFC	SFW-D	SFW-F	P-Value
Nutrient analysis[2]						
DM, %	85.20	83.50	77.90	82.20	79.00	
CP, %	9.90	9.60	8.80	14.70	14.70	
Starch, %	70.60	73.40	74.00	64.60	65.30	
Starch Availability, %	9.00	16.00	49.00	30.00	30.00	
Bulk density, kg/L	0.64	0.46	0.41	0.43	0.42	
Digestible Fractions[2]						
A	0.00^{b}	0.00^{b}	1.11^{ab}	0.42^{ab}	2.90^{a}	< 0.01
B	62.51^{bc}	54.48^{c}	68.57^{abc}	81.70^{a}	75.00^{ab}	< 0.01
C	37.55^{ab}	47.08^{a}	30.32^{bc}	17.88^{c}	22.09^{c}	< 0.01
DM Disappearance[3]						
1	4.19^{c}	2.30^{c}	14.46^{b}	21.61^{a}	22.55^{a}	< 0.01
3	4.96^{c}	3.37^{c}	14.80^{b}	20.26^{ab}	21.98^{a}	< 0.01
6	6.93^{c}	4.24^{c}	17.95^{b}	24.16^{ab}	28.46^{a}	< 0.01
9	13.06^{c}	9.92^{c}	29.75^{b}	37.60^{a}	40.89^{a}	< 0.01
12	18.77^{c}	12.12^{c}	31.17^{b}	41.95^{ab}	43.49^{a}	< 0.01
18	25.67^{b}	22.17^{b}	42.33^{a}	52.88^{a}	54.91^{a}	< 0.01
24	37.93^{c}	29.52^{c}	54.09^{b}	65.31^{a}	66.03^{a}	< 0.01
48	62.45^{bc}	52.92^{c}	69.78^{b}	77.91^{a}	82.12^{a}	< 0.01

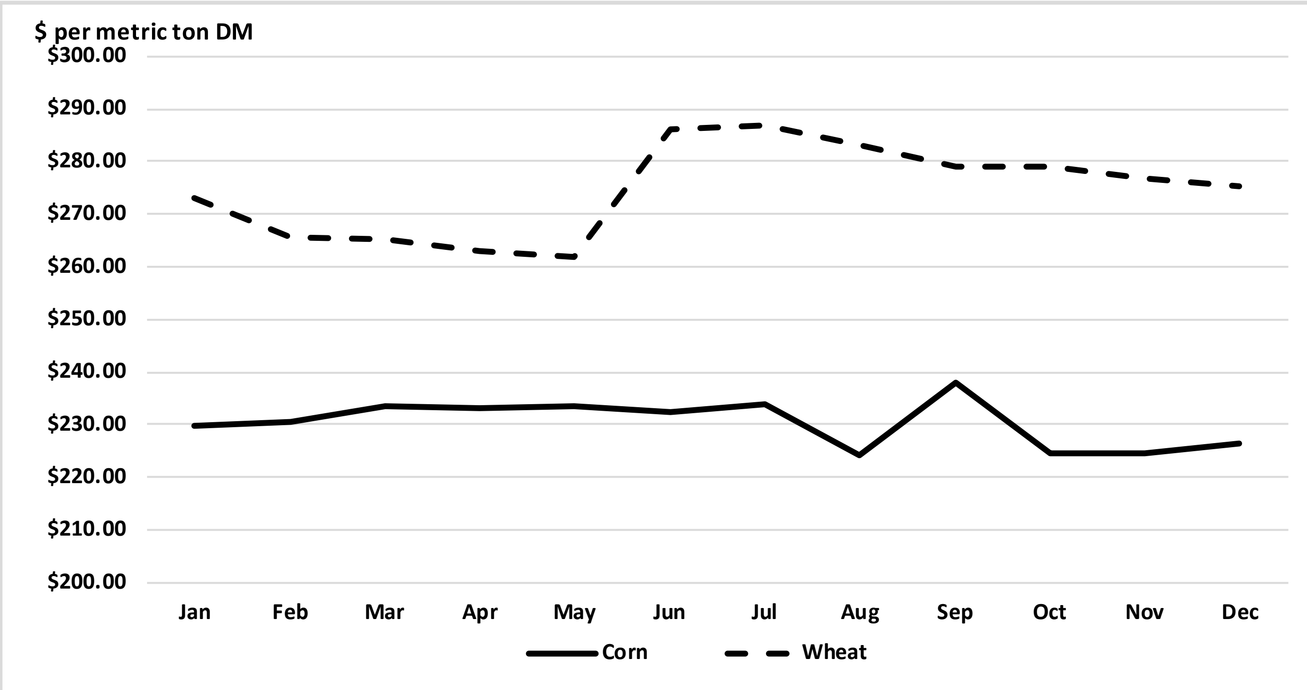
[1]DRC = dry-rolled corn, SPC = steam-processed corn, SFC = steam-flaked corn from a commercial feedyard in western Kansas, SFW-D = steam-flaked wheat sampled after passing through vacuum air lift, SFW-F = steam-flaked wheat sampled immediately after flaking

[2]A fraction = DM digested during 20 min soak; C Fraction = DM remaining after 48 h incubation. B fraction = 100 - A fraction – C fraction

[3]Dry matter disappearance from *in situ* bags incubated for 1, 3, 6, 9, 12, 18, 24, 48 h. Data represents the mean of 6 cannulated steers used in the experiment

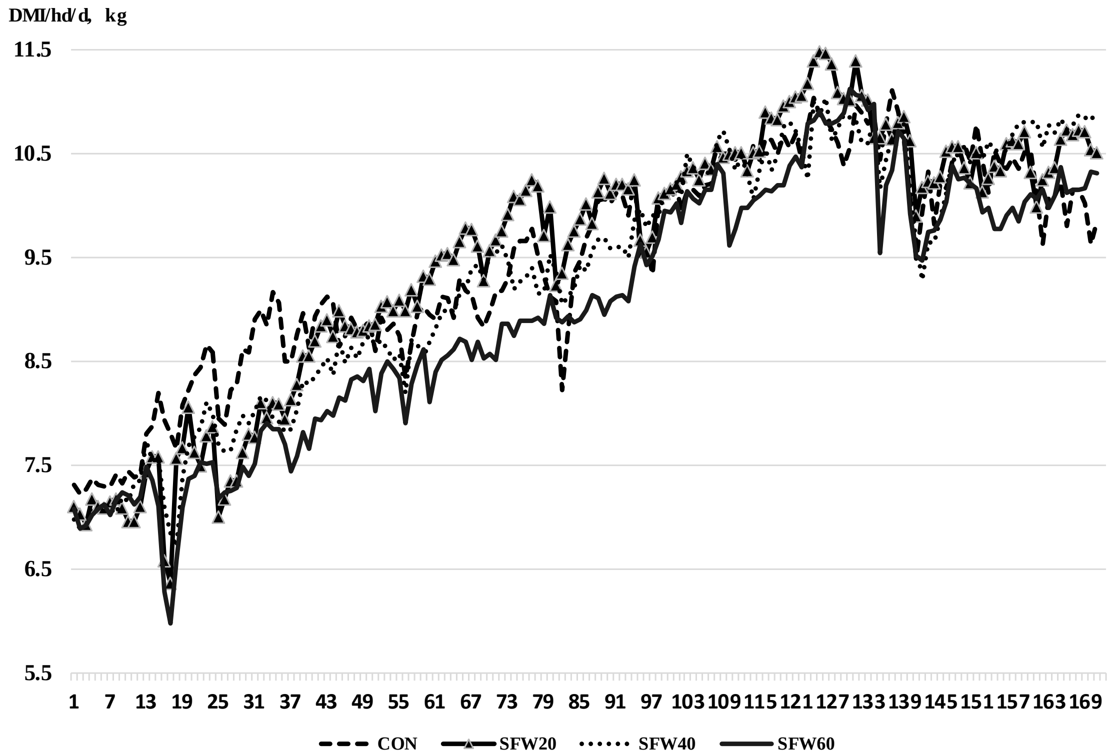
4

Figure 3.1 USDA average corn and hard red winter wheat prices 2011-2016



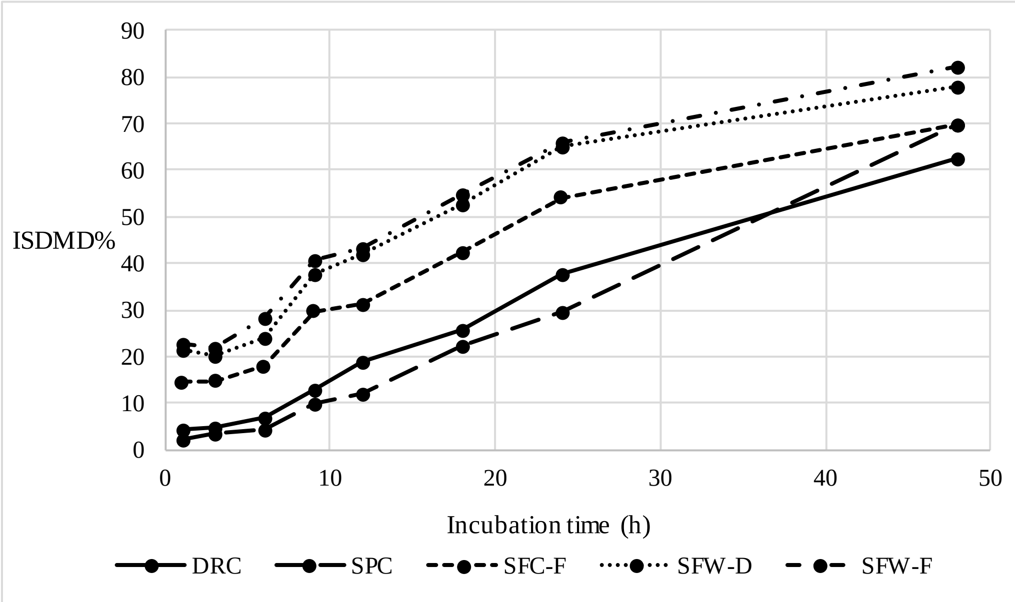
Source: USDA Economic Research Service, 2017

Figure 3.2 Average daily DMI of finishing steers fed diets containing steam-processed corn (SPC), steam-flaked wheat (SFW), or a mixture of SPC:SFW and 20% dried distillers grains plus solubles



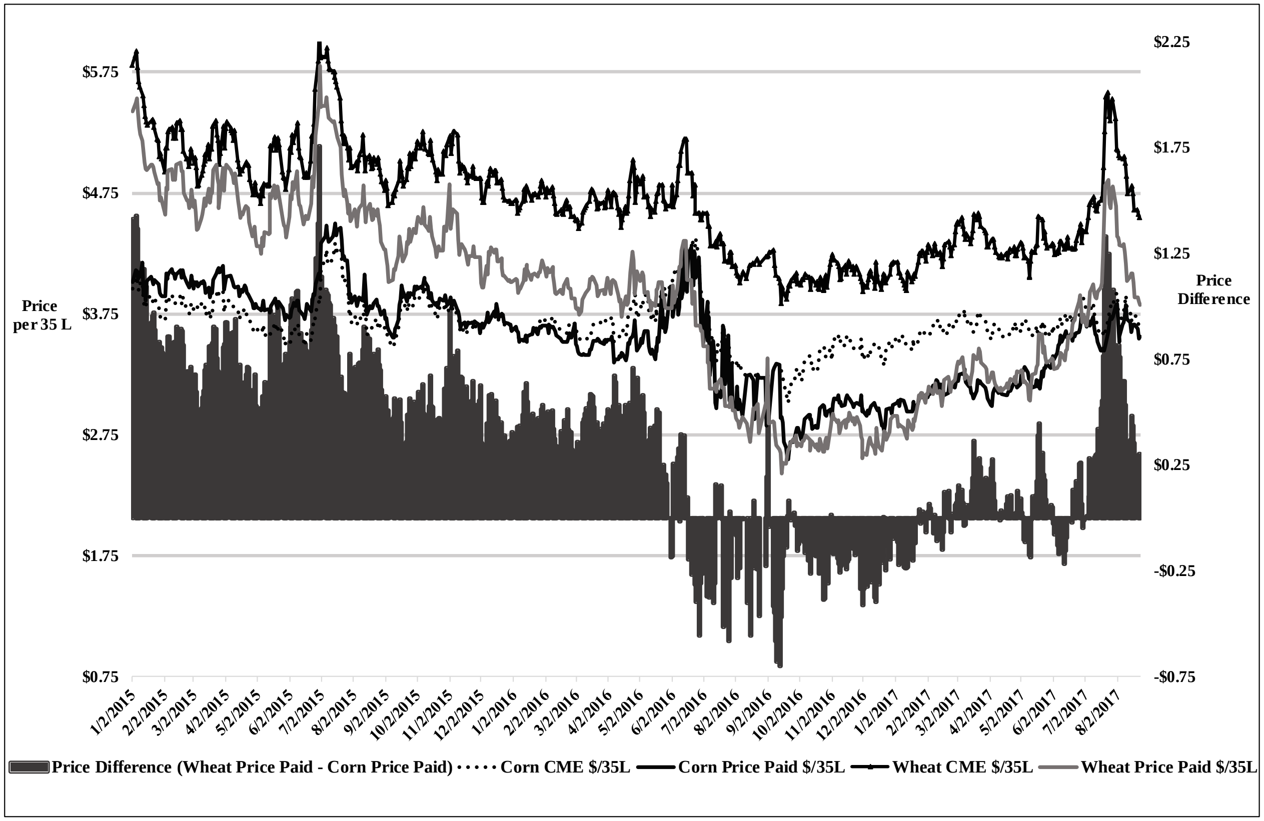
[1]Treatments were due to type and inclusion of grain in the diet. CON = control diet with steam-processed corn (SPC) 59.5% diet DM basis; SFW20= steam-flaked wheat (SFW) 20% of the diet DM basis; SFW40 = SFW 40% of the diet DM basis; SFW60 = SFW 60% of the diet DM basis

Figure 3.3 *In situ* dry matter disappearance (ISDMD)[1] of grains fed in Exp. 1 and industry standard feedstuffs



[1]DRC = Dry rolled corn, SPC = steam-processed corn fed in the feeding trial Exp. 1, SFC-F = steam flaked corn attained from commerical feedlot, SFW-D = steam-flaked wheat fed during feeding trial Exp. 1, SFW-F = steam-flaked wheat that was not exposed to air drying in vacuum lift after flaking.

Figure 3.4 Wheat and Corn prices from Chicago Mercantile Exchange and the mean of 5 cooperative grain elevators in western Kansas



Prices adapted from data provided by 5 cooperative grain elevators in Western Kansas.
Price difference calculated as the price of wheat/bu after applying the regional basis subtracted from the price in corn after applying the regional basis.

CHAPTER IV

FEEDING BEHAVIOR OF STEERS DURING ADAPTATION TO A FINISHING DIET

ABSTRACT: Two hundred and twenty-three steers (initial BW= 556.5 ± 4.2 kg) were adapted to an 90.75% concentrate diet using 4 diets fed for 6 d each to analyze feeding behavior during adaptation to a finishing diet. Intake and feeding behavior traits were continuously monitored using an Insentec feeding system. Composition of diets on a DM basis was as follows: 22.5% dry-rolled corn (**DRC**), 42.3% Sweet Bran® (**SB**), and 30% prairie hay (PH) (**STEP1)**; 34.8% DRC, 30% SB, and 30% PH (**STEP2)**; 42.8% DRC, 30% SB, and 22.5% PH (**STEP3)**; 49.8% DRC, 30% SB, and 15% PH; (**STEP4)**; 57.5% DRC, 30% SB, and 7% PH (**FIN).** Diet volume intake (VI, L), energy intake (EI, Mcal), and DMI were calculated per meal and per d. Dry matter intake per d was greatest in FIN and STEP4 for winter and summer, respectively (P < 0.0001), and EI per d was greatest in FIN both winter and summer ($P < 0.0001$). Energy intake per meal was greatest in STEP4 and FIN for both winter and summer ($P < 0.0001$). Increase in eating rate was likely due to less ensalivation needed in low forage diets. Steers consumed more feed from 0700 to 1259 and 1300 to 1859 in winter and more feed from 1900 to 0059 in summer ($P < 0.0001$). Data suggests that cattle consumed to physical fill in STEP1 and

STEP2 and consumed to chemostatic fill in STEP3, STEP4 and FIN. Previous water restriction, animal size (> 550 kg), and previous nutrition, (54.8% SB for 160d) may have increased caloric capacity.

Key words: Feeding behavior, high-grain diet adaptation, corn by-product, feed intake

INTRODUCTION

Adaptation to a high grain finishing diet is an important period when cattle are transitioned from a typically low energy, high fiber diet to a high energy, high starch diet. The primary goal of adaptation to a finishing diet is to limit the risk of acidosis. Fulton et al. (1979) adapted cattle to high concentrate diets using step diets containing 35, 55, 75, and 90% concentrate. Cannulated steers were fed either DRC or dry rolled wheat (DRW). When both grains were fed, the level of propionate increased while acetate increased. However, lactate levels early on in the grain adaptation before being reduced in the 90% concentrate diet. In addition, the rate of feed consumption (kg/h) decreased as more concentrate was fed. Fulton et al. (1979) theorized that meal size and feeding rate was decreased to maintain rumen pH.

When consuming a forage-based diet, cattle will eat until tension receptors in the rumen wall provide negative feedback to stop feeding. Diets with greater physical density and a greater proportion of grain relative to forage provides less stimulation of the rumen wall. As energy density of the diet increases, a new mechanism of satiety must be used by the animal. Allen et al. (2005) proposed that the chemostatic mechanism is likely regulated by the metabolic potential of the animal. Feed intake is therefore regulated by the speed of absorption and metabolism of organic acids (Allen et al., 2005). Adaptation to the finishing diet is primarily affected by changes in microbial environment and changes in feeding behavior by the animal. According to a review by Gonzalez et al. (2012) feeding behavior is determined primarily by the amount and type of grain, feed additives such as sodium bicarbonate and monensin, feed bunk management, and number of feedings per d.

The objective of this experiment was to determine how individual animal feeding behavior changes during adaptation from a low energy, high forage diet to a high energy, high concentrate diet. Differences in DM, calories, and liters will be used to evaluate changes in mass, energy, and volume, respectively, consumed per meal and per d. The changes in feed intake regulation will be observed during transition to a finishing ration to determine when animals change from physical to a chemostatic fill mechanism.

MATERIALS AND METHODS

Experiment design

Before initiation of both groups, 2 previous 70-d feed efficiency tests had been performed to meet Beef Improvement Federation protocols (BIF, 2016). During allocation to pens on d -168, animals greater than the group average BW were assigned to 2 pens and considered the heavy block, while those lighter than the average were assigned to 2 pens and considered the light block (25 to 27 steers/pen in Group 1; 29 to 32 steers/pen Group 2). Group 1 (Winter) began on October 21, 2016 and ended on December 2, 2016. In the winter group 105 crossbred (Angus x Simmental x South Devon) steers (BW 572.9 ± 4.1 kg) were adapted to a 90.75% concentrate diet over 24 d. Group 2 (Summer) began on June 6, 2017 and ended on July 20, 2017. In the summer group 123 purebred Angus steers (BW 542.5 ± 4.3 kg) were adapted to a high concentrate diet in the same manner as Group 1.

The steers for both groups were used for a previous experiment that determined changes in performance during water restriction. During that experiment from d -146 to d -77 steers were given *ad libitum* feed and water intake. During this period each animal's average daily water consumption was determined. From d -76 to d -48 steers were given 10% less water each week from 100% to 50% *ad libidum*. From d -47 to d -7 steers were limited to 50% of average *ad libitum* WI. Following the restriction steers were reacclimated to full WI from d -6 to 0.

Individual BW were measured (Tru-Test, Inc. Mineral Wells, TX) on d 1, and steers were given 120 mg trenbolone acetate and 24 mg estradiol (Component TE-S with Tylan, Elanco Animal Health Greenfield, IN). Diet composition and nutrient analysis is included in Table 4.1. The first diet contained 22.5% dry-rolled corn (**DRC**), 42.3% Sweet Bran® (**SB** Cargill Corn Milling, Dalehart, TX), and 30% prairie hay (PH), DM Basis (**STEP1)**; the second diet contained 34.8% DRC, 30% SB, and 30% PH, DM Basis (**STEP2)**; the third diet contained 42.8% DRC, 30% SB, and 22.5% PH, DM Basis (**STEP3)**; the fourth diet contained 49.8% DRC, 30% SB, and 15% PH, DM Basis (**STEP4)**; the final finishing diet contained 57.5% DRC, 30% SB, and 7% PH, DM Basis (**FIN).** Monensin and tylosin concentrations were kept constant in the BASE and STEP diets (28.4 mg/kg and 8.47 mg/kg DM, respectively) and increased slightly in the FIN diet (30.0 mg/kg and 8.97 mg/kg DM, respectively). Data was collected for 6 d on each of the 4 step diets and 10 d FIN diet for 10 d.

Feed samples were taken twice over each 6 d period. DM was determined using a forced air oven at 60°C (VWR Radnor, Pennsylvania). Animals were fed at 0700, 1000, and 1400 (Rotomix Forage Express 274 Dodge City, KS). Feed was delivered so that at least 5 kg of feed remained from the previous day's feeding in each of the 6 feed bunks at 0700. Remaining feed was removed from the bunks each d at 0700. This feed was then included with the new day's feed. On the first d of each diet, any remaining feed from the previous d was discarded. After each group, fresh samples from each diet were composited sent to commercial lab (Servitech Labs, LLC. Dodge City, KS).

Feeding data

Individual animal intake was monitored using a Roughage Intake Control (Insentec, Hokofarm Group B.V. The Netherlands) system as described by Mader et al. (2009). Each pen contained 6 feed bunks and 1 water bunk that continually measured individual animal intake. Each time an animal came to the feed or water bunk, the current time and weight of the bunk was recorded. When the animal removed its head from the bunk, the end weight and time were also recorded. At this time the Insentec system recorded a feeding event with a start and end time, start and end weight, feed or water intake, and total time spent at the bunk. The start of each d was considered to be 0700 at the first feeding. Dry matter intake, energy intake (**EI**, Mcal of NEg), and feed volume (**VI**, L) of each meal was calculated based on the nutrient composition of each diet in Table 4.1.

Each feeding event was considered to be a meal. However, due to the nature of the feeding system, it was common for animals to remove their head from the bunk frequently during one feeding session resulting in multiple events per session. To account for this, meal interval was calculated as the difference in time between the end of a feeding event and the start of the next feeding event by the same animal. If the meal interval was 7 minutes or less, the feeding events were added together and considered 1 meal (Forbes, 1995; Montanholi, et. al., 2010). The time between meals was included as active feeding time because all steers in the pen shared 6 feed bunks and only a fraction of the animals could feed simultaneously. It was common for animals to stop feeding for a time and return to eat again shortly thereafter. It was not uncommon to occupy the same bunk while other steers were between feeding events. The total feeding time from combined feeding events was calculated by adding the meal intervals and feeding time from each event in order to calculate total feeding time. The DMI, VI, and EI of events within the same meal were also added together. Meals per hour and meals per d were calculated. Feeding time was calculated as the total time each animal spent in the bunk as well as the meal intervals of combined events added together. Total intake was calculated as DMI, EI, VI, and WI (water intake) per d as well as per meal. Feeding rate per meal was calculated as the amount consumed per meal divided by the total time of each meal. Feeding events were categorized into 4 parts of the d: 0700 to 1259, 1300 to 1859, 1900 to 0059, and 0100 to 0659. The percent of intake during each of these 6 h periods was calculated for each ration.

These calculations were also performed to analyze drinking behavior. Water events were each considered episodes. If drinking interval was less than 7 minutes, then water events were combined. Any feeding or drinking events with no intake and events greater than 60 min in length were not included in the data set.

Daily mean, maximum, and minimum Cattle Comfort Index (CCI) data was collected by Oklahoma Mesonet (2017). Temperature, wind speed, relative humidity, surface temperature, and solar radiation are used to calculate if weather conditions are causing heat stress (>30), heat danger (>40), cold stress (<-10) or cold danger (< -30) (Mader, et. al., 2010). Daily mean, maximum and minimum CCI was calculated for each ration.

Statistical analysis

Feeding behavior data was analyzed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, Cary, N.C.). Steer within diet was considered the experimental unit, and diet and season were considered fixed effects. Each steer was given each diet. Since the diets were required to be administered in a specific order, the sequence of diets was analyzed using linear mixed models methods for repeated measure. Steers were not blocked. When effects were significant, means were separated using Tukey's least significance difference method. Linear, quadratic, cubic and quartic polynomial orthogonal contrasts were calculated to examine the relationship between measured response variables and the percent DRC in the diet. Differences in CCI were analyzed using PROC MIXED (SAS Institute, Cary, N.C.). Differences were considered significant when $P < 0.05$, and trends when $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Orthogonal polynomial contrasts were used to test for trends in the response variables as a function of the percent DRC in the diet. While trend components were significant, there was also lack of fit indicating that a polynomial function did not adequately model the responses as a function of the percent DRC in the diet.

Feeding behavior

Summary of feeding behavior during adaptation to the finishing diet are presented in Table 4.2. During both winter and summer the number of meals per d decreased from STEP1 to STEP3 and then increased in STEP4 to FIN ($P < 0.0001$). Eating time per meal was greatest in STEP3 for winter and STEP2 for summer, and in both groups was lowest in FIN ($P < 0.0001$). Eating time per d was greatest in STEP1 and decreased to FIN in both summer and winter ($P < 0.0001$). Eating rate for both DM and energy in summer and winter was greatest in FIN and least in STEP1 ($P < 0.0001$). Eating rate of volume was the greatest in STEP1 (0.47 and 0.50 L/min for winter and summer respectively) and least for FIN (0.31 and 0.33 L/min for winter and summer, respectively).

Summary of intake per d and per meal is in Table 4.3. No Season x ration interaction occurred in DMI, VI, or EI per meal. DMI per meal was not different between STEP1 and STEP2 (1.35 kg) and increased to 1.53 kg in STEP3, STEP4, and FIN. Energy intake per meal was greatest in STEP4 and FIN ($P < 0.0001$). Volume intake per meal decreased from STEP1 (8.96 L/meal) to FIN (3.91 L/meal). DMI per d was greatest in STEP4 and FIN in the winter. In the summer DMI was greatest in STEP4 and decreased in FIN ($P < 0.0001$). Energy intake per d was greatest in FIN in winter (18.60 Mcal/d) and greatest in STEP4 and FIN in summer (18.68 Mcal/d). Volume intake per d decreased from STEP1 (76.94 and 86.94 L/d for winter and summer, respectively) to FIN (35.10 and 35.49 L/d for winter and summer, respectively).

Drinking behavior

A summary of drinking intake and behavior is presented in Table 4.4. The number of drinking episodes per d was greatest for STEP1 (6.62 and 7.21 for winter and summer, respectively) and least for FIN (5.17 and 6.56 for winter and summer, respectively). There was no season x ration interaction and no difference between rations for WI per meal. Water intake per d in winter and summer decreased from STEP1 (45.37 and 60.23 kg/d, respectively) to FIN (34.72 and 55.46 kg per d, respectively). Time spent drinking per episode decreased in winter from 2.93 min/episode in STEP1 to 2.40 min/episode in STEP3 and increased to 2.92 min/episode in FIN. During summer total time spent drinking was greatest in STEP1 (19.78 min/d) and decreased to 12.75 min/d in STEP3. There was no difference in drinking time per d in summer between STEP2, STEP4, or FIN. During winter the same pattern occurred, however, FIN spent the most time drinking per d with 24.63 min per d. and the least during STEP3 20.25 min per d.

Summary of intake in 6 h periods of the d are presented in Table 4.5. Feed and energy during different times of the d differed between ration and season. During winter and summer, STEP3 consumed the most feed between 0700 and 1259 ($P < 0.0001$). During winter, the most feed consumed from 1300 to 1859 was in STEP4 and FIN, while during summer steers consumed the least amount of feed in STEP4 and FIN. From 1900 to 0059 during winter, steers consumed more feed during STEP1 and STEP2 while in the summer cattle consumed more feed during STEP4 and FIN. From 0100 to 0659 steers consumed the most feed in STEP1 in winter ($P < 0.0001$), and no significant differences were observed in summer.

During adaptation to the finishing diet steers consumed more DM and energy per d as well as per meal. In both summer and winter STEP3 had the least number of meals per d, but little variation occurred in the other diets. Previous research has shown a decrease in meal size and an increase in meal number with DRC processed to a lower density, but time feeding per meal was not affected by DRC processing or level of DDGS (Swanson et al., 2014). While number of meals per d remained relatively unchanged, there was a decrease in the amount of time spent feeding per d and per meal. As a result, steers consumed more feed at a more rapid rate. Feeding rate per meal (DM and Mcal/min) increased as concentration of corn increased in the diet. Gonazalez et al. (2012) reported that as roughage content of the diet decreased, ensalivation of the feed and rumination decrease. This decrease in rumination allows for eating rate to increase. Others have found when forage was titrated into the diet at 5% intervals (5 to 20%) quadratic relationships have been observed with feeding time and DMI (Swanson et al., 2017), with feeding time greatest at 10% forage and DMI the least at 20% forage. Volume intake per meal and per d decreased as physical volume of the diet decreased. Volume intake may be a contributing factor in high roughage (>20%) diets, but the rate of VI decreased as adaptation to the finishing diet progressed. Small changes occurred in VI in STEP2 and STEP3, however in STEP4 and FIN diet, volume and VI decreased significantly as PH was replaced by DRC. When feeding diets with 5, 10, 15, or 20% roughage, Swanson et al. (2017) reported a quadratic effect on feeding rate (g DM/min) with 5% roughage having the greatest and 20% roughage having the lowest feeding rate. Steers may have been able to consume more feed per bite due to the lower roughage content of a finishing diet and physical density of the feed.

While DMI per meal increased from STEP1 to FIN, there was no difference in DMI per meal in STEP3, STEP4, and FIN. Based on feed intake, negative feedback seemed to regulate meal size to a constant DM when SB inclusion decreased from 42.3% to 30%. During STEP3, STEP4, and FIN there was no change in DMI per meal as roughage inclusion was decreased. Fill mechanisms and feeding behavior associated with low energy, high forage diets are predominantly a result of physical fill, and limited effect of energy density (Bines, 1971; Fisher, 2002, Mertens, 1987). Therefore, data would suggest that meal feed intake is not regulated by gut fill after roughage inclusion is 22% or less. In both summer and winter, steers consumed to a constant energy intake per meal in STEP4 and FIN even as DMI per meal was changing, and fill was regulated by a chemostatic mechanism.

In winter DMI per d increased from 11.23 kg per d in STEP1 to 13.37 kg in STEP4 and FIN. While DMI was not different in STEP4 and FIN, EI continued to increase to its maximum in FIN. In summer DMI increased to 14.26 kg/d in STEP4 and decreased to 13.63 kg/d in FIN. However, EI per d continued to increase even as DMI per d decreased in FIN in summer. Feed regulation per d in winter was to a constant DM while EI continued to climb. During summer DMI per d decreased and steers consumed to a constant EI per d. Krehbiel, et. al. (2006) in a meta-analysis of 65 feeding trials calculated found that the slope of ME intake (Mcal/kg of MBW) vs. dietary ME did not differ from zero. The author concluded that ruminants consuming a high-grain diet will eat to a constant energy intake per d. The difference between winter and summer may have been due to differences in weather. Environmental conditions during both experiments are presented in Table 4.6. Mean, minimum and maximum Cattle Comfort

Index were greater in summer than winter. The high ambient temperatures may partially explain the lower intake that was observed in FIN in summer.

Eating rate of both DM and energy increased from STEP1 to FIN as a result of small changes in meal per d and a decrease in a decrease in eating time per d. When grass hay was offered *ad libitum* and DDGS offered at various levels, feeding rate per meal was greater for DDGS (Islas et al., 2014). In addition, feed intake of DDGS per meal increased quadratically as hay intake per meal decreased linearly with increased DDGS supplementation. Feeding rate per minute increased linearly in hay as DDGS feeding rate increased quadratically with greater DDGS supplementation. Islas et al., (2014) found that supplementation of corn by-product (DDGS) resulted in steers consuming fewer, smaller meals at a faster rate which was concluded to be a result of satiety being attained from greater energy density. In the current experiment meals were shorter because cattle consumed a greater amount of energy and DM in a shorter amount of time. This may have been negative feedback for steers to stop eating once a certain amount of energy was consumed.Feed consumption from 0700 to 1259 was greatest in STEP3 for both winter and summer. Feed consumption on average was greater from 1300 to 1859 in winter than summer, and in summer feed consumption was greater from 1900 to 0059. Differences in environment (mean CCI -9.7 and 27.1 in winter and summer, respectively) may have been a factor. Ray and Roubicek (1971) reported greater percent of steers feeding after 1700 during summer while more steers consumed feed from 0800 to 1600 during the winter. A greater proportion of feed consumed may have occurred in summer after 1900 when ambient temperatures begin to decline. This may have contributed to steers on FIN consuming the greatest proportion of feed from 1300 to 1859 in winter and the least proportion amount of feed in summer relative to other rations. Previous research (Fulton et al., 1979) has shown that feeding rate decreases as diets become more energy dense, but a consistent intake pattern showed a larger proportion of intake immediately after animals are fed, and then a slow decrease in DMI as the d progressed. These data show the same pattern, however, unlike Fulton et al. (1979), DMI increased during adaptation to the finishing diet. In the current experiment, both DMI and eating rate increased. Therefore, because both DMI and eating rate increased, the proportion of intake in the different 6 h periods of the d remained relatively unchanged by adaptation to the finishing diet even though DMI and EI increased.

Reduction in DMI and greater variation in DMI are indicators of subclinical acidosis (Bevans et al., 2005; Britton and Stock, 1989). With no reduction in DMI in the current experiment, subacute acidosis may not have occurred in most of the steers (Gonzalez et al 2012). Daily DMI is summarized in Table 4.7. In the current experiment DMI on the first d of each diet was greater than DMI on the second d. On the third, fourth, and fifth days there were either numeric or statistically greater DMI. These data indicate that steers consumed more of the new diet on the first d, and then consumed less feed which may have been the result of subacute acidosis. The increase in DMI on third, fourth, and fifth days indicate that steers adapted to the greater energy content and increased intake. Dohme et al. (2008) and DeVries et al. (2009) conducted repeated acidosis challenges on the same animals. During each consecutive challenge cattle were able consume more feed per meal and rumen pH was reduced indicating that cattle are able to adapt to higher acid production and consume more of a highly fermentable diet.

The number of drinking episodes and the amount of WI per d was greater in summer which was likely due to differences in CCI. The number of episodes in both summer and winter decreased as DRC inclusion increased. This may have been associated with lower roughage content and therefore less rumination. In addition, it may have been associated with less time at the feed bunk, and as a result, cattle may receive less stimulation to go to the water bunk. The consumption of a more palatable diet with less roughage may also have decreased stimulation for WI. Swanson et al. (2014) reported drinking time decreased with finer ground DRC and increased with greater inclusion of DDGS (Swanson et al., 2014). In the current experiment energy concentration of the diet was increasing in a similar way, and the same response in drinking time occurred in STEP2, STEP3, and STEP4 in winter and summer. The level of WI during adaptation seemed to follow the CCI for each d, and is likely the reasoning for the large WI difference between the winter and summer groups. During the previous WI experiment, steers were limited to 7 kg of water every time they gained access to the bunk in order to prevent steers from drinking over their allotted amount. Steers also consumed 7 kg per episode in the current experiment which may indicate that those steers were still drinking to that same amount

The diet that was used during the previous WI experiment contained 54.8% SB, 30% PH, 10% DRC, and 5.2% dry supplement. Wet corn gluten feed (WCGF) has been used to adapt cattle to grain. Huls et al. (2016) used SB to adapt cattle to a finishing diet and compared it to a traditional step up program replacing alfalfa and corn silage with high moisture corn (HMC) and dry rolled corn (DRC). When steers were fed individually and feeding behavior was continually monitored, steers spent more time feeding, had more meals per d, and had greater DMI when adapted using SB (Huls et. al., 2016). Schneider et al. (2017) evaluated the use of a complete starter feed (RAMP, Cargill Corn Milling, Blair, NE) a proprietary mixture SB, alfalfa, cottonseed hulls, molasses, vitamins and minerals (MacDonald et al., 2011) during adaptation to the finishing diet. Cannulated steers were adapted to a finishing diet either in one d or blending RAMP and the finishing ration over a period of 24 d. There was no difference in DMI between treatments, however the cattle adapted in 1 d spent more time feeding. Both studies involving WCGF gave evidence that traditional adaptation to the finishing diet, exchanging forage for grain may not be necessary if corn by-products are properly utilized. The steers in the current experiment may have been adapted to eating moderate levels of energy for a long period of time before the initiation of grain adaptation. Because all steers received the same previous treatment, additional research is needed to determine if these results are accurate or were affected by previous diet.

To better explain previous performance of these cattle before, during, and after water restriction, previous growth performance and intake is shown in Table 4.8. In both winter and summer cattle gained greater than 1 kg per d and consumed greater than 10 kg DM per d. After the 28 d step down to 50% water restriction, ADG was 0.71 and -0.02 for winter and summer, respectively. During the current grain adaptation experiment, cattle gained 1.19 and 1.63 kg per d for winter and summer, respectively. This compensatory gain was likely due to the lack of performance during water restriction. This may have also affected DMI during transition to a high grain diet. At the start of both winter and summer groups, steers weighed greater than 500 kg. The steers used for this experiment likely had large potential intake capacity because of age, size, and limited previous nutrition. In most feeding scenarios cattle adapted to grain have received feed from a bunk for 0 to 45 d and weigh less than 300 kg. Both the size and compensatory gain of the steers in the experiment may explain unexpected increase in DMI. Additional research is needed to determine the effect of adaptation to a finishing diet on feeding behavior with smaller cattle that are more naïve to concentrates. Research investigating feeding behavior during grain adaptation programs with and without grain by-products is also needed to estimate the value of forage and corn by-product when adapting cattle to high concentrate diets.

The use of corn by-products has become commonplace in feedlot diets (Klopfenstein, et. al., 2007). Further research is needed to determine not only the effect of grain concentration but also the effect of corn by-product concentration on feeding behavior. This will help determine if corn-byproduct prevents further decrease in DMI and EI per meal that was previously reported (Fulton, et. al., 1979). Additional research is needed to investigate changes in feeding behavior using different adaptation programs mentioned above. Metabolism research that provides both feeding behavior and rumen fermentation measurements (pH, VFA concentration, passage rate, etc) will be valuable.

IMPLICATIONS

During adaptation to a finishing diet steers may consume a greater amount of DM and energy and decrease volume intake as diet caloric and physical density rises. Feeding time per d and per meal may decrease as cattle are able to consume more feed and energy in a shorter amount of time. Removing both low quality forage and wet corn gluten feed from the starter diet may result in changes in intake and feeding behavior. Understanding how different feed ingredients can affect intake, behavior, rumen environment and overall performance will help improve current grain adaptation programs. More information is needed to determine how body weight, previous nutrition, weather, and feed ingredients affect individual animal feeding patterns throughout the d and over time.

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Table 4.1 Composition of dietary treatments and nutrient composition of diets used during adaptation to a finishing diet for finishing steers[1]

Item	STEP 1	STEP 2	STEP 3	STEP 4	FIN
Days	6	6	6	6	10
Ingredient, %					
Dry Rolled Corn	22.50	34.80	42.80	49.80	57.50
Sweet Bran®[2]	42.30	30.00	30.00	30.00	30.00
Prairie hay	30.00	30.00	22.00	15.00	7.00
Dry Supplement[3]	5.20[4]	5.20[4]	5.20[4]	5.20[4]	5.50[5]
Nutrient Analysis					
Density, kg/L	0.146	0.205	0.232	0.310	0.384
NEm, Mcal/kg DM[6]	1.76	1.75	1.85	1.94	1.98
NEg, Mcal/kg DM[6]	1.13	1.13	1.22	1.30	1.38
DM, %					
Winter	71.90	80.25	74.66	76.68	78.46
Summer	76.47	79.66	79.93	79.81	80.72
NDF, %					
Winter	47.90	37.1	36.1	33.6	26.5
Summer	37.57	34.55	29.98	25.99	21.43
ADF, %					
Winter	23.1	17.4	15.8	14.3	10.7
Summer	25.4	28.5	22.3	19	10.8
CP, %					
Winter	15.6	15.0	13.8	13.9	15.6
Summer	15.1	12.4	13.6	14.5	14.0
Ca, %					
Winter	0.56	0.75	0.81	0.65	0.59
Summer	0.64	0.51	0.59	0.71	0.71
P, %					
Winter	0.54	0.52	0.55	0.46	0.51
Summer	0.58	0.41	0.43	0.52	0.52

[1]Data represent the mean results from independent lab analysis from winter and summer (Servitech Labs, LLC. Dodge City, KS).

[2]Sweet Bran® is a WCGF product by Cargill Corn Milling (Dalehart, TX).
[3]Base to Step 4 were formulated to provide 28.36 mg/kg and 8.47 mg/kg for monensin and tylosin, respectively. Finish diet formulated to provide 30 mg/kg and 8.97 mg/kg for monensin and tylosin, respectively.
[4]Supplement was formulated to provide: monensin (Rumensin 90) 28.3 mg/kg, tylosin (Tylan 40) 8.48 mg/kg (90% DM Basis, Elanco Animal Health, Greenfield, IN), fine ground corn 2.01%, limestone 1.57%, wheat midss 1.10%, urea 0.36%, magnesium oxide 0.05%, zinc sulfate 0.03%, salt 0.02%, Vitamin A 0.02%, cobalt sulfate 0.006%, manganous oxide 0.006%, Vitamine E 0.004%, and selenium 0.003%.
[5]Supplement formulated to supply: 31.6 mg/kg monensin (Rumensin 90), 9.39 mg/kg tylosin (Tylan 40), 290 mg of ractopamine/hd/d (Optaflexx, 90% DM basis, Elanco Animal Health, Greenfield, IN), 2.1% fine ground corn, 1.56% limestone, 1.16% wheat midds, 0.36% Urea, 0.057% magnesium oxide, 0.034% zinc sulfate, 0.02% salt, 0.02% Vitamin A, 0.006% copper sulfate, 0.006% manganous oxide, 0.005% Vitamin E, and 0.003% selenium.

[6]Diet energy values were calculated using tabular ingredient energy values from NASEM 2016.

Table 4.2 Feeding behavior of steers during transition to a high grain diet during winter or summer[1]

Item	STEP1	STEP2	STEP3	STEP4	FIN	SEM	Ration[2]	Linear[3]	Quadratic[3]	Cubic[3]	Quartic[3]
Meals per d[4]											
Winter	8.83^{ab}	8.55^{ab}	7.75^{c}	8.50^{b}	8.83^{c}	0.09	< 0.0001	0.317	< 0.0001	0.013	< 0.0001
Summer	9.92^{a}	9.54^{bc}	9.35^{c}	9.49^{bc}	9.76^{ab}	0.09	< 0.0001	0.027	< 0.0001	0.545	0.453
Eating time per meal, min[4]											
Winter	19.40^{b}	20.25^{b}	21.75^{a}	16.72^{c}	13.32^{d}	0.33	< 0.0001	< 0.0001	< 0.0001	0.232	< 0.0001
Summer	17.97^{b}	19.07^{a}	16.98^{b}	15.52^{c}	11.60^{d}	0.27	< 0.0001	< 0.0001	< 0.0001	0.585	0.020
Eating time per d, min[4]											
Winter	167.32^{ab}	169.45^{a}	164.53^{b}	139.27^{c}	115.35^{d}	1.19	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.537
Summer	174.73^{a}	178.12^{a}	156.53^{b}	145.12^{c}	111.03^{d}	1.18	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.294
Eating Rate, DM (g/min)[4]											
Winter	69^{d}	70^{d}	76^{c}	97^{b}	120^{a}	0.62	< 0.0001	< 0.0001	< 0.0001	0.679	< 0.0001
Summer	74^{d}	70^{e}	90^{c}	100^{b}	127^{a}	0.69	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Eating Rate, Energy (Mcal/min)[4]											
Winter	0.08^{d}	0.08^{d}	0.09^{c}	0.13^{b}	0.16^{a}	0.0008	< 0.0001	< 0.0001	< 0.0001	0.5021	< 0.0001
Summer	0.08^{d}	0.08^{d}	0.11^{c}	0.13^{b}	0.17^{a}	0.0009	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Eating Rate, Volume (L/min)[4]											
Winter	0.47^{a}	0.34^{b}	0.33^{c}	0.31^{d}	0.31^{d}	0.002	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0041
Summer	0.50^{a}	0.34^{c}	0.39^{b}	0.32^{d}	0.33^{d}	0.002	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[1]STEP 1 = 22.5%, DM Basis; DRC, STEP 2 = 34.8% DRC, DM Basis; STEP 3 = 42.8% DRC, DM Basis; STEP4 = 49.8% DRC, DM Basis; FIN = 57.5% DRC, DM Basis.

[2]F-test separating ration means

[3]Orthogonal contrasts calculated with percent DRC in the diet

[4]Significant season x ration interaction was observed (P < 0.05)

Table 4.3 Intake of DM, energy, and volume of steers during transition to a high grain diet during winter or summer[1]

	STEP1	STEP2	STEP3	STEP4	FIN	SEM[1]	Ration[2]	Linear[3]	Quadratic[3]	Cubic[3]
DMI, per meal, kg										
	1.31^{b}	1.37^{b}	1.57^{a}	1.57^{a}	1.50^{a}	0.19	< 0.0001	< 0.0001	< 0.0001	< 0.0001
DMI, per d, kg[4]										
Winter	11.23^{d}	11.69^{c}	12.28^{b}	13.30^{a}	13.48^{a}	0.09	< 0.0001	0.010	< 0.0001	< 0.0001
Summer	12.59^{c}	12.30^{c}	13.76^{b}	14.26^{a}	13.63^{b}	0.09	< 0.0001	< 0.0001	0.107	< 0.0001
Energy intake, per meal, Mcal										
	1.48^{c}	1.54^{c}	1.91^{b}	2.04^{a}	2.07^{a}	0.02	< 0.0001	< 0.0001	0.987	< 0.0001
Energy intake, per d, Mcal[4]										
Winter	12.69^{e}	13.20^{d}	14.98c	17.30^{b}	18.60^{a}	0.11	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Summer	14.23^{c}	13.90^{c}	16.79^{b}	18.54^{a}	18.81^{a}	0.12	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Volume Intake, per meal, L										
	8.96^{a}	6.67^{b}	6.76^{b}	5.07^{c}	3.91^{d}	0.09	< 0.0001	< 0.0001	0.113	< 0.0001
Volume Intake, per d, L[4]										
Winter	76.94^{a}	57.00^{b}	52.93^{c}	42.92^{d}	35.10^{e}	0.35	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Summer	86.26^{a}	60.02^{b}	59.32^{b}	46.00^{c}	35.49^{d}	0.37	< 0.0001	< 0.0001	< 0.0001	< 0.0001

[1]STEP 1 = 22.5%, DM Basis; DRC, STEP 2 = 34.8% DRC, DM Basis; STEP 3 = 42.8% DRC, DM Basis; STEP4 = 49.8% DRC, DM Basis; FIN = 57.5% DRC, DM Basis.

[2]F-statistic separating ration means

[3]Orthogonal contrasts calculated with percent DRC in the diet

[4]Significant season x ration interaction was observed ($P < 0.05$)

Table 4.4 Drinking intake and behavior of steers during adaptation to a high grain diet during winter or summer[1]

	STEP1	STEP2	STEP3	STEP4	FIN	SEM[1]	Ration	Linear[2]	Quadratic[2]	Cubic[2]
Drinking episodes, per d[4]										
Winter	6.62^{a}	5.90^{b}	5.36^{cd}	5.48^{c}	5.17^{d}	0.08	< 0.0001	< 0.0001	< 0.0001	0.489
Summer	7.21^{a}	7.00^{ab}	6.73^{bc}	6.79^{bc}	6.56^{c}	0.08	< 0.0001	< 0.0001	0.709	0.81
Water Intake, per episode										
	7.90	8.04	7.83	7.95	7.84	0.14	0.8205	0.667	0.650	0.700
Water Intake, per d[4]										
Winter	45.37^{a}	40.22^{b}	36.04^{cd}	37.22^{c}	34.72^{d}	0.40	< 0.0001	< 0.0001	< 0.0001	0.2628
Summer	60.23^{a}	60.56^{a}	56.20^{b}	57.23^{b}	55.46^{b}	0.65	< 0.0001	< 0.0001	0.537	0.083
Drinking Time, per episode, minutes[4]										
Winter	2.93^{a}	2.67^{ab}	2.40^{b}	2.77^{ab}	2.92^{a}	0.10	< 0.0001	0.870	0.0001	0.858
Summer	2.97^{b}	2.93^{b}	3.02^{b}	3.25^{b}	3.67^{a}	0.08	< 0.0001	< 0.0001	< 0.0001	0.618
Drinking Time, per d[4]										
Winter	19.78^{a}	15.72^{b}	12.75^{c}	15.23^{b}	15.12^{b}	0.38	< 0.0001	< 0.0001	< 0.0001	0.507
Summer	21.35^{bc}	20.60^{bc}	20.25^{c}	22.20^{b}	24.63^{a}	0.45	< 0.0001	< 0.0001	< 0.0001	0.428

[1]STEP 1 = 22.5%, DM Basis; DRC, STEP 2 = 34.8% DRC, DM Basis; STEP 3 = 42.8% DRC, DM Basis; STEP4 = 49.8% DRC, DM Basis; FIN = 57.5% DRC, DM Basis.

[2]F-statistic separating ration means

[3]Orthogonal contrasts calculated with percent DRC in the diet

[4]Significant season x ration interaction was observed (*P* < 0.05)

2

Table 4.5 Percent of total daily intake during 6 h periods in different diets during adaptation to a finishing diet in winter and summer[1,2]

Item	STEP1	STEP2	STEP3	STEP4	FIN	Linear[2]	Quadratic[2]	Ration
0700 to 1259								
Winter	37.25[c]	38.02[c]	47.05[a]	42.38[b]	39.16[bc]	< 0.0001	< 0.0001	< 0.0001
Summer	41.23[b]	40.58[b]	45.36[a]	39.50[b]	42.00[b]	0.6149	0.0923	< 0.0001
1300 to 1859								
Winter	41.81[b]	43.84[ab]	41.32[b]	43.99[ab]	46.87[a]	< 0.0001	0.0045	< 0.0001
Summer	38.55[a]	35.79[b]	37.49[ab]	34.74[bc]	32.94[c]	< 0.0001	0.1037	< 0.0001
1900 to 0059								
Winter	12.60[a]	12.74[a]	9.28[b]	10.95[ab]	9.72[ab]	< 0.0001	0.7423	< 0.0001
Summer	16.90[bc]	18.89[ab]	14.10[c]	20.77[a]	21.17[a]	< 0.0001	< 0.0001	< 0.0001
0100 to 0659								
Winter	8.91[a]	5.82[b]	3.55[b]	3.54[b]	4.43[b]	< 0.0001	< 0.0001	< 0.0001
Summer	5.08[ab]	5.62[ab]	4.12[b]	5.88[ab]	4.36[b]	0.3571	0.4261	< 0.0001

[1]STEP 1 = 22.5%, DM Basis; DRC, STEP 2 = 34.8% DRC, DM Basis; STEP 3 = 42.8% DRC, DM Basis; STEP4 = 49.8% DRC, DM Basis; FIN = 57.5% DRC, DM Basis.

[2]Values represent percent of daily total consumed during each 6 h period

[3]Linear and quadratic orthogonal contrasts calculated from percent DRC in the diet from STEP1 to FIN

3

Table 4.6 Environmental conditions during adaptation to a high grain diet[1]

CCI[2]	STEP1	STEP2	STEP3	STEP4	FIN	SEM	*P*-Value[3]
Mean							
Winter	-7.07^{a}	-7.93^{a}	-12.50^{bc}	-12.16^{b}	-14.84^{c}	0.82	< 0.0001
Summer	24.99^{b}	29.23^{a}	27.48^{a}	26.41^{ab}	28.40^{a}	1.14	< 0.0001
Minimum							
Winter	-10.65^{a}	-11.41^{b}	-17.19^{c}	-17.38^{c}	-19.04^{c}	1.13	< 0.0001
Summer	16.34^{b}	20.60^{a}	17.55^{b}	18.04^{b}	17.73^{b}	1.32	< 0.0001
Maximum							
Winter	-0.86^{a}	-2.33^{a}	-5.73^{b}	-4.31^{b}	-7.80^{c}	1.00	0.031
Summer	38.46^{a}	43.15^{a}	41.42^{a}	41.28^{a}	46.44^{a}	4.25	0.012

[1]STEP 1 = 22.5%, DM Basis; DRC, STEP 2 = 34.8% DRC, DM Basis; STEP 3 = 42.8% DRC, DM Basis; STEP4 = 49.8% DRC, DM Basis; FIN = 57.5% DRC, DM Basis.

[2]Cattle Comfort Index as described by Mader et al. (2010)

[3]Overall F-test

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Table 4.7 Daily DMI during adaptation to a high grain diet during winter or summer[1]

Day	1	2	3	4	5	6	*P*-Value
STEP 1							
Winter	11.04	10.95	10.89	11.32	11.34	10.83	*NS*
Summer	12.97^{a}	12.80^{a}	11.82^{ab}	11.58^{b}	12.21^{ab}	12.69^{ab}	$P < 0.0001$
STEP 2							
Winter	12.09^{a}	11.21^{ab}	11.27^{ab}	10.96^{b}	11.97^{a}	11.52^{ab}	$P < 0.0001$
Summer	12.07^{ab}	12.79^{a}	12.34^{ab}	11.76^{ab}	12.20^{ab}	11.40^{b}	$P < 0.0001$
STEP 3							
Winter	11.67	12.11	12.13	12.16	12.19	12.49	*NS*
Summer	11.60^{c}	12.75^{bc}	14.58^{a}	14.83^{a}	13.81^{ab}	13.47^{b}	$P < 0.0001$
STEP 4							
Winter	13.55	12.76	13.03	13.10	12.97	13.25	*NS*
Summer	14.32	13.91	13.90	13.35	13.47	13.87	*NS*
FIN							
Winter	14.49^{a}	13.75^{a}	12.62^{b}	13.17^{ab}	13.56^{ab}	13.41^{ab}	$P < 0.0001$
Summer	14.47^{ab}	13.95^{ab}	13.52^{b}	14.05^{ab}	14.68^{a}	14.83^{a}	$P < 0.0001$

[a-d]Means within a row with unlike superscripts differ ($P < 0.05$)

[1]STEP 1 = 22.5%, DM Basis; DRC, STEP 2 = 34.8% DRC, DM Basis; STEP 3 = 42.8% DRC, DM Basis; STEP4 = 49.8% DRC, DM Basis; FIN = 57.5% DRC, DM Basis.

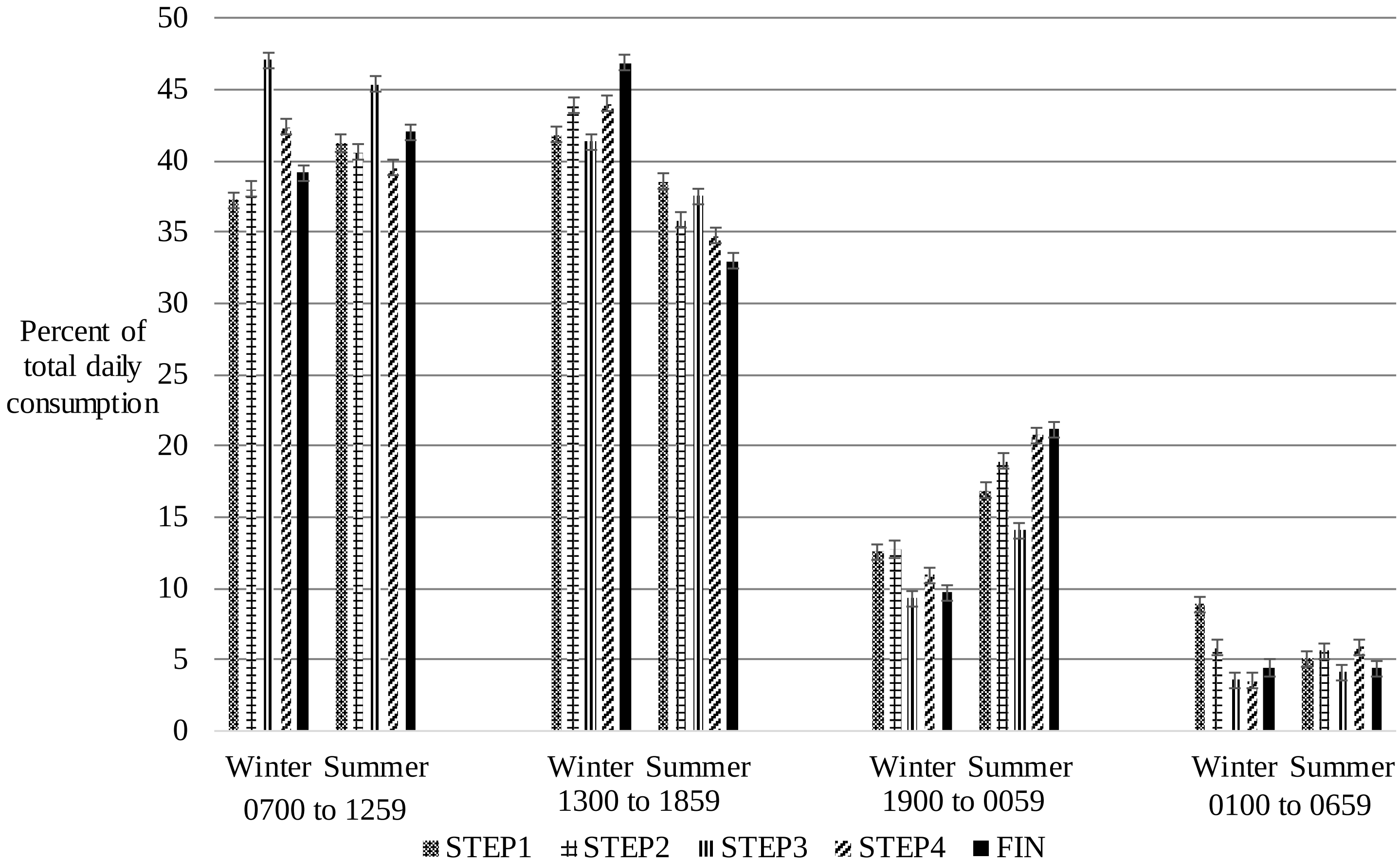
Table 4.8 Performance of steers during previous water-intake experiment and during adaptation to a finishing diet in winter and summer[1]

Item	ADLIB	STEP	RES	FIN	*P*- value[2]
Days	70	28	42	44	
DMI					
Winter	10.29[b]	9.69[c]	8.58[d]	12.18[a]	< 0.0001
Summer	12.03[a]	10.42[b]	8.98[c]	12.33[a]	< 0.0001
ADG					
Winter	1.17[a]	1.01[b]	0.71[c]	1.19a	< 0.0001
Summer	1.89[a]	1.40[b]	-0.02[c]	1.63[ab]	< 0.0001
G:F					
Winter	0.114[a]	0.103[ab]	0.081[c]	0.010[b]	< 0.0001
Summer	0.159[a]	0.136[b]	-0.002[c]	0.135[b]	< 0.0001

[1]ADLIB = 70 d ad libitum feed and water; STEP = 28 d step-down from ad libitum to 50% ad libitum water intake; RES = 42 d 50% of ad libitum water intake; FIN = 34 d adaptation to grain finishing period

[2]Different superscripts within a row are significantly different (P < 0.05)

Figure 4.1 Percent of total daily intake during 6 h periods in different diets during grain adaptation in winter and summer[1]



[1]STEP 1 = 22.5%, DM Basis; DRC, STEP 2 = 34.8% DRC, DM Basis; STEP 3 = 42.8% DRC, DM Basis; STEP4 = 49.8% DRC, DM Basis; FIN = 57.5% DRC, DM Basis.

APPENDIX

All procedures involving live animals were approved by the

Oklahoma State University Institutional Animal Care and Use Committee

VITA

Levi James McPhillips

Candidate for the Degree of

Master of Science/Arts

Thesis: GRAIN ADAPTATION AND SOURCE IMPACT ON EATING BEHAVIOR AND PERFORMANCE OF FEEDLOT STEERS

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