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Evaluation of corn processing method and Sweet Bran inclusion on beef cattle performance and nutrient digestion and individual Sweet Bran components on nutrient digestion

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EVALUATION OF CORN PROCESSING METHOD AND SWEET BRAN INCLUSION ON BEEF CATTLE PERFORMANCE AND NUTRIENT DIGESTION AND INDIVIDUAL SWEET BRAN COMPONENTS ON NUTRIENT DIGESTION

by

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One feedlot trial (Exp. 1) and one digestion trial (Exp. 2) were conducted to evaluate the interaction of corn processing method and Sweet Bran inclusion on nutrient digestion, ruminal fermentation parameters, and feedlot performance. In Exp. 1 when no Sweet Bran was fed, cattle fed steam-flaked corn (SFC) had greater ADG, HCW and a 12.4% improvement in feed efficiency compared to cattle fed a high-moisture corn/ dry-rolled corn (HMC/DRC) blend. However, as Sweet Bran increased in the diet to 40%, cattle fed HMC/DRC had greater improvements in ADG and HCW than cattle fed SFC resulting in similar performance at 40% Sweet Bran. Steers fed Sweet Bran in SFC diets had no improvement in feed efficiency while cattle fed HMC/ DRC diets displayed a 5.6% linear improvement in feed efficiency as Sweet Bran increased in the diet to 40%. As a result, feed efficiency was only improved by 5.3% for SFC diets when compared to HMC/DRC diets containing 40% Sweet Bran. Additionally, as Sweet Bran increased in the diet, cattle fed both SFC and HMC/DRC had greater DMI in both experiments and as a result, greater digestible energy (DE) intakes. Increased DE intakes improved ADG and feed efficiency when feeding Sweet Bran in Exp 1. and matched with greater DMI and increased DE observed in Exp. 2. Overall, feeding Sweet Bran in HMC/DRC based

finishing diets makes HMC/DRC diets more competitive with SFC-based finishing diets allowing producers without steam-flaking capabilities to achieve similar gains and more similar conversions.

An additional digestion trial (Exp. 3) was conducted to evaluate individual Sweet Bran components (corn bran, mixed steep, and solvent-extracted germ meal) on nutrient digestion and ruminal fermentation parameters. Dry matter and organic matter digestibility were lowest for bran, intermediate for solvent extracted germ meal, and greatest for steep and the corn control. Neutral detergent fiber digestibility was lowest for control and intermediate for bran and steep with a tendency for solvent extracted germ meal to have the greatest digestibility. Steep and solvent-extracted germ meal had energy densities similar to the corn control, while bran had a lower energy density. Additionally, apparent energy digestibility was greatest for steep and control and least for bran with solvent extracted germ meal being intermediate. These data suggest the

the physical and nutrient digestibility characteristics of bran, steep, and SEM are complementary when fed in combination and contribute to the higher energy value of Sweet Bran compared to DRC.

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CHAPTER 1 - LITERATURE REVIEW

Introduction

Corn is the most widely utilized cereal grain in the cattle feeding industry due to its competitive cost per unit of energy when compared to other cereal grains. Corn is high in energy with a net energy for maintenance (NEm) of 2.17 Mcal/kg and a net energy for gain (Neg) of 1.49, resulting in high gains and improved feed efficiencies (NASEM, 2016). Corn is commonly processed to improve the extent of ruminal and total tract digestion. Corn processing encompasses grinding, rolling, tempering, steamrolling, or steam-flaking to break down the pericarp and protein matrix (McAllister et al., 2006) .The main goal of corn processing is to increase starch availability to improve animal performance. The corn processing method(s) used is dependent on cost and the size, capability, and location of the feedlot.

Corn is also the primary cereal grain used in the U.S. wet milling industry for products such as ethanol, corn oil, and high fructose corn syrup for human consumption. By-products from wet milling are used in cattle feeding to replace a portion of the corn in the diet. Wet corn gluten feed is the primary by-product from wet milling and is used widely in beef finishing diets to replace dietary starch with steep and highly digestible fiber and thus reduce the incidence and severity of acidosis. Nutrient composition of wet corn gluten feed can vary from plant to plant due to differences in the proportions of bran, steep, solvent-extracted germ meal, and cracked corn. Therefore, it is important to understand the nutrient profile and digestion characteristics of the individual ingredients used to make wet corn gluten feed. The type of processed corn and inclusion of wet corn gluten feed can also influence performance and digestibility in beef finishing diets. The

objective of this literature review is to: 1) understand starch digestion in ruminants and how corn processing can influence the site and extent of digestion and ultimately cattle performance, 2) the by-products produced by the wet milling process and their effect on digestion and performance in beef steers, and 3) the interaction between corn processing method and wet corn gluten feed inclusion in beef finishing diets.

Corn Characteristics

Parts of the corn kernel

There are four components of the corn kernel: tip cap, pericarp, germ, and endosperm. The tip cap is the point of the kernel that attaches to the corn cob. The pericarp or outer hull is the outer most waxy covering of the kernel and constitutes 5-7% of the kernel (García-Lara et al., 2019). The pericarp is made up of 71% non-starch polysaccharides, 6% protein, 2% ash, 20% cellulose, and 0.5% fat on a DM basis (Delcour and Hoseney, 2010). The pericarp encases and protects the endosperm and germ from attack by fungi and bacteria and is therefore resistant to microbial attachment in the rumen (Huntington et al., 1997). Processing corn and mastication breaks the pericarp and allows for more efficient microbial attachment and digestion. The germ is the living part of the corn kernel and constitutes 10-12% of the kernel on a dry weight (García-Lara et al., 2019). The germ includes the embryo and scutellum. The scutellum is a thin, high surface area specialized cotyledon to absorb nutrients from the endosperm during germination (Watson, 1987). The germ is high in corn oil (33.2%), the most valuable part of the kernel, but is also composed of 18.4% protein, 10.8% sugar, and 10.5% ash (Watson, 1987). The endosperm is the largest portion accounting for 82% of the kernel

and is approximately 86-89% starch and the energy source of the kernel (García-Lara et al., 2019). In a mature corn kernel, the starch granules are embedded in a zein protein matrix. The hardness of the endosperm is characterized by the strong interaction between the starch granules and the protein matrix.

Starch

Starch is the primary carbohydrate fed in beef cattle finishing diets. Starch is a polysaccharide formed by units of glucose and the storage form of carbohydrates in plants. Most cereal grains are 70% starch with corn containing approximately 72% starch (Huntington, 1997). Starches are alpha glucans composed almost entirely of two highly organized polysaccharides, amylose and amylopectin, held together by hydrogen bonding (Bertoft, 2017). Amylose is a linear glucose polymer with alpha 1,4 glycosidic linkages (Svihus et al., 2005). Amylopectin is a polymer of glucose containing both a linear chain with alpha 1,4 glycosidic bonds and branched points with alpha 1,6 bonds at every 20-25 glucose units (Svihus et al., 2005). The branches account for 5% of amylopectin and result in a more complex molecular structure (Bertoft, 2017). In most cereal starches, amylopectin is the largest component, constituting 65-84% of starch and amylose constituting the remaining 16-35% (McAllister et al., 1994; Svihus et al., 2005). In non-ruminants, the amylose: amylopectin ratio is negatively correlated with starch digestion. Thus, as the ratio of amylose: amylopectin increases, digestion decreases. The ratio is not as important in ruminants when corn is processed (NASEM, 2016).

Corn Processing Methods

Most of the corn fed to finishing cattle is processed before feeding. In a survey of nutritionists across the southern plains, Samuelson et al. (2016), reported steam flaking

(70.8%), high moisture harvest and storage (16.7%) and dry rolling (12.50%) were the primary grain processing methods used. The main purpose of corn processing is to increase starch availability to improve cattle performance (Owens et al., 1997). Dry rolled corn (DRC) refers to passing corn kernels between two rollers to mechanically crack the pericarp (NASEM, 2016) which reduces particle size, increases the surface area and allows ruminal microbes and enzymes to have greater accessibility to starch (McAllister et al., 1994). The particle size of DRC is influenced by spacing between the rollers, the pressure of the rollers, and moisture content of the corn.

High- moisture corn (HMC) refers to corn that is harvested and ensiled between 25-33% moisture (Mader and Rust, 2006). High-moisture corn can be harvested and processed as whole corn or processed through a roller mill or hammer mill before storage to ensure adequate packing. High-moisture corn is commonly stored in a bunker, oxygen limiting silo, or bag. Exclusion of oxygen to allow anaerobic fermentation is crucial for proper ensiling (Mader and Rust, 2006). High-moisture corn is rapidly degraded in the rumen because ensiling greatly affects the starch-protein matrix. The alpha, beta, and delta prolamin-zein subunits of the starch-protein matrix are reduced from 10-40% and gamma prolamin-zein subunits of the starch protein matrix are more extensively reduced by 60% (Hoffman et al, 2010). The gamma prolamin-zein subunits are primarily responsible for cross linking the starch granules together. Therefore, degradation of the gamma prolamin-zein subunits results in dissociation of the starch granules from one another increasing the number of individual starch granules and surface area for ruminal microbes (Hoffman et al, 2010). The improved ruminal degradability of HMC increases the risk of digestive upsets, therefore it is common to replace a portion of HMC with a

slower fermentable grain such as DRC (Stock et al., 1991). Feeding a blend of HMC and DRC decreases the incidence of acidosis while increasing the extent of digestion in rumen and improving feed efficiency.

Steam flaked corn refers to corn that has been steamed at high temperatures (100 °C) with 5-7% added water for 30 to 40 min followed by flaking the corn through two rotating rollers (Armbruster, 2006). Steaming also increases moisture content by contributing to the 19-24% moisture of flakes when they exit the rollers (Armbruster, 2006). The five factors influencing the quality of flakes are: steam chest temperature, steaming time, roll corrugation, roll gap, and roll tension (Zinn et al., 2002). For example, when adjusting the gap between the rotating rollers to produce flake densities of 0.42, 0.36, and 0.31 kg/L (32.6, 28.0, and 24.1 lb/bu) and there was a linear increase in the extent of starch digestion was observed in the rumen and in the total digestive tract (Zinn, 1990). The optimal flake density is between 0.32-0.39 kg/L (24.9-30.3 lb/bu; Plascencia and Zinn, 1996). Below this range, acidosis increases due to rapid fermentation while above this range results in less improvement in animal performance is observed. Adding heat and moisture during steam flaking, results in gelatinization of the starch granules making starch (energy) more readily digestible (Zinn et al., 2002). The energy value of SFC is 10.9% greater in NEg than DRC and 6.8% greater than HMC (Vasconcelos and Galyean, 2007).

Starch Digestion

Ruminal Starch Digestion

When starch is consumed by an animal, mechanical digestion begins through the process of mastication. Mastication reduces particle size, increases surface area and results in the production of saliva. The main function of saliva is to buffer pH in the reticulum and rumen. Once starch enters the ruminoreticulum, degradation by the microbes begin. Microbes in the rumen consist of protozoa, fungi and bacteria, although bacteria are responsible for the majority of fermentation (Huntington, 1997). The number of protozoa is relatively small compared to bacteria, but attribute to decreasing the risk of acidosis by engulfing large starch particles in the rumen and increasing starch available in the small intestine (Castillo-González et al., 2014). Many amylotic bacterial species such as *Streptococcus bovis* and *Selenoma ruminantium* utilize starch as their primary substrate and as a result there is competition for energy-yielding substrates and ultimately rapid degradation of starch (Huntington et al., 2006). Three-fourths of starch digestion in the rumen occurs via attachment to feed particles by ruminal bacteria, therefore attachment to feed particles is important in the initiation of bacterial digestion (McAllister et al., 1994). Bacterial attachment refers to either loosely attached via an electrical charge or firmly attached via receptors (Huntington, 1997). Whole grains with an intact pericarp are resistant to digestion by ruminants because kernels are resistant to bacterial attachment. Corn processing increases starch accessibility for bacterial attachment and therefore increases starch digestibility in the rumen. Once bacteria are attached, amylase is produced to hydrolyze alpha 1,4 and alpha 1,6 bonds of amylose and amylopectin (Huntington, 1997).

The end products of fermentation include volatile fatty acids (VFAs), lactate, methane and carbon dioxide. Methane is a fraction of carbon that is not available for reconversion into usable substrate. McLeod et al. (2006) demonstrated that 6.8-9.6% of starch energy for a typical feedlot steer consuming 6.0 kg of starch, with a ruminal digestibility of 80%, would be lost as methane. In contrast, there is essentially no loss in the form of methane when starch is digested in the small intestine and absorbed as glucose indicating an advantage to post ruminal starch digestion. However, there are limitations to starch digestion in the small intestine such as accessibility of starch by enzymes and inadequate activity of amylase (Owens et al., 1986; Swanson, 2019). The primary VFAs produced are acetate, butyrate, and propionate which are absorbed across the rumen wall via passive, bicarbonate dependent, nitrate sensitive or electrogenic transport and converted to energy for the host animal (Penner et al., 2009). Volatile fatty acids provide up to 75% of the total energy for ruminants (Penner et al., 2009). Each VFA produces a different amount of energy. Propionate results in the most energy due to no carbon loss as methane or carbon dioxide and consumes two hydrogens when derived from glucose (Lindsay, 1970). Propionate is the only glucogenic VFA and once absorbed and transferred to the liver contributes 43 to 77% of blood glucose (McLeod et al., 2006). Most of the absorbed acetate will enter the portal vein to the liver where it is converted to Acetyl-CoA or ketones to be utilized by the tissues. Approximately 90% of butyrate absorbed is metabolized by the rumen epithelium resulting in the formation of ketone bodies or oxidation to carbon dioxide (Bergman, 1990).

The ratio of acetate: propionate: butyrate is dependent on the type of substrate available for ruminal microbes. Forage-based diets promote the formation of acetate

resulting in a VFA ratio of 65% acetate, 25% propionate, and 10% butyrate (NASEM, 2016). In contrast, high concentrate diets shift VFA production towards propionate production at the expense of acetate altering the VFA ratio to 50% acetate, 40% propionate, and 10% butyrate (NASEM, 2016).

Post Ruminal starch digestion

Energetic advantages can be gained if digestion and absorption of starch is shifted to the small intestine due to an increase in glucose absorption and a decrease in de novo synthesis of glucose to meet demands (Huntington et al., 2006, McLeod et al., 2006). Shifting digestion and absorption to the small intestine does not always result in energetic advantages because as starch flowing to the small intestine increases, digestion of starch typically decreases (Owens, 2005b). Huntington et al. (2006) reviewed the three phases of digestion and absorption in the small intestine: 1) secretion of alpha-amylase from the pancreas 2) action of brush border carbohydrases, and 3) transport of glucose out of the lumen and into portal circulation.

In the first phase, pancreatic alpha-amylase is secreted into the duodenum in response to chyme, specifically protein, entering the small intestine. Alpha-amylase hydrolyzes alpha 1,4 glycosidic bonds resulting in maltose, maltotriose, and limit dextrins (Harmon et al., 2004).

The second phase occurs at the brush border membrane through the action of carbohydrases such as isomaltase and disaccharidases (Huntington et al., 2006). Isomaltase also known as alpha-dextrinase is the only enzyme capable of hydrolyzing alpha 1, 6 glycosidic bonds in the amylopectin of starch. Disaccharidases (sucrase, maltase, and lactase) hydrolyze disaccharide bonds yielding monosaccharides such as

sucrose, maltose, and lactose. The enzyme activity of ruminants is like non-ruminants in the small intestine, except for sucrase. Sucrase has been characterized in the bovine, but is not expressed (Harmon et al., 2004). Monosaccharides (glucose, galactose, and fructose) are freely absorbed by the enterocyte and further taken into the bloodstream for tissue uptake.

The third and final phase is the transport out of the lumen of the intestine and into portal circulation. The three major pathways for absorption of glucose are paracellular, active, and passive transport. Paracellular transport involves sugars exiting the lumen via the intercellular spaces (Harmon and McLeod, 2001). For paracellular transport to occur, luminal glucose concentrations must be greater than 25 mM (Pappenheimer and Reiss, 1987). Paracellular diffusion is a minor contributor to total glucose uptake because luminal glucose concentration only approach 30 mM for a limited time and space in the small intestine (Huntington, 1997). The second major means of glucose transport is through active transport via the sodium dependent glucose transporter (SGLT 1). For each monosaccharide absorbed, one ATP is required. The active transporter, SGLT 1, is a high affinity glucose transporter that transports glucose into the enterocyte by a Na+ gradient that is maintained by Na+/K+-ATPase in the basolateral membrane (Harmon, 2009). The final transport of glucose is passive transport which utilizes a carrier protein to transport sugar across the brush border membrane without the use of energy. The carrier protein, GLUT 2, is located in both the brush border and basolateral membrane of the enterocyte and is responsible for sugar transport both in and out of the enterocyte (Thorens, 1993). Additionally, GLUT2 is low affinity, high volume; glucose and insulin concentrations play an important role in regulating GLUT2. For example, when intestinal

lumen glucose concentrations are high GLUT2 will translocate to the brush border membrane for increased uptake of glucose and reversely when insulin concentrations are high GLUT2 will translocate from the brush border membrane back into the cytosol (Kellett et al., 2008).

Effect of corn processing methods on site and extent of starch digestion

The rate and extent of starch digestion are determined by several factors including mechanical alterations (grain processing, mastication) and chemical alterations (degree of hydration, gelatinization; Huntington, 1997). Huntington (1997), Cooper et al. (2002), and Owens (2005a) examined starch digestion of DRC, HMC, and SFC and reported ruminal, postruminal, and total tract digestibility of starch.

Huntington et al. (1997) summarized data from 14 experiments published from 1986 through 1995 and reported ruminal starch digestibility of 76.2, 89.9, and 84.8% for DRC, HMC, and SFC, respectively. As a comparison, Owens et al. (1986) reported ruminal digestibility of whole corn to be 58.9%. Compared to whole corn, corn processing significantly increases ruminal starch digestibility as a result of increased starch availability and accessible space for microbial attachment. Post-ruminal starch digestibility averaged 68.9, 67.8, and 92.6% for DRC, HMC, and SFC, respectively. These data suggest SFC has 35% greater postruminal starch digestion than the average of DRC and HMC. Furthermore, total tract digestibility was 92.2, 95.3, and 98.9% for DRC, HMC, and SFC, respectively. The HMC and SFC had greater total tract digestibility compared to DRC suggesting more highly processed grains are more extensively degraded in the rumen resulting in greater total tract digestibility (Theurer, 1986).

Owens (2005a) summarized data from 48 published trials and two unpublished trials from 1990 to 2004. Ruminal digestibility was 70, 91, 85, and 75% for DRC, HMC, SFC, and whole corn. The extent of starch disappearing in the rumen aligned with Huntington's (1997) findings: as HMC and SFC were considerably greater than DRC. Whole corn had numerically greater ruminal digestibility than DRC. Owens (2005a) attributed this to longer retention time in the rumen for whole corn compared to DRC as a result of lower roughage levels (10% vs 15%) in whole corn diets. The lower roughage inclusion can prolong rumen retention time and lead to more extensive ruminal fermentation (Owens, 2005a). Postruminal digestibility were 72, 89, 94, and 42% for DRC, HMC, SFC, and whole corn. High-moisture corn and SFC had significantly greater intestinal digestibility compared to DRC and whole corn. Past reviews have suggested that postruminal starch digestibility decreases as starch flow to the small intestine increases (Cooper et al., 2002). Owens (2005a) reported a greater ruminal digestibility for whole corn compared to DRC meaning less starch is flowing to the small intestine and thus postruminal starch digestibility would presumably be greater. However, postruminal digestibility for whole corn was considerably lower compared to DRC. Therefore, postruminal starch digestibility is likely related to the degree of processing and accessibility of starch by enzymes in addition to the amount of starch flowing to the small intestine (Owens, 2005a). For example, the low postruminal starch digestibility for whole corn could be attributed to the large particle size when compared DRC. Additionally, enzymes cannot penetrate an intact kernel Lastly, total tract digestibility was 91, 99, 99, and 85% for DRC, HMC, SFC, and whole corn, resulting in an 8% and 14% increase for HMC and SFC compared to DRC and whole corn.

Cooper et al. (2002) measured ruminal digestibility of 76, 92, and 90% for DRC, HMC, and SFC. Cooper et al. (2002) reported SFC had 18% greater ruminal digestibility compared to DRC whereas Huntington (1997) reported 12%. Postruminal digestibility was 84.4, 86.5, and 98.3% for DRC, HMC, and SFC demonstrating a 15% increase in postruminal starch digestibility for SFC compared to the DRC and HMC. Total tract digestibility was 96.1, 98.7, and 99.8% for DRC, HMC, and SFC. These values agree with the trends reported in Huntington (1997) and Owens (2005a): SFC and HMC have greater total tract digestibility compared with DRC. On average, ruminal, postruminal, and total tract digestibility was 74.1, 75.1, and 93.1% for DRC, 91, 81.1, and 97.7% for HMC, and 86.6, 95, and 99.3% for SFC, respectively. In summary, as corn processing increases, ruminal, postruminal, and total tract starch digestion increases in response to greater starch availability/ accessibility for microbes in the rumen and enzymes in the intestine.

Effect of corn processing methods on cattle performance

Owens et al. (1997) summarized 183, 117, and 53 trials for DRC, HMC, and SFC in journals, experiment station publications, and feeder's day reports. The trials included in the review had to meet the following criteria: 1) roughage as a percent of diet was under 15%, 2) corn was more than 55% of diet DM, 3) cattle were given ad libitum access to feed, 4) only one processing method was used, and 5) cattle were on feed for more than 99 days. Dry matter intake decreased as corn processing increased: DMI was 8.4 and 13.2% greater for DRC compared to HMC and SFC. The reduction in DMI for more extensively processed corn such as HMC and SFC is attributed to higher rate of acid production in the rumen and incidences of subclinical acidosis (Fulton et al., 1979).

In addition, as corn processing increases, the energy density also increases, thus intake would decrease in achieve the same energy intake. Average daily gain was similar for DRC and SFC, but significantly lower for HMC. Feed conversion was 11.9 and 9.5% greater for SFC compared to DRC and HMC. Although not statistically different, cattle fed HMC were 2.2% more efficient than cattle fed DRC.

Huck et al. (1998) fed diets that contained 74.5% (DM basis) of corn that was processed as DRC, rolled HMC, or SFC. High-moisture corn was harvested, rolled, and stored in a concrete bunker at 35% moisture. Steam-flaked corn was processed to a flake density of 0.34 kg/L (26 lb/bu). No differences were observed for DMI among treatments ($P = 0.25$). Average daily gain was 7.7 and 8.8% greater for cattle fed SFC compared to cattle fed DRC and rolled HMC, with no differences between DRC and rolled HMC. Feed efficiency was improved by 8.6 and 5.0% for cattle fed SFC compared to cattle fed DRC and rolled HMC. Although not statistically different, cattle fed rolled HMC were 3.4% more efficient compared to cattle fed DRC due a 0.4 kg/d lower DMI which was consistent with Owens et al. (1997).

Corrigan et al. (2009) fed diets that contained 82.5% (DM basis) corn that was processed as DRC, HMC, and SFC. High-moisture corn was harvested at 30% moisture, processed through a double roller mill, and stored in a bunker silo. Steam-flaked corn was processed to a flake density of 0.42 kg/L (28 lb/bu). Dry matter intake was greater for DRC ($P < 0.01$) compared to SFC and HMC which were not different. Average daily gain was similar across treatments, resulting in a 12.0% improvement in feed efficiency for cattle fed SFC and HMC compared to cattle fed DRC.

Zinn et al. (2002) summarized trials comparing SFC to dry corn [fine ground corn (FGC), WC, or DRC]. Over all the trials, DMI was 6.1% less and ADG was improved by 5.4% for cattle fed SFC compared to cattle fed dry corn. Similar to Corrigan et al. (2009), cattle fed SFC had a 12.1% improvement in feed efficiency compared to dry corn.

Brown et al. (2000) conducted an additional study feeding SFC at two flake densities [0.36 kg/L (28 lb/bu) and 0.26 kg/L (20 lb/bu)] and DRC at 77% of diet DM. Cattle fed corn flaked to 0.26 kg/L had 5.6% lower DMI and an 2.3% improvement in ADG compared to cattle fed corn flakes to 0.36 kg/L. Steam-flaked corn fed cattle, averaged across flake density, had 2.6% lower DMI and an 8.2% improvement in ADG compared to cattle fed DRC. A lower DMI and greater ADG translated into a 9.4% improvement in feed efficiency for cattle fed SFC which is consistent with trends observed by Corrigan et al. (2009) and Zinn et al. (2002) when comparing SFC to DRC. In general, as corn processing increases, DMI decreases and ADG is maintained or improved. As a result, cattle fed SFC and HMC are more efficient than cattle fed DRC.

Wet Corn Milling

The purpose of the wet corn milling process is to isolate and recover starch to be utilized in production of glucose, high fructose corn syrup, ethanol, and other products from starch (Rausch and Belyea, 2006). The byproducts of this process (germ, fiber, and protein) are recombined in a variety of ways to yield animal feed products. Only U.S. Grade No. 1 and 2 corn grain can be utilized for wet milling because most products are intended for human consumption (Stock et al., 2000). The wet milling process can be

broken down into five basic steps: steeping, germ recovery, fiber recovery, protein recovery, and starch washing (Rausch and Belyea, 2006).

Before the steeping process begins, corn kernels are cleaned through a series of screens to remove broken kernels, crop residue, and foreign objects. The broken kernels are often added to byproducts such as corn gluten feed. In the first step, corn is steeped by soaking for 40-48 hours in a dilute sulfurous dioxide solution (Stock et al., 2000). Steeping softens the kernel for grinding in the subsequent steps, removes solubles, loosens the protein matrix to expose the starch, and facilitates the separation of the corn components (Blanchard, 1992). The water used for steeping enters the milling process as fresh water to wash starch but flows countercurrent to the flow of corn. The corn passes through many screens and separations so wash water acquires soluble nutrients along the way. The water remaining after the steeping process is referred to as light steepwater (4-8% solids); it can be concentrated through evaporation to yield heavy steepwater (35-40% solids; Rausch and Belyea, 2006).

The steeped corn is then passed through a series of degerminating mills to expose the germ. Because the germ is the lightest component (mostly oil), it can be recovered in hydrocyclones (Blanchard, 1992). Once the germ is separated, it is dried and sent to a germ plant for oil extraction (Stock et al., 2000). After oil extraction, solvent extracted germ meal (SEM) is the feed byproduct remaining (Grigsby, 2010). Solvent extracted germ meal is 90% DM and contains 22% CP, 40% NDF, and 12% fat (NASEM, 2016). In the next step, the remaining fractions (starch, gluten, and fiber) are passed through fine screens to separate the fiber fraction, commonly called corn bran, which contains pericarp and cell-wall fiber (Rausch and Belyea, 2006). The starch and gluten slurry remaining is

centrifuged at high speeds to separate the lighter component, gluten (Blanchard, 1992). The gluten or protein fraction is concentrated via a gluten thickening centrifuge, dewatered, and dried resulting in corn gluten meal (CGM, Rausch and Belyea, 2006). Corn gluten meal is 90% DM, high in protein (68%) and low in fiber (8% NDF; NASEM, 2016). Corn gluten meal is high in bypass protein and therefore primarily used for higher valued markets such as the aqua, dairy, poultry, and pet industries (Erickson et al., 2005).

After the removal of gluten, the starch slurry is purified by washing through a series of hydrocyclones to remove residual protein. The purified starch slurry may be dried and sold as-is or processed into a variety of products such as conversion to dextrose for fermentation to produce ethanol or sweetener (Blanchard, 1992; Stock et al., 2000). Distillers solubles from ethanol production, which contain unfermented sugars and yeast cells, are a feed byproduct of this process and used in combination with heavy steepwater to produce mixed steep (40-45% DM). Mixed steep is high in protein and consists of free amino acids, ammonia, polypeptides of various lengths, minerals and lactic acid (Blanchard, 1992). Rausch et al. (2019) reported the wet milling industry typically yields 67.5% starch, 7.5% SEM, 4.0% gluten, 11.5% fiber, and 7.6% steepwater solubles on a dry basis.

Wet Corn Gluten Feed

Corn gluten feed is the primary feed ingredient produced by the wet milling process and can be marketed as wet (43.8% DM) or dry (88.9% DM; NAEM, 2016). Nutritionally, wet corn gluten feed (WCGF) is superior to dry corn gluten feed (DCGF) when fed to cattle because drying corn gluten feed reduces its energy value relative to corn (Green et al., 1987; Ham et al., 1995). Therefore, WCGF is most common in beef

finishing diets, especially in the midwest and southern plains. Because few wet corn milling plants exist in the deep southeast, dry corn gluten feed is most commonly fed due to efficiency in shipping a dry product.

Wet corn gluten feed is typically characterized as being 2/3 corn bran and 1/3 mixed steep on a dry basis (Watson, 1987) but can vary among plants depending on the amount of mixed steep included, moisture content of the bran (dry or wet), and inclusion of SEM and broken kernels. Some plants add mixed steep to wet bran, but this limits the amount of mixed steep that can be added to the bran and as a result the wet bran cannot hold the mixed steep capacity of the plant. In this case, mixed steep (heavy steepwater plus distiller's solubles) can be sold as a separate liquid feed ingredient containing 31.78% crude protein (NASEM, 2016). Other plants dry the bran to 85% DM before adding steep, thus increasing the proportion of steep to corn bran (Stock et al., 2000). Drying corn bran before the addition of mixed steep has limited effect on the apparent energy value of the corn bran, and has minimal impacts on cattle performance (Macken et al., 2004a; Milton et al., 2000). The amount of steep influences the energy, with CP varying from 14 to 24% (DM basis) of the corn gluten feed. For these reasons, the nutrient composition of corn gluten feed is not consistent among plants (Stock et al., 2000).

Wet corn gluten feed has been shown to reduce ruminal acidosis in steers fed high concentrate diets. Wet corn gluten feed has a lower starch content than corn, therefore inclusion of WCGF reduces starch content of the diet by replacing corn with highly digestible fiber and energy. Krehbiel et al. (1995) conducted an acidosis challenge experiment to evaluate the effect of 100% DRC, 50% DRC: 50% WCGF, and 100%

WCGF on ruminal pH and organic acids. Three ruminally cannulated steers were used in a repeated Latin square design and adapted to a 70% concentrate diet. Two additional ruminally cannulated steers were used as donors for ruminal fluid and fed 33% DRC, 33% corn silage, 33% alfalfa hay, and 1% supplement. On d 1 of the period, 10 L of ruminal contents from each test steer was replaced with 10 L of ruminal contents from donor steers. From d 1 to 11, steers were adapted to their respective treatment. On d 12, feed was withheld from the three test steers and 7.9 kg on a DM basis of 100% DRC, 50% DRC: 50% WCGF, and 100% WCGF was dosed intraruminally. A time by treatment interaction was observed for ruminal pH ($P < 0.01$). Steers fed 100% WCGF and 50% DRC: 50% WCGF had lower ruminal pH at 3 and 6 h compared to the cattle fed 100% DRC, but then reached a plateau and returned to pre-challenge pH by 24 h. The ruminal pH of cattle fed 100% DRC continued to gradually decrease until 15 h and did not return to pre-challenge pH by 24 h. Because the ruminal pH for cattle fed 100% DRC decreased gradually, the ruminal pH remained lower for a longer period of time. Ruminal VFA concentration was greater ($P < 0.03$) at 3 h and remained elevated longer ($P < 0.01$) for cattle fed 100% DRC compared to WCGF treatments. Lactate concentration was numerically greater for cattle fed WCGF resulting in no differences in total organic acids. The greater concentration of lactate in the WCGF treatments could be a function of appreciative amounts of lactic acid in the steep portion of the wet corn gluten feed (Blanchard, 1992; Scott et al., 1998). These data suggest that substituting corn with WCGF does not eliminate ruminal acidosis as total organic acid concentration were similar but does mitigate the amount of the time exposed to low ruminal pH.

Sindt et al. (2002) conducted a 153-d study with beef steers (n = 615) to compare SFC diets containing 0, 30, or 60% WCGF. On d 114 to 118, ruminal samples were collected from 180 steers and analyzed for pH and VFA. Increasing the dietary inclusion of WCGF linearly decreased total ruminal VFA, propionate and valerate concentrations ($P < 0.05$). The decrease in total VFA and propionate concentration is similar to Krehbiel et al. (1995). Additionally, increasing the inclusion of WCGF linearly increased isovalerate and the acetate to propionate ratio ($P < 0.05$). As a result, ruminal pH linearly increased as the inclusion of WCGF increased ($P < 0.05$). There were no differences in ruminal lactate concentration among dietary treatments. These data, similar to Krehbiel et al. (1995), suggest WCGF helps control ruminal acidosis.

Feeding Individual Ingredients of Corn Gluten Feed

Due to the variation in wet corn gluten feed composition among plants, it is important to understand how the individual feed ingredients affect animal performance. Individual WCGF ingredients and various combinations of WCGF feed ingredients have been previously studied to determine nutritional and digestion properties. Scott et al. (1997) individually fed sixty yearling steers various concentrations of corn bran and/ or mixed steep in finishing diets. Dietary treatments included 0, 15, or 30% corn bran or mixed steep alone or in combinations replacing dry rolled corn. Steers fed 15% corn bran, mixed steep alone, or a combination of mixed steep and corn bran gained more than cattle fed dry rolled corn ($P < 0.01$). Dry matter intake was greater for steers fed corn bran alone, 15% mixed steep, and a combination of corn bran and mixed steep ($P < 0.10$). Feed efficiency responded quadratically for corn bran inclusion with cattle fed 15% corn bran having the greatest feed efficiency and cattle fed the DRC control and 30% corn

bran having similar feed efficiencies. These data suggest corn bran has less energy than DRC, but at low levels (15% inclusion) bran potentially helps to mitigate acidosis resulting in greater feed efficiency. Corn bran has approximately 80% the feeding value of DRC when fed alone (Scott et al., 1997; Sayer et al., 2013). When mixed steep was included in the diet at 15 and 30%, feed efficiency was improved compared to the DRC control suggesting mixed steep has a greater energy value than the DRC it replaced. As a result, cattle fed a combination of mixed steep and corn bran tended to be less efficient than cattle fed mixed steep alone. This is consistent with a study by Macken et al. (2004b) in which feed efficiency linearly improved as the proportion of mixed steep increased from 37.5 to 50% relative to corn bran/germ meal mix in SFC diets. The addition of 15% mixed steep to 30% corn bran increased feed efficiency by 12% when compared to corn bran fed alone at 30%, suggesting an associative effect between mixed steep and corn bran.

Scott et al. (1998) did a subsequent digestion trial to determine the effect of corn bran and/ or mixed steep on ruminal metabolism and digestibility. Dietary treatments were arranged as a 2 × 3 factorial with treatments based on the addition of corn bran (15%) and mixed steep (15 and 30%) alone or in combination (15% corn bran/15% mixed steep and 15% corn bran/30% mixed steep) to a DRC control diet. No differences were observed for DMI when mixed steep and/ or corn bran were included in the diet which differs from what Scott et al. (1997) observed. The inclusion of corn bran reduced DM digestibility ($P < 0.05$) suggesting the corn bran, although highly digestible, is less digestible than DRC it replaced. No differences were observed for CP or starch digestibility ($P > 0.20$). The addition of mixed steep in the diet reduced ruminal pH and

corn bran tended ($P = 0.14$) to increase the average ruminal pH. Scott et al. (1998) attributed this to the low pH (4.0-4.5) from lactic acid and unfermented carbohydrates in steep. Sayer et al. (2013) conducted a similar experiment, evaluating the effect of replacing DRC and molasses with corn bran and mixed steep on rumen metabolism and digestion (DRC control, 30% corn bran, 30% corn bran/15% mixed steep, and 45% corn bran/ 15% mixed steep, DM basis). Sayer et al. (2013) did not observe reduced ruminal pH when mixed steep was included in the diet but did observe greater ruminal pH when corn bran was included at greater concentrations. In fact, all the diets with byproducts resulted in greater ruminal pH than the control. These results support the idea that wet corn gluten feed (corn bran and mixed steep) helps mitigate ruminal acidosis.

Scott et al. (1998) observed a corn bran × mixed steep interaction for molar proportion of acetate and propionate and acetate to propionate ratio. Inclusion of mixed steep alone resulted in reduced acetate, increased propionate, and as a result a reduced acetate to propionate ratio. Although, when mixed steep was fed in combination with corn bran, acetate, propionate, and the acetate to propionate ratio were similar to the DRC control. The changes in fermentation when mixed steep is fed alone could be a result of metabolism of lactic acid in steep to propionate. Furthermore, the increased molar proportion of propionate when mixed steep replaced DRC could contribute to the higher energy value of mixed steep compared to DRC. Sayer et al. (2013) observed differing results: the DRC control diet had the lowest acetate to propionate ratio while the diet including 45% corn bran and 15% mixed steep resulted in the greatest molar proportion of acetate compared to the DRC control with the other treatments being intermediate. The acetate to propionate response could be contributed to fiber digestion being promoted due

to the level of corn bran in the diet. The increased levels of corn bran (30 and 45%) in this trial compared to 15% (Scott et al. 1998) could have diluted the effects of mixed steep explaining the differences seen in propionate and acetate.

Thus far, the experiments have only evaluated the effects of feeding corn bran and mixed steep, the two most prevalent ingredients in corn gluten feed. A study was conducted by Herold et al. (1998) to determine the nutritional properties of SEM as a singular ingredient in DRC based finishing diets on digestibility and performance in lambs. Treatments consisted of a DRC control and SEM at 13.7, 27.4, 41.0, or 81.8% of the diet DM replacing dry-rolled corn. As SEM inclusion increased in the diet, DMI, ADG, and feed efficiency decreased ($P < 0.10$). Consequently, total tract DM digestibility and diet OM digestibility decreased linearly as SEM inclusion increased ($P < 0.01$). The SEM utilized in the study was 21% starch and 68% NDF, whereas DRC was 68% starch and 9% NDF. The physical properties of SEM may play a role in diet digestibility differences due the smaller particle size of SEM compared to DRC.

In a study by Firkins et al. (1985) a greater cellulose digestibility was observed for wet corn gluten feed compared to dry corn gluten feed. Firkins et al. (1985) speculated the difference in cellulose digestibility was a result of the larger particle size of WCGF which allowed for an increase in rumen retention time and therefore more extensive fiber digestion. Dry corn gluten feed contains SEM, corn bran, and steep, but the consistency and particle size are comparable to SEM. The differences in cellulose digestibility may also be attributed to the drying process of corn gluten feed, rather than particle size. Previous studies by Ham et al. (1995) observed that drying corn gluten feed reduces its energy value. Milton et al. (2000) and Macken et al. (2004b) evaluated the

energy value of wet bran, dry bran, and rehydrated bran in beef finishing diets. The form of bran fed to cattle did not affect animal performance nor the energy value of the bran. As a result, the reduced energy value of dry corn gluten feed may be attributed to the drying of bran in the presence of steep. Stock et al. (2000) reported that drying WCGF at temperatures greater than 60°C resulted in 1-4% DM losses in volatile compounds, which could help explain why dry corn gluten feed has a lower energy value.

Herold et al. (2000) conducted an additional study to compare wet corn gluten feed comprised of corn bran and steep with or without the inclusion of SEM on subacute acidosis potential in finishing cattle. Dietary treatments included a DRC control, a WCGF treatment (50% dried corn bran and 50% mixed steep), and an SEM treatment (33% dried corn bran, 33% mixed steep, and 33% SEM). Each period was 28 d. On d 1 through 12, adaption diets containing 45, 25, and 15% alfalfa hay were fed and from d 13 through 18, the final diet containing 7.5% alfalfa hay was fed. Feed was delivered at 9 am on d 1-18. On d 19, the acidosis challenge was initiated. The cattle received the 7.5% alfalfa hay diet, but the feed was withheld until 1 pm and increased by 25% from the previous day's intake to induce hunger and increase potential for overconsumption of feed. The acidosis challenge model was used to mimic a feedlot situation when cattle overeat as a result of being fed late or changes to intake due to weather, etc. The post challenge portion of the study began at feed reintroduction at 1 pm on d 19. On day 20 and 23, cattle resumed the 9 am feeding. On day 1 post challenge, DMI was similar across treatments, but on day 2 cattle fed DRC had a sharp decline in DMI and did not reach the intake levels of WCGF and SEM until day 4. Minimum pH for SEM and the DRC control were dramatically less as a result of the acidosis challenge on day 1. The WCGF treatment was not diminished

to the same extent as the DRC control and SEM treatments. This is likely due to the higher inclusion of bran (21.51%) in the WCGF compared to 14.34% and 0% in the SEM and DRC control treatments (Scott et al., 1998). Additionally, time under pH 5.6 tended to be greater for cattle fed DRC than cattle fed WCGF and SEM throughout the post challenge period ($P = 0.13$). Average pH of the WCGF and SEM treatments were similar reflecting the consistency in DMI throughout the post challenge period. These data suggest the cattle fed WCGF and SEM treatments did not experience acidosis to the extent of DRC control and recovered at a faster rate. Furthermore, solvent extracted germ meal can be added as a component of WCGF without compromising the control of acidosis in finishing cattle.

Based on animal performance, steep has the greatest energy value compared to bran and SEM but feeding large amounts of steep without bran or SEM can be difficult to handle and store. Additionally, feeding a combination of steep, bran, and SEM in wet corn gluten feed results in a complementary effect due to the acidosis control of bran, high energy value of steep, and a combination of energy and protein in SEM.

Feeding Value of Wet Corn Gluten Feed

The feeding value of corn gluten feed is dependent on whether it is fed wet or dry, the steep to bran ratio, and inclusion in the diet. The feeding value of WCGF is 99 to 100% the value of DRC and Sweet Bran is 109-112% the value of DRC when fed at 20-60% of diet DM (Stock et al., 2000). In comparison, the feeding value of dry corn gluten is 88% the value of DRC when fed at 25-30% of diet DM (Green et al., 1987).

Sweet Bran (Cargill, Blair, NE), is a branded corn gluten feed, recognized for its consistency in nutrient profile due to controlled mixing, improvements in beef cattle

performance, and rumen health. Sweet Bran has a greater DM (60%) compared corn gluten feed byproducts (40-45% DM) because the corn bran is dried before the addition of steep. Sweet Bran is also greater in CP (23.76%) compared to WCGF (21.70%) and lower in NDF content (26.75 and 38.53%; NASEM, 2016). These nutrient composition differences in Sweet Bran compared to WCGF are associated with the addition of more steep relative to corn bran (Stock et al., 2000). Because of the greater proportion of steep, corresponding greater CP, and inclusion of SEM, Sweet Bran has a higher feeding value compared to WCGF. Bremer et al. (2008) conducted a meta-analysis of feedlot trials conducted at the University of Nebraska to evaluate the effect increasing dietary inclusions (0, 10, 20, 30, and 40% of diet DM) of two wet corn gluten feeds (WCGF-A and WCGF-B) on feedlot cattle performance and carcass characteristics. Wet corn gluten feed A was composed of wet bran and steep and contained 40-42% DM and 15-18% CP (DM basis). Dry matter intake of cattle fed increasing levels of WCGF-A was not different among treatments ($P > 0.38$) and ADG tended to increase linearly as WGCF-A increased in the diet ($P = 0.10$) but did not result in differences in feed efficiency among treatments ($P > 0.59$). Feedlot performance and carcass characteristics were similar among cattle fed increasing levels of WCGF-A and corn alone resulting in a feeding value of 99% of corn for WCGF-A. Wet corn gluten feed B (Sweet Bran) was composed of dry bran and steep and contained 60% DM and 22-25% CP (DM basis). Dry matter intake and ADG increased linearly as cattle were fed increasing level of WCGF-B ($P < 0.01$) resulting in a linear improvement in feed efficiency ($P = 0.03$) compared to cattle fed corn alone. Cattle fed WCGF-B were also fatter with corresponding greater marbling scores compared to cattle fed corn alone ($P < 0.01$). These data suggest improvements in

cattle performance are observed when Sweet Bran is fed up to 40% in the diet and as a result of the linear improvements in performance and carcass characteristics, the feeding value of WCGF-B (Sweet Bran) is 112% of corn.

Interaction of Corn Processing and Wet Corn Gluten Feed

Using WCGF to replace a portion of corn in finishing diets has been shown to increase DMI and ADG while maintaining or improving feed efficiency (Stock et al., 2000) as a result of reduced potential for acidosis as shown by Krehbiel et al. (1995). Feeding WCGF with more intensively processed corn may be advantageous to cattle performance due the reduction in acidosis when feeding processed corn while simultaneously getting the full energy potential of the processed corn. Various inclusions of WCGF have been evaluated in diets with several corn processing methods.

Scott et al. (2003) conducted two studies to determine the effect of corn processing method on performance and carcass characteristics of calf fed (trial 1) and yearling steers (trial 2) fed diets containing Sweet Bran. In trial 1, Sweet Bran was included at 32% of diet DM and the corn processing methods evaluated were WC, DRC, FGC, rolled HMC, and SFC. Dry matter intake tended to decrease as the degree of processing increased which is consistent with a review by Owens et al. (1997) comparing DRC, HMC, and SFC. Cattle fed WC consumed 5.8% more DM than cattle fed DRC. Additionally, cattle fed DRC consumed 5.5, 6.3, and 7.3% more DM than cattle fed FGC, SFC, or rolled HMC. There were no differences observed for ADG, thus differences in DMI resulted in improved feed efficiency as the degree of processing increased. Feed efficiency was on average 6.6% greater for cattle fed SFC and HMC compared to cattle

fed FGC, DRC, and WC. Cattle fed WC had the lowest feed efficiency (0.168) compared to processed corn (0.187).

In trial 2, Sweet Bran was included at 22% of diet DM and DRC, SFC, fine rolled corn (FRC), and rolled HMC were utilized. Dry matter intake was similar across treatments, differing from trial 1. Daily gain was greater for cattle fed SFC, but not different among the other corn processing methods. Cattle fed DRC and FRC had similar feed efficiencies while cattle fed rolled HMC and SFC had 3.5 and 8.1% improvements in feed efficiency, respectively, compared to DRC. Macken et al. (2006) reported a similar trend in DMI as shown in trial 1 when DRC, FGC, rolled HMC, ground HMC and SFC were fed to calf-fed steers with a 25% inclusion of Sweet Bran. Additionally, ADG was not different among treatments. As a result, feed efficiency was improved 12.1, 8.8, and 7.1%, respectively, for SFC, ground HMC, and rolled HMC compared to DRC. Improvements in feed efficiencies between 9 and 12 % are common when feeing SFC compared to DRC without Sweet Bran included in the diet, however the improvements in feed efficiency in this study are greater than expected when Sweet Bran is included in the diet. These data suggest cattle fed more intensely processed corn were more efficient than minimally processed corn when feeding Sweet Bran. This could be a result of a reduction in acidosis potential when more highly processed corn is fed.

The majority of Sweet Bran is shipped from Iowa and Nebraska to the Southern Plains where steam-flaking is a common corn processing method; therefore, many trials have been conducted to determine the optimal level of Sweet Bran in SFC based finishing diets. Parsons et al. (2007) fed 40% DM inclusion of Sweet Bran replacing SFC in the diet. Dry matter intake and ADG were 3.6 and 7.2% greater for cattle fed Sweet Bran but

feed efficiency was reduced by 3.2% when Sweet Bran was fed. Block et al. (2002) investigated the effects of Sweet Bran inclusion (0, 20, 30, or 40%) in SFC based finishing diets. There was a quadratic response for HCW, ADG, and feed efficiency for Sweet Bran inclusion with 20 and 30% being optimal ($P < 0.05$). A linear improvement in DMI was also observed as Sweet Bran increased in the diet ($P < 0.05$). These data suggest 20 to 30% Sweet Bran should be fed in SFC diets to optimize cattle performance. Macken et al. (2004b) evaluated six concentrations of Sweet Bran (0, 10, 20, 25, 30, and 35% of diet DM) in SFC based finishing diets. Final weights, ADG, and feed efficiency did not differ among treatments ($P > 0.25$). There was a tendency for DMI to increase linearly as Sweet Bran increased in the diet ($P = 0.07$). The linear effect on concentration of Sweet Bran concentration on DMI is consistent with Block et al. (2002) in SFC diets. These data suggest that Sweet Bran can be fed at concentrations up to 35% in SFC differing from what Block et al. (2002) concluded. This could be due to a combination of a numerically lower feed efficiency when 10% Sweet Bran was fed and a lack of a 40% inclusion of Sweet Bran treatment which has been shown to lower feed efficiency in SFC diets (Block et al. 2002, Parsons et al., 2007).

In the Midwest, it is common to feed a blend of HMC/DRC blend due to the combination of a rapid rumen degradation of HMC increasing the extent of digestibility and slower fermentation of DRC reducing the incidence of acidosis. Buckner et al. (2007) and Loza et al. (2007) evaluated the effect of Sweet Bran (30%) in diets containing a 50:50 HMC/DRC blend. In both trials, steers fed 30% Sweet Bran had increased DMI and ADG compared to the control ($P < 0.01$). Loza et al. (2007) observed a 4.7% improvement in feed conversion for yearling steers fed Sweet Bran compared to the

control cattle, but Buckner et al. (2007) observed similar feed conversions for calf-fed steers fed diets with or without Sweet Bran. Previous research feeding Sweet Bran in HMC/DRC based finishing diets, similar to Loza et al. (2007) and Buckner et al. (2007), compare one concentration of Sweet Bran to a control. Therefore, Bremer et al. (2008) summarized 6 studies feeding DRC, HMC, or an HMC/DRC blend with Sweet Bran and observed a linear increase in DMI, ADG and feed efficiency as Sweet Bran increased in the diet from 0 to 40% Sweet Bran. Because cattle gained more, cattle fed Sweet Bran had more rapid deposition of fat resulting in greater 12^{th} rib fat. In summary, Sweet Bran increases DMI and ADG, regardless of corn processing method, and can maintain or improve feed efficiency when up to 40% is included in the diet depending on the corn processing method used. More research is warranted to evaluate the interaction that may occur with Sweet Bran and corn processing method.

Conclusion

Corn processing is used to improve the extent of starch digestion and ultimately cattle performance but can increase the risk of acidosis and compromise performance. The use of corn milling by-products such as Sweet Bran, a branded corn gluten feed, from the wet milling industry can be fed to replace a portion of starch in the diet with highly digestible fiber to mitigate acidosis while simultaneously maintaining or improving performance. Previous research has extensively studied the effect of increasing concentrations of Sweet Bran in SFC based finishing diets; however, studies evaluating Sweet Bran in HMC/DRC based finishing diets only compare a control diet to one concentration of Sweet Bran. Furthermore, limited data are available directly

comparing SFC and HMC/DRC with increasing inclusions of Sweet Bran to determine how corn processing method and Sweet Bran interact. Lastly, while extensive work has been conducted feeding Sweet Bran in finishing diets to determine performance, limited work has been conducted to determine nutrient digestion, digestible energy, and rumen parameters to better explain performance responses. Therefore, the objectives of the research presented in this thesis include:

1. Evaluate the interaction of corn processing method and Sweet Bran inclusion on feedlot performance, nutrient digestion, digestible energy, and rumen fermentation parameters in beef finishing diets.
2. Evaluate the effect of three Sweet Bran feed ingredients on total tract digestibility and rumen fermentation characteristics.

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CHAPTER 2 - INTERACTION OF CORN PROCESSING METHOD AND SWEET BRAN INCLUSION ON PERFORMANCE AND NUTRIENT DIGESTION IN BEEF FINISHING DIETS

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Abstract

Two studies were conducted to evaluate the effects of corn processing method and Sweet Bran (Cargill, Blair, NE) inclusion on feedlot performance, nutrient digestion, and rumen fermentation parameters. Treatments were arranged as a 2 × 3 factorial, consisting of two corn processing methods steam-flaked corn (SFC) or a high-moisture corn/ dry-rolled corn blend (HMC/DRC) and three inclusions of Sweet Bran (0, 20, or 40% of diet dry matter). In Exp. 1, yearling steers (n = 480; initial body weight = 363 ± 15.1 kg) were utilized in a generalized randomized block design. A linear interaction was observed ($P < 0.01$) for average daily gain (ADG), feed efficiency, and hot carcass weight (HCW). At 0% Sweet Bran, cattle fed SFC had greater ADG and HCW than cattle fed HMC/DRC. However as Sweet Bran increased, ADG and HCW increased at a greater rate for cattle fed HMC/DRC than cattle fed SFC resulting in similar ADG and HCW between corn processing methods at 40% Sweet Bran. At 0% Sweet Bran, cattle fed SFC were 12.4% more efficient than cattle fed HMC/DRC, but as Sweet Bran increased, the improvement declined to 5.3% at 40% Sweet Bran inclusion. In Exp. 2, six ruminally cannulated steers were utilized in a 6 × 6 Latin square design. Cattle fed SFC had greater starch digestibility ($P < 0.01$), while cattle fed HMC/DRC tended to have greater NDF digestibility ($P = 0.08$). As Sweet Bran increased, cattle fed SFC and HMC/DRC had greater dry matter intakes (DMI) in both studies ($P > 0.01$), and as a result, greater digestible energy (DE) intakes as observed in Exp. 2 ($P > 0.01$). Increased DE intake improved ADG and feed efficiency when feeding Sweet Bran in Exp. 1 as explained by greater DMI and increased DE intake observed in Exp. 2. Feeding up to 40% Sweet Bran

in SFC diets doesn't affect feedlot performance and feeding Sweet Bran in HMC/DRC based finishing diets linearly improves performance at inclusions up to 40%.

Keywords: corn processing, digestibility, finishing cattle, wet corn gluten feed

Introduction

Feeding Sweet Bran replaces a portion of starch with energy-dense, highly digestible fiber, steep, and solvent extracted germ meal (SEM) in finishing diets, which increases dry matter intake (DMI) resulting in greater average daily gain (ADG; Stock et al., 2000). Depending on the corn processing method employed, feeding Sweet Bran may maintain or improve feed efficiency (Scott et al., 2003, Macken et al., 2004, Loza et al., 2007). Most of the Sweet Bran is shipped from Nebraska and Iowa to the Southern Plains where steam-flaking is a common corn processing method. Research has evaluated increasing concentrations of Sweet Bran in steam-flaked corn (SFC) based finishing diets, but cattle performance responses have differed among studies. Macken et al. (2004) observed similar final weights, ADG, and feed efficiency across treatments (0, 10, 20, 25, 30, and 35% Sweet Bran) suggesting up to 35% Sweet Bran can be fed in SFC based finishing diets. However, Block et al. (2002) observed a quadratic response in feed efficiency and ADG when feeding four concentrations of Sweet Bran (0, 20, 30, and 40%) suggesting the optimal inclusion of Sweet Bran was between 20-30%. The differences across these two studies could be a result of slightly different Sweet Bran concentrations.

While steam-flaking is becoming more popular in the Midwest, high-moisture corn (HMC), dry-rolled corn (DRC), and combinations of HMC and DRC are still

common corn processing methods. Previous research has evaluated HMC and DRC based finishing diets comparing 0% Sweet Bran to only one other Sweet Bran concentration (Scott et al., 2003; Loza et al., 2007). Bremer et al. (2008) conducted a meta-analysis of 6 experiment from the University of Nebraska that fed HMC, DRC, or a HMC/DRC blend with Sweet Bran. Linear increases in DMI, ADG, and feed efficiency were observed as Sweet Bran increased in the diet from 0 to 40%. In the current study, increasing concentrations of Sweet Bran were fed and the interactions between increasing the concentration of Sweet Bran and corn processing method were evaluated. While previous research has evaluated Sweet Bran in SFC and HMC/DRC diets separately, there is a need for a direct comparison of Sweet Bran in SFC and HMC/DRC diets. Therefore, the objectives of these experiments were to evaluate the interaction of corn processing and Sweet Bran inclusion to 1) evaluate the interaction between increasing the concentration of Sweet Bran and corn processing method, 2) determine the optimal level of Sweet Bran in SFC and HMC/DRC based finishing diets and 3) evaluate total tract digestibility, digestible energy, and rumen fermentation characteristics to understand the performance response observed in the finishing study.

Materials and Methods

All procedures involving animal care and management were approved by the University of Nebraska Lincoln's Institutional Animal Care and Use Committee protocol #1785.

Experiment 1- Cattle Finishing Experiment

A 161-d finishing study was conducted utilizing 480 crossbred yearling steers (initial BW = 363 ± 15.1 kg) to evaluate Sweet Bran (Cargill, Blair, NE) inclusion in diets with SFC or HMC /DRC at 0, 20, and 40% of diet DM on performance and carcass characteristics. Steam-flaked corn was processed to a flake density of 0.34 kg/L (26.5 lb/bu) at a commercial feedlot (Raikes Feedyard, Ashland, NE) and delivered to the research feedlot on a weekly basis. High-moisture corn was harvested at approximately 27% moisture, processed through a 48" roller mill (Renn Mill Center Inc., Alberta, Canada), and stored in a concrete bunker for approximately 250 d before feeding. The moisture content of the HMC during the feeding period was 30%, respectively. The experiment was conducted at the University of Nebraska Lincoln's Eastern Nebraska Research, Extension, and Education Center (ENREEC) feedlot near Mead, NE. Steers were received to ENREEC in October/November of 2019. Steers grazed corn stalks until March and then held on grass until trial initiation in June 2020. Upon arrival to the feedlot, steers were administered a modified live vaccine for prevention of infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), parainfluenza-3 (PI3), bovine respiratory syncytial virus (BRSV), *Mannheimia haemolytica*, 73 and *Pasteurella multocida* (Vista Once, Merck Animal Health, De Soto, KS), a killed vaccine for clostridial toxoids and Histophilus somnus (Ultrabac 7/Somubac, Zoetis Inc, Florham Park, NJ), and an injectable solution for the treatment and control of gastrointestinal and external parasite control (Dectomax, Zoetis Inc.).

Steers were limit-fed a common diet consisting of 50% Sweet Bran and 50% alfalfa hay for 5 d at 2% (DM basis) of BW before weighing to minimize gut fill effects

and achieve an accurate initial body weight (Watson et al., 2013). Steers were individually weighed using a hydraulic squeeze chute (Silencer, Moly Manufacturing Inc., Loraine, KS) for 2 consecutive d for initial BW determination (Stock et al., 1983). Steers were blocked by BW into light, medium, and heavy BW blocks (n=4, 3, and 1 replicate, respectively) based on first weigh day BW, stratified by BW within block, and assigned randomly to pen within block. A total of 48 pens were then assigned randomly to one of six treatments, with a total of 10 steers per pen and 8 replications per treatment.

On d -2 of the trial, steers were implanted with 80 mg of trenbolone acetate and 16 mg of estradiol (Revalor-IS, Merck Animal Health, De Soto, KS). On d 75 the light block and on d 76 the medium and heavy blocks, steers were re-implanted with 200 mg of trenbolone acetate and 20 mg estradiol (Revalor-200, Merck Animal Health).

Dietary treatments were designed as a 2 x 3 factorial arrangement. One factor was corn processing method: either as a 2/3 HMC 1/3 DRC blend, or as 100% SFC. The other factor was the inclusion of Sweet Bran; either 0, 20, or 40% of diet DM. Steers were adapted to the finishing diets over a 24-d period with four steps (six days each). During each step, 10% corn replaced 5% corn silage and 5% wheat straw, while inclusion of supplement and Sweet Bran (0, 20, or 40%) remained constant. The final treatment diets contained 15% corn silage and 5% supplement with Sweet Bran replacing corn in the diet (Table 2.1). All supplements were formulated to include 33 mg/kg DM of monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and to provide 90 mg/steer DM of tylosin (Tylan, Elanco Animal Health). Ractopamine hydrochloride (Optaflexx, Elanco, Animal Health) was fed the last 28 (heavy or middle blocks) or 42 (light block) days on feed to target 300 mg/steer daily followed by a two-day withdrawal before slaughter.

Metabolizable protein (MP) and rumen degradable protein (RDP) balances were calculated using the 2000 revised NRC model using initial body weight and treatment DMI and ADG (Table 2.1).

Cattle were fed once daily between 0700 and 1000 h and managed for *ad libitum* feed intake. Feed was delivered with a truck mounted mixer and delivery unit (Roto-Mix, Dodge City, KS). When needed, refused feed was removed from the feed bunks, weighed, subsampled, and dried in a forced-air oven at 60°C (model LBB2-21-1; Despatch Industries, Minneapolis, MN) for 48 h to determine DM (AOAC, 1999, method 4.1.03) and calculate refusal DM weight. Ingredient samples were sampled weekly for DM analysis and as-fed ingredient inclusions were adjusted weekly. At the end of the trial, weekly ingredient samples were composited by month and sent to a commercial laboratory (Ward Laboratories, Kearney, NE) to be analyzed for DM (Gales, 1990), total starch (YSI Inc., 2000), crude protein (CP; LECO Co.), neutral and acid detergent fiber (ADF and NDF; ANKOM Technology 1998; Mertens, 1992), and minerals (Campbell and Plank, 1991; Kovar, 2003).

The medium and heavy blocks were shipped on November 3, 2020 (154 days on feed). The light block was shipped 2 weeks later to achieve similar fat thickness on November 17, 2020 (168 days on feed). On the day of shipping, 50% of the previous day's DM was offered. Steers were shipped in the evening and harvested the following morning at a commercial abattoir (Greater Omaha, Omaha, NE). On the day of harvest, hot carcass weight (HCW) was recorded, and carcass adjusted final BW was calculated using a common 63% dressing percentage. Carcass-adjusted final BW was used to determine average daily gain (ADG) and feed efficiency (G:F). On the day of harvest,

liver abscess scores were recorded immediately after evisceration. The following scoring system was used: 0 for no liver abscesses, A- for one or very few small abscesses, A for 1 large abscess or a few small abscesses, and A+ for many large abscesses. Liver abscesses were then combined to determine the total proportion of liver abscesses per treatment. Following a 48 h-chill, USDA marbling score, 12^{th} rib fatness thickness, and *longissimus* muscle (LM) area were recorded. Yield grade was calculated using the USDA YG equation: YG = 2.5 + (2.5 X 12^{th} rib fat, cm) + (0.2 x 2.5 [2.5 assumed average steer KPH, %] + (0.0038 x HCW, kg) – (0.32 x LM area, cm2) (USDA, 1997).

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC) as a generalized randomized block design with pen as the experimental unit and block as a fixed effect. The experiment was analyzed as a 2 × 3 factorial with two corn processing methods (steam-flaked corn or high-moisture/dry rolled corn) and three inclusions of Sweet Bran (0, 20, or 40% of diet DM). Data were tested for a linear and quadratic interaction between treatment factors using covariate regression. If an interaction was observed, then simple effects of Sweet Bran inclusion were evaluated within each corn processing method. If no interaction was observed, then main effects of corn processing method and Sweet Bran inclusion were evaluated. Liver abscesses were analyzed using the MIXED procedure of SAS as a binomial evaluating the presence or absence of liver abscesses. Arithmetic means are presented due to unbalanced replications across blocks for initial BW. Probabilities less than or equal to alpha ($P \leq 0.05$) were considered significant, with tendencies acknowledged at $P > 0.05$ and $P \leq 0.10$.

Experiment 2- Cattle Digestion Experiment

A digestion experiment was conducted to evaluate the interaction of corn processing method and Sweet Bran inclusion in finishing diets on total tract digestibility and rumen fermentation parameters. Six ruminally cannulated, crossbred steers were used in a 6 x 6 Latin square design with 21-d periods consisting of a 16-d adaptation period followed by a 5-d collection period. The study was conducted over 126 d. Dietary treatments were designed in a 2 × 3 factorial arrangement with factors identical to Exp. 1. All supplements were formulated to provide 33 mg/kg of monensin (Rumensin, Elanco Animal Health) and provide 90 mg/steer of tylosin (Tylan, Elanco Animal Health; Table 2.1).

Diets were mixed twice weekly in a stationary ribbon mixer (model S-5 Mixer; H.C. Davis, Inc., Bonner Springs, KS) and stored in 200 L barrels. The barrels were stored in a cooler held at 4°C to ensure diet quality was maintained. Diets were offered twice daily in amounts following *ad libitum* intake; 60% was fed at 0700 h and 40% was fed at 1300 h. Feed refusals were removed before feeding at 0700 h. Refusals collected from d 16 to 19 were dried in a forced-air oven at 60°C (Model LBB2-21-1, Despatch, Minneapolis, MN) for 48 h (AOAC, 1999, Method 4.1.03) to determine DM content and then saved for further nutrient analysis. Individual feed ingredients were dried in a 60°C forced-air oven weekly to ensure that accurate DMs were used when mixing dietary treatments.

Steers were individually fed in 3.7 m x 1.8 m slatted floor pens covered with rubber mats in 20°C controlled room with 12 h of light and 12 h of dark. Intakes were

measured continuously for the 4-d collection period to report DMI. The diets differed greatly in neutral detergent fiber content due to the presence and absence of Sweet Bran which resulted in difficult transitions from one period to the next in a Latin square design. Therefore, diets were transitioned between periods over the course of 7 d during the adaptation period by mixing the previous treatment diet with the current treatment diet. On day 1 of the period, 75% of the daily DM offered was the previous treatment diet and 25% was the current treatment. On days 2, 3, and 4 a 50/50 blend of the previous treatment diet and current treatment diet was fed. On days 5, 6, and 7, 25% of total DM offered was the previous treatment diet and 75% was the current treatment diet. On day 8 and the remainder of the period, each steer was fed 100% of DM offered as their assigned treatment diet for the period.

Individual ingredient samples were collected before mixing diets for the collection period, dried, ground through a Wiley mill using a 1-mm screen and composited by period. High-moisture corn, corn silage, and Sweet Bran samples were lyophilized (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis, MO) to prevent volatilization of nutrients. The remaining samples, DRC, SFC, and supplements, were dried in a forced-air oven at 60°C (Model LBB2-21-1, Despatch, Minneapolis, MN) for 48 h (AOAC, 1999; Method 4.1.03). Ort samples were collected on d 18 and 19, weighed, and subsampled to determine nutrient intake. The subsample of orts was dried in a forced air oven at 60°C (Model LBB2-21-1, Despatch, Minneapolis, MN) for 48 h (AOAC, 1999; Method 4.1.03), ground through a Wiley mill using a 1-mm screen and composited by steer within collection period. Additionally, feed ingredient and ort period composites were ground through a 0.5-mm screen (Cyclotec 1093, Foss, Hillerod,

Denmark) for starch analysis and neutral detergent fiber (NDF) analysis for high starch samples. Feed ingredient and ort samples were analyzed for lab DM, organic matter (OM), NDF, and total starch content (Megazyme International, AOAC International, 2000; Method 996.11; AACC Method 76.13). Lab DM was determined by placing samples in a 100°C forced air oven for 24 h. Ash was determined by placing samples in a muffle furnace for 6 h at 600°C (AOAC, 1999, Method 4.1.10). Neutral detergent fiber analysis was conducted using a modified procedure described by Van Soest et al. (1991). All NDF analyses included the addition of 2 doses (0.5 mL/dose) of heat stable alpha amylase (Catalog # FAA, Ankom Technologies, Macedon, NY) and 0.5 g of sodium sulfite during the hour reflux in neutral detergent solution. Additionally, ingredient samples were analyzed for crude protein and gross energy. Crude protein was determined by using combustion method (FlashSmart N/Protein Analyzer CE Elantech, Inc. Lakewood, NJ; AOAC, 1999; method 990.03). Gross energy (GE) was determined by bomb calorimetry (Parr 6400 Automatic Isoperibol Calorimeter, Parr Instrument Co., Moline, IL).

Fecal output was estimated by dosing a 5 g bolus of titanium dioxide twice daily into the rumen in a gel cap. Cattle were dosed at 0700 and 1700 h on d 7 through d 20 to provide a total of 10 g/d. Fecal grab samples (approximately 300 g) were collected for 2 days (d 19 and 20) at 4 time points (0700, 1100, 1500, 1900, 2300, and 0300 h). Fecal samples were composited by day (wet weight basis) within steer, lyophilized (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis, MO), ground through a Wiley Mill using a 1 mm screen, and composited by steer within collection period. Period fecal composites were ground through a 0.5 mm screen (Cyclotec 1093, Foss, Hillerod,

Denmark) for starch and titanium dioxide analysis. Period fecal samples were analyzed for DM, OM, NDF, starch, and GE using the same procedures as described earlier. Furthermore, fecal samples were analyzed for titanium dioxide to determine fecal output (Myers, et al., 2004). Concentration of titanium dioxide was then used to calculate fecal DM output using the following equation: [g marker dosed per day) / (concentration of marker in feces)]. Total tract digestibility was calculated using the following equation: [(g of nutrient fed – g of nutrient refused – g of nutrient in the feces) / (g of nutrient fed – g of nutrient refused)] x 100. Gross energy values from the fecal and ingredient samples were used to calculate digestible energy (DE), by subtracting fecal energy from total energy intake.

Rumen pH was monitored using SmaXtec (Graz, Austria) remote monitoring system. Probes were first activated in a pH 7.00 buffer then submerged into the rumen and then into the reticulum on the first day of the experiment. The probes remained in the reticulum until the last day of the experiment, a total of 126 d. Ruminal pH was monitored continuously, with one reading every 10 minutes. Recorded data were continuously transmitted to the SmaXtec base station, then transmitted to the SmaXtec software on the computer. Ruminal pH data were analyzed for d 16 through 20 to capture the collection period and get four full days of rumen pH measurements. Measurements for ruminal pH include average pH, minimum and maximum pH, pH magnitude, and pH variance. Ruminal pH variance was calculated using the standard deviation of daily ruminal pH. Rumination was monitored using sensor ear-tags (Cow Manager, The Netherlands) based on ear movement via a three-dimensional accelerometer. The number

of minutes spent ruminating per day and eating per day were predicted using the sensor ear tags.

Due to behavioral challenges, one animal was removed after the second period. Another animal replaced the removed animal for periods 3-6 to maintain 6 replications per treatment. Steer within period was experimental unit.

Statistical Analysis

Intake, excretion, and digestibility data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) as a 6 × 6 Latin square experimental design with period and steer as a fixed effect. The treatment design was a 2 × 3 factorial with two corn processing methods (SFC or HMC/DRC) and three inclusions of Sweet Bran (0, 20, or 40%). The main effect of corn processing, Sweet Bran inclusion, and the interaction between corn processing and Sweet Bran inclusion were included in the model. Data were tested for linear and quadratic interactions between treatment factors using covariate regression. If an interaction was observed, then simple effects of Sweet Bran inclusion were evaluated within each corn processing method. If no interaction was observed, then main effects of corn processing and Sweet Bran inclusion were evaluated. Ruminal pH was analyzed as a repeated measure using the MIXED procedure of SAS. Hour across days was the repeated measure. The model for ruminal pH included period, corn processing, Sweet Bran inclusion, hour, hour^2, and the resultant interaction terms. Six covariate structures were tested, and the structure with the lowest Bayesian information criterion were determined to be the best fit. The Toeplitz covariate structure provided the best fit for ruminal pH. Probabilities less than or equal to alpha ($P \leq 0.05$) were considered significant, with tendencies acknowledged at at $P > 0.05$ and $P \leq 0.10$.

Results and Discussion

Experiment 1- Cattle Finishing Experiment

Interaction of Corn Processing Method and Sweet Bran Inclusion

There were no quadratic interactions of corn processing method and Sweet Bran inclusion or quadratic effects of Sweet Bran ($P > 0.22$). A linear interaction of corn processing method and Sweet Bran inclusion was observed for ADG ($P < 0.01$; Table 2.2; Figure 2.1). In both SFC and HMC/DRC diets, ADG increased linearly from 0 to 40% Sweet Bran inclusion ($P < 0.05$). Steam-flaked corn fed cattle had greater gains than the HMC/DRC fed cattle at 0% SB (2.18 and 1.93 kg), but as Sweet Bran increased in the diet, ADG for HMC/DRC fed cattle increased at a greater rate compared to SFC fed cattle resulting in similar gains between the corn processing methods at 40% Sweet Bran (2.21 and 2.27 kg). Scott et al. (2003) compared diets containing DRC and SFC with (32% inclusion) or without Sweet Bran and observed similar results for ADG. When 0% Sweet Bran was fed, cattle fed SFC had greater gains (1.80 kg) than cattle fed DRC (1.74 kg; $P < 0.10$). But when Sweet Bran was included in the diet at 32%, ADG increased at greater rate for cattle fed DRC compared to cattle fed SFC resulting in similar gains when Sweet Bran was included in the diet. In SFC based finishing diets, Macken et al. (2004) observed no improvements in ADG containing 0, 10, 20, 25, 30, and 35% Sweet Bran. However, Block et al. (2002) reported a quadratic response for ADG in SFC diets containing 0, 20, 30, and 40% Sweet Bran and optimizing in the range of 20 to 30% inclusion. The slight differences in concentrations of Sweet Bran could explain differences among studies.

A linear interaction of corn processing method and Sweet Bran inclusion was observed for feed efficiency ($P < 0.01$; Figure 2.2). As Sweet Bran increased in the diet, there was no change in feed efficiency was observed for SFC diets ($P = 0.19$). A linear improvement in feed efficiency was observed in HMC/DRC diets ($P < 0.01$). Macken et al. (2004) observed similar feed efficiencies for cattle fed 0 to 35% Sweet Bran in SFC based finishing diets. When feeding up to 40% Sweet Bran in SFC diets, Block et al. (2002) and Parsons et al. (2007) observed a slight decline in feed efficiency when compared to the control. In the current study, cattle fed 40% Sweet Bran had numerically lower feed efficiencies, although not statistically different. Bremer et al. (2008) summarized 6 studies feeding Sweet Bran in HMC and DRC based finishing diets and reported a linear improvement in ADG and feed efficiency as Sweet Bran increased in the diet from 0 to 40% which agrees with the linear improvement observed in the current study. At 0% Sweet Bran, there was a 12.4% improvement in feed efficiency when feeding SFC compared to HMC/DRC, which is consistent with previous research: in comparisons with DRC and SFC without WCGF, improvements of greater than 9.4% for feed efficiency have been consistency reported (Zinn et al., 1998; Brown et al., 2000; Corrigan et al., 2009). While the feed efficiency for SFC remained greater than HMC/DRC when 40% Sweet Bran was fed ($P = 0.04$), the improvement of SFC over HMC/DRC in feed efficiency was only 5.3% when 40% Sweet Bran was fed compared to 12.4% when no Sweet Bran was fed.

There was a linear interaction for HCW and carcass-adjusted final BW ($P < 0.01$). At 0% Sweet Bran, the cattle fed SFC had greater HCW and carcass-adjusted final BW than cattle fed HMC/DRC. As Sweet Bran inclusion increased, HCW and carcass-

adjusted final BW tended ($P = 0.06$) to increase for cattle fed SFC and significantly increased ($P < 0.01$) for cattle fed HMC/DRC resulting in similar HCW and carcass-adjusted final BW between the two corn processing methods fed with 40% Sweet Bran.

No interactions were observed for DMI, LM area, 12th rib fat, marbling, calculated yield grade, or liver abscesses, so main effects of corn processing method or Sweet Bran inclusion will be discussed.

Main Effects of Corn Processing on Performance and Carcass Characteristics

Steers fed SFC tended to have greater fat depth ($P = 0.10$) than steers fed HMC/DRC (Table 2.3). Accordingly, steers fed SFC had a greater degree of marbling compared to steers fed HMC/DRC ($P < 0.01$). Steers fed SFC had a larger LM area than steers fed HMC/DRC ($P < 0.01$). Impacts on carcass traits likely reflect changes in ADG as cattle fed SFC generally gained faster. Steers fed HMC/DRC had a greater prevalence of liver abscesses compared to steers fed SFC ($P < 0.02$). It is unclear why liver abscess rates were abnormally high as all steers were fed tylosin in this study. Feeding tylosin has shown to reduce liver abscess prevalence by 40 to 70% (Nagaraja et al., 1999). Liver abscesses still affect 12 to 18% of feedlot cattle even when tylosin is fed (Elanco, 2014). However, liver abscesses are approximately 45% when tylosin is not fed (Brown and Lawerance, 2010). The liver abscess occurrence observed in this experiment (46.15% on average among all treatments) is similar to the liver abscess occurrence of cattle not fed tylosin.

Main Effects of Sweet Bran Inclusion on Performance and Carcass Characteristics

Dry matter intake increased as Sweet Bran increased in the diet regardless of corn processing method ($P < 0.01$; Table 2.4). The linear effect of increasing DMI as inclusion

of Sweet Bran increased is consistent with previous research in SFC (Block et al., 2002; Macken et al., 2004) and HMC and DRC based finishing diets (Bremer et al., 2008). A linear increase in 12th rib fat was observed with fat increasing as Sweet Bran increased in the diet ($P = 0.02$), which led to a linear increase in calculated yield grade ($P = 0.05$). Feeding diets with Sweet Bran increased ADG resulting in a more rapid deposition of back fat (Bremer et al., 2008). As Sweet Bran increased in the diet, LM area also tended to increase linearly ($P = 0.07$).

Experiment 2- Cattle Digestion Experiment

Intake

Following the same trend as in Exp. 1, increasing the concentration of Sweet Bran in the diet, resulted in a linear increase in DMI, regardless of corn processing method ($P < 0.01$; Table 2.5). Similarly, OM intake increased linearly as Sweet Bran increased in the diet, regardless of corn processing method ($P < 0.01$). A tendency for a quadratic interaction for corn processing and Sweet Bran inclusion was observed for starch intake ($P = 0.09$). At 0% Sweet Bran, starch intake was similar (5.3 and 5.1 kg/d) for cattle fed SFC and HMC/DRC. Even though starch concentration of the diet was less at 20% Sweet Bran, cattle fed SFC with 20% Sweet Bran inclusion had dramatically greater intakes than 0% resulting in a similar starch intake as steers fed SFC and 0% Sweet Bran (5.5 kg/d). Thus, as Sweet Bran increased in the diet up to 20%, starch intake was not diminished due to the dramatic increase in DMI. Dry matter intake also increased for cattle fed HMC/DRC at 20% Sweet Bran; however, the increase in DMI was much less than cattle fed SFC. Because the starch concentration of the diet was less, starch intake

was lower for cattle fed HMC/DRC at 20% Sweet Bran (4.2 kg/d) compared to 0% Sweet Bran. As Sweet Bran increased to 40% of diet DM, starch intake continued to decrease for cattle fed HMC/DRC (3.9 kg/d) and significantly decreased for cattle fed SFC (4.4 kg/d). There was a linear increase in NDF intake as Sweet Bran increased in the diet from 0 to 40%, reflecting the relative differences in NDF concentration of corn and Sweet Bran ($P < 0.01$).

Fecal Excretion and Digestion

Dry matter and OM excreted increased linearly as Sweet Bran increased in the diet ($P < 0.01$). The increase in excretion could be due to increasing DMI as Sweet Bran increased in the diet and similar digestibility among treatments or a result of slightly lower digestibility with increasing Sweet Bran inclusion. No differences were observed for DM digestibility ($P \geq 0.24$), but OM digestibility tended to decrease as Sweet Bran increased in the diet ($P = 0.10$). Organic matter digestibility decreased while ADG and feed efficiency for HMC/DRC in Exp. 1 improved from 0 to 40% Sweet Bran. As Sweet Bran concentration increased in the diet, the NDF: starch ratio increased and highly digestible carbohydrate (starch, average digestibility 97.6%) was replaced with less digestible carbohydrate (NDF, average digestibility 50.0%; Beckman and Weiss, 2005). Thus, the increase in NDF intake is likely the cause of a decrease in OM digestibility as Sweet Bran increases in the diet. Neutral detergent fiber excreted, and digestibility increased as Sweet Bran increased in the diet ($P < 0.01$). The increase in NDF digestibility is due to the NDF in Sweet Bran being more digestible than the NDF from corn silage. Cattle fed HMC/DRC excreted less NDF and thus had greater NDF digestibility than cattle fed SFC ($P = 0.04$). In addition, starch excretion tended to

decrease as Sweet Bran increased due a lower starch concentration in the diet ($P = 0.09$). Cattle fed SFC had greater starch intakes, but excreted less starch than cattle fed HMC/DRC ($P < 0.01$), thus having greater starch digestibility ($P < 0.01$). Cattle fed SFC had 99.1% total tract digestibility compared to 95.4% in cattle fed HMC/DRC. This is consistent with the averages of total tract digestibility for DRC, HMC, and SFC observed by Huntington (1997), Cooper et al. (2002), and Owens (2005): 93.1, 97.7, and 99.3%. Lastly, no differences were detected for digestible energy per kg of diet ($P \geq 0.25$), but digestible energy intake per day increased as Sweet Bran concentration increased in the diet ($P < 0.01$). This was a result of the linear increase in DMI from 0 to 40% Sweet Bran observed in both Exp. 1 and Exp. 2.

Ruminal pH

There were no interactions ($P \geq 0.16$, Table 2.6), no effect of corn processing method ($P \geq 0.64$) and no effect of Sweet Bran ($P \geq 0.29$) observed for minimum, maximum, average, magnitude of change, or variation of ruminal pH. Average ruminal pH (6.15-6.24) and maximum ruminal pH (6.58-6.78) appear to be higher than what would be expected for cattle on a high-grain diet. Nagaraja and Titgemeyer (2007) reported that ruminal pH in cattle fed high-grain diets can range from 5.6 to 6.5 with the average ruminal pH between 5.8 and 6.2, although ruminal pH can drop lower than 5.6 for a period during the feed cycle.

Moderate differences in ruminal pH would be expected as Sweet Bran inclusion increased in the diet. Sindt et al. (2002) observed a linear increase in ruminal pH values as wet corn gluten fed increased in the diet from 0 to 60% ($P < 0.05$). The linear increase in DMI as Sweet Bran increased in the diet could indicate a reduction in ruminal acidosis

and as a result ruminal pH would be expected to be greater for cattle fed Sweet Bran. Or the linear increase in DMI could be due to a reduction in the energy density of the diet. However, the measured digestible energy (Mcal/kg) of the diets and the improvements in performance from Exp. 1 would not support this idea. Therefore, it is likely the absolute values from the Smaxtec pH probes are not accurate. SmaXtec pH probes were originally designed for dairy cattle consuming a high forage diet and used primarily as a management tool for producers to detect changes in pH associated with eating behavior and/ or acidosis, rather than an absolute value for ruminal pH. Therefore, the ruminal pH values from the probes may not accurately reflect the actual ruminal pH values.

Rumination

There were no interactions ($P \geq 0.73$, Table 2.7), effect of corn processing method ($P \geq 0.20$), or effect of Sweet Bran ($P \geq 0.35$) observed for time spent ruminating or eating per day.

Conclusion

In both experiments, DMI increased linearly as Sweet Bran increased in the diet regardless of corn processing method which increased digestible energy intake. Greater energy intake allowed more energy for gain over maintenance, thus contributing to the greater gains and conversions observed in the finishing study. Furthermore, 20-40% Sweet Bran can be fed with SFC without affecting feed efficiency and the optimal level of Sweet Bran for HMC/DRC based finishing diets was 40% in this experiment. Therefore, feeding Sweet Bran in HMC/DRC based finishing diets makes HMC/DRC diets more competitive with SFC-based finishing diets allowing producers without steam-flaking capabilities to achieve similar gains.

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Table 2.1. Dietary treatment composition (DM basis) and chemical analysis for finishing steers fed steam-flaked corn (SFC) or high-moisture and dry-rolled corn (HMC/DRC) with 0, 20, or 40% Sweet Bran (Exp. 1 and 2)

	Treatment[1]					
	SFC			HMC/DRC		
Ingredient	0	20	40	0	20	40
Steam-flaked corn	80	60	40	-	-	-
High-moisture corn	-	-	-	53.33	40	26.67
Dry-rolled corn	-	-	-	26.67	20	13.33
Sweet Bran	0	20	40	0	20	40
Corn silage	15	15	15	15	15	15
Supplement[2]						
Fine ground corn	1.32	2.39	2.96	1.32	2.39	2.96
Limestone	1.66	1.59	1.52	1.66	1.59	1.52
Tallow	0.125	0.125	0.125	0.125	0.125	0.125
Urea	1.5	0.5	0	1.5	0.5	0
Salt	0.3	0.3	0.3	0.3	0.3	0.3
Vitamin A-D-E[3]	0.015	0.015	0.015	0.015	0.015	0.015
Trace mineral[4]	0.05	0.05	0.05	0.05	0.05	0.05
Rumensin 90	0.017	0.017	0.017	0.017	0.017	0.017
Tylan 40	0.009	0.009	0.009	0.009	0.009	0.009
Chemical Composition, %[5]						
Organic matter	96.2	94.9	93.7	95.6	94.4	93.3
Neutral detergent fiber	11.9	17.2	22.5	13.5	18.4	23.4
Acid detergent fiber	5.76	7.21	8.65	6.05	7.43	8.80
Crude protein	12.2	12.5	14.6	12.6	13.0	14.8
Calcium	0.796	0.793	0.791	0.772	0.775	0.779
Phosphorus	0.194	0.395	0.535	0.292	0.439	0.584
MP balance[6], g/d	148.90	172.50	196.78	207.54	221.28	234.87
RDP balance[6], g/d	6.77	16.49	207.12	1.41	6.46	195.15

[1]Treatments included SFC 0: steam-flaked corn with 0% Sweet Bran, SFC 20: steam-flaked corn with 20% Sweet Bran, SFC 40: steam-flaked corn with 40% Sweet Bran, HMC/DRC 0: high-moisture corn/dry-rolled corn with 0% Sweet Bran, HMC/DRC 20: high-moisture corn/dry-rolled corn with 20% Sweet Bran, and HMC/DRC 40: high-moisture corn/dry-rolled corn with 40% Sweet Bran.
[2]Supplement fed at 5% of dietary DM for all treatments.
[3] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin per gram.
[4]Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.
[5]Based on monthly composites from Exp. 1, analyzed for each ingredient. Sample analysis was conducted at Ward Laboratories (Kearney, NE). All values are presented on a DM basis.
[6]Based on the 2000 revised NRC model using cattle initial BW and treatment ADG and DMI.

Table 2.2. Simple Effects of carcass adjusted performance of cattle fed steam-flaked corn (SFC) or a combination of high-moisture and dry rolled corn (HMC/DRC) with 0, 20, or 40% Sweet Bran (Exp. 1)[1]

	Treatment[1]							P-value[2]		
	SFC			HMC/DRC						
	0	20	40	0	20	40	SEM	Corn x SB Linear	SFC Linear	HMC/DRC Linear
Performance										
Initial BW, kg	362	362	362	362	362	362	5.3	0.77	-	-
Final BW[3], kg	709	716	723	668	690	712	4.9	< 0.01	0.06	< 0.01
DMI, kg/d	12.1	12.5	12.8	12.0	12.5	13.0	0.14	0.14	-	-
ADG, kg	2.18	2.23	2.27	1.93	2.07	2.21	0.030	<0.01	0.05	< 0.01
G:F	0.181	0.179	0.177	0.161	0.166	0.170	0.0020	< 0.01	0.19	< 0.01
Carcass Characteristics[3]										
HCW, kg	446	450	455	421	435	449	3.1	< 0.01	0.06	< 0.01
LM area, cm	96.8	97.4	98.1	93.5	94.8	96.1	1.03	0.60	-	-
12th rib fat, cm	1.55	1.60	1.68	1.47	1.55	1.60	0.05	0.92	-	-
Marbling[4]	512	520	528	486	488	490	11.3	0.60	-	-
Calculated YG[5]	3.45	3.51	3.57	3.31	3.43	3.54	0.08	0.57	-	-
Liver abscesses, %[6]	41.6	29.1	43.6	58.8	55.0	48.8	5.6	0.17	-	-

[1]Arthmetic means are reported.

[2]Corn x SB Linear = *P*-value for the linear interaction between corn processing method and Sweet Bran inclusion, SFC Linear= *P*-value for the SB linear effect for SFC, HMC/DRC= P-value for the SB linear effect for HMC/DRC

[3]Calculated on a carcass-adjusted basis using a common dressing percentage (63%).

[4]Marbling score 300=slight, 400=small, 500=modest, etc.

[5]Yield Grade = 2.5 + (2.5 x 12th rib fat) + (0.02 x 2.0 [KPH]) + (0.0038 x HCW) - (0.32 x LM area).

[6]Calculated as a percent of total steers; dead steers removed

Table 2.3. Main effect of corn processing method on carcass adjusted performance of cattle fed steam-flaked corn (SFC) or a combination of high-moisture and dry rolled corn (HMC/DRC) with 0, 20, or 40% Sweet Bran (Exp. 1)[1]

	Treatment			
Item	**SFC**	**HMC/DRC**	**SEM**	***P*-value[2]**
Performance				
Initial BW, kg	362	362	5.3	0.81
Final BW[3], kg	716	690	4.9	< 0.01
DMI, kg/d	12.5	12.5	0.14	0.89
ADG, kg	2.23	2.07	0.030	< 0.01
G:F	0.179	0.166	0.0020	< 0.01
Carcass Characteristics[3]				
HCW, kg	445	435	3.1	< 0.01
LM area, cm^2	97.4	94.8	1.03	<0.01
12th rib fat, cm	1.61	1.54	0.05	0.10
Marbling[4]	520	488	11.3	< 0.01
Calculated YG[5]	3.51	3.43	0.08	0.27
Liver abscesses, %[6]	38.1	54.2	5.6	< 0.02

[1]Arithemtic means are reported

[2]Corn=*P*-value for main effect of corn processing method

[3]Calculated on a carcass-adjusted basis using a common dressing percentage (63%).

[4]Marbling score 300=slight, 400=small, 500=modest, etc.

[5]Yield Grade = 2.5 + (2.5 x 12th rib fat) + (0.02 x 2.0 [KPH]) + (0.0038 x HCW) - (0.32 x LM area).

[6]Calculated as a percent of total steers; dead steers removed

Table 2.4. Main effect of Sweet Bran Inclusion of carcass adjusted performance of cattle fed steam-flaked corn (SFC) or a combination of high-moisture and dry rolled corn (HMC/DRC) with 0, 20, or 40% Sweet Bran (Exp. 1)[1]

	Treatment				***P*-value[2]**
	Sweet Bran Inclusion				
Item	**0%**	**20%**	**40%**	**SEM**	**SB Linear**
Performance					
Initial BW, kg	362	362	362	5.3	0.34
Final BW[3], kg	689	703	718	4.9	< 0.01
DMI, kg/d	12.1	12.5	12.9	0.14	< 0.01
ADG, kg	2.10	2.15	2.24	0.030	< 0.01
G:F	0.171	0.173	0.174	0.0020	0.24
Carcass Characteristics[3]					
HCW, kg	434	443	452	3.1	< 0.01
LM area, cm^2	95.5	96.1	97.4	1.03	0.07
12th rib fat, cm	1.52	1.57	1.65	0.05	0.02
Marbling[4]	499	504	509	11.3	0.42
Calculated YG[5]	3.45	3.51	3.57	0.08	0.05
Liver abscesses, %[6]	50.2	42.1	46.2	5.6	0.33

[1]Arithemtic means are reported

[2]SB Linear=*P*-value for the linear main effect of Sweet Bran inclusion; SB Quad= *P*-value for the quadratic main effect of Sweet Bran inclusion

[3]Calculated on a carcass-adjusted basis using a common dressing percentage (63%).

[4]Marbling score 300=slight, 400=small, 500=modest, etc.

[5]Yield Grade = 2.5 + (2.5 x 12th rib fat) + (0.02 x 2.0 [KPH]) + (0.0038 x HCW) - (0.32 x LM area).

[6]Calculated as a percent of total steers; dead steers removed

Table 2.5. Nutrient intake and digestibility of cattle fed steam-flaked corn (SFC) or a combination of high-moisture corn and dry-rolled corn (HMC/DRC) with 0, 20, or 40% Sweet Bran (Exp. 2)

	Treatment							*P*-value[1]			
	SFC			HMC/DRC							
Item	**0**	**20**	**40**	**0**	**20**	**40**	**SEM**	**Corn x SB Linear**	**Corn x SB Quad**	**Corn**	**SB Linear**
DM											
Intake, kg/d	8.45	11.2	11.9	9.07	10.0	11.2	0.46	0.19	0.14	0.29	< 0.01
Excreted, kg/d	2.09	2.65	3.01	2.08	2.29	2.83	0.17	0.65	0.56	0.19	< 0.01
Digestibility, %	75.0	76.3	74.8	77.4	77.6	74.6	1.32	0.30	0.40	0.26	0.24
OM											
Intake, kg/d	8.27	10.6	10.9	8.85	8.94	10.6	0.55	0.42	0.14	0.31	< 0.01
Excreted, kg/d	1.80	2.25	2.56	1.84	1.99	2.40	0.16	0.54	0.68	0.32	< 0.01
Digestibility, %	78.3	78.6	76.4	79.6	78.1	77.2	1.35	0.76	0.74	0.60	0.10
NDF											
Intake, kg/d	1.12	2.25	3.23	1.11	1.87	3.05	0.15	0.64	0.37	0.11	< 0.01
Excreted, kg/d	0.848	1.14	1.57	0.801	0.939	1.23	0.12	0.22	0.79	0.04	<0.01
Digestibility, %	36.3	49.0	51.7	40.0	51.1	59.8	4.78	0.66	0.32	0.08	< 0.01
Starch											
Intake, kg/d	5.27	5.51	4.39	5.07	4.21	3.89	0.27	0.57	0.09	< 0.01	< 0.01
Excreted, kg/d	0.0500	0.0340	0.0340	0.275	0.171	0.133	0.040	0.09	0.77	< 0.01	0.04
Digestibility, %	99.0	99.4	99.2	95.1	96.1	96.6	0.75	0.31	0.87	< 0.01	0.24
DE											
App. Energy Digestibility, %	73.8	74.4	73.9	74.9	75.7	73.7	1.19	0.62	0.55	0.41	0.70
DE, Mcal/d	26.5	35.3	37.9	28.9	32.4	36.1	1.74	0.25	0.25	0.58	< 0.01
DE, Mcal/kg	3.13	3.16	3.19	3.20	3.26	3.19	0.061	0.58	0.66	0.25	0.59

[abcd]Means in a row with subscripts are different when the linear interaction is significant ($P \leq 0.05$).

[1]CornxSB Linear= *P*-value for linear interaction between corn processing method and Sweet Bran inclusion; corn=*P*-value for main effect of corn processing method; SB= *P*-value for linear main effect of SB inclusion

Table 2.6. Ruminal pH characteristics of cattle fed steam-flaked corn (SFC) or a combination of high-moisture corn or dry rolled corn (HMC/DRC) with 0, 20, or 40% Sweet Bran (Exp. 2)[1]

	Treatment							*P*-value[2]		
Item	SFC 0	SFC 20	SFC 40	HMC/DRC 0	HMC/DRC 20	HMC/DRC 40	SEM	Corn x SB Linear	Corn	SB Linear
Minimum pH	5.88	5.77	5.76	5.78	5.83	5.72	0.078	0.67	0.80	0.29
Maximum pH	6.58	6.68	6.63	6.71	6.66	6.58	0.067	0.23	0.75	0.71
Average pH	6.24	6.20	6.15	6.19	6.21	6.15	0.087	0.66	0.81	0.33
pH magnitude	0.690	0.910	0.870	0.920	0.790	0.860	0.087	0.20	0.64	0.48
pH variance[3]	0.170	0.210	0.230	0.340	0.180	0.220	0.027	0.16	0.68	0.46

[1]Arithmetic means are reported

[2]Corn x SB= *P*-value for linear interaction between corn processing method (a combination of high-moisture corn and dry rolled corn or steam-flaked corn) and Sweet Bran inclusion (0, 20, or 40%); corn=*P*-value for main effect of corn processing method; SB= *P*-value for linear main effect of SB inclusion

[3]Standard deviation of daily ruminal pH

Table 2.7. Rumination characteristics of cattle fed steam-flaked corn (SFC) or a combination of high-moisture corn or dry rolled corn (HMC/DRC) with 0, 20, or 40% Sweet Bran (Exp. 2)[1]

	Treatment							P-value[2]		
Item	SFC 0	SFC 20	SFC 40	HMC/DRC 0	HMC/DRC 20	HMC/DRC 40	SEM	Corn x SB Linear	Corn	SB Linear
Rumination, min/d	212	282	325	228	207	249	59.0	0.81	0.20	0.35
Eating, min/d	59.8	46.5	89.9	72.0	75.6	57.6	20.0	0.73	0.80	0.67

[1]Arithmetic means are reported

[2]Corn x SB= *P*-value for linear interaction between corn processing method (a combination of high-moisture corn and dry rolled corn or steam-flaked corn) and Sweet Bran inclusion (0, 20, or 40%); corn=*P*-value for main effect of corn processing method; SB= *P*-value for linear main effect of SB inclusion

Figure 2.1. Effect of processing method and Sweet Bran inclusion on ADG. Corn methods include steam flaking (SFC) or a blend of 2/3 high-moisture corn and 1/3 dry-rolled corn (HMC/DRC). The linear interaction of corn processing method and Sweet Bran was significant ($P < 0.01$; SEM = 0.03; Exp. 1).

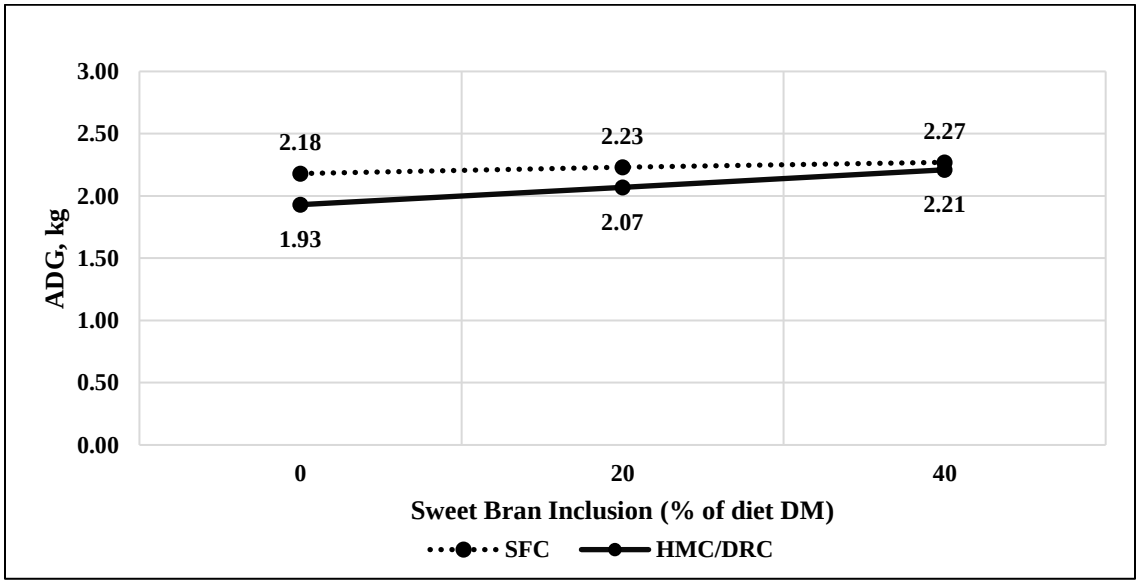
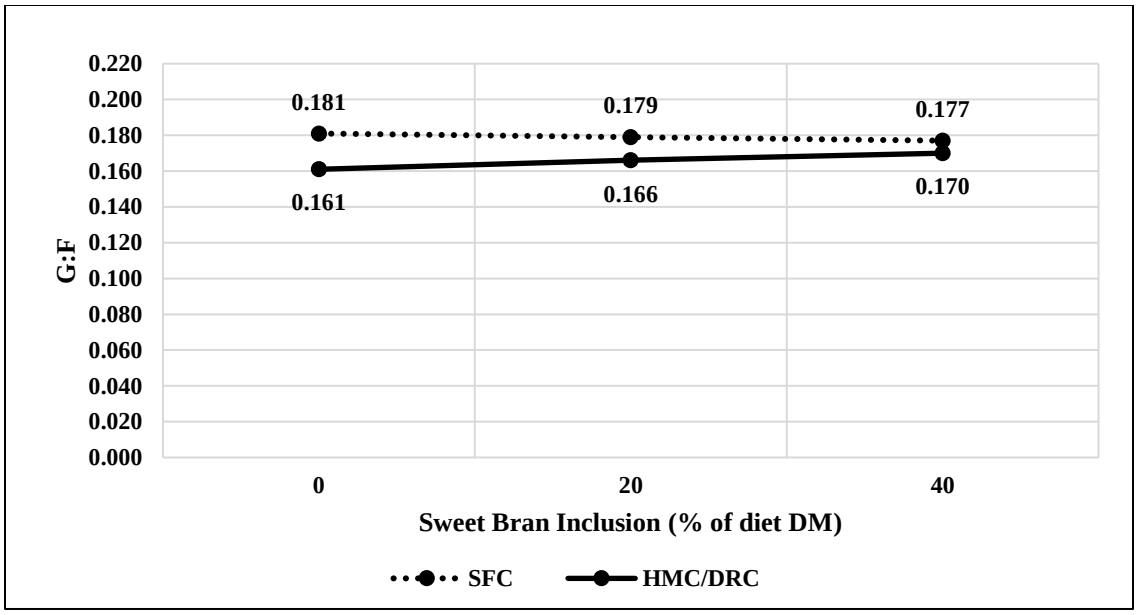


Figure 2.2. Effect of processing method and Sweet Bran inclusion on gain to feed ratio. Corn methods include steam flaking (SFC) or a blend of 2/3 high-moisture corn and 1/3 dry-rolled corn (HMC/DRC). The linear interaction of corn processing method and Sweet Bran was significant ($P < 0.01$; SEM = 0.002; Exp. 1).



CHAPTER 3 - EFFECT OF INDIVIDUAL SWEET BRAN COMPONENTS ON NUTRIENT DIGESTION IN BEEF FINISHING DIETS

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Abstract

Eight ruminally cannulated steers were utilized in a replicated 4 × 4 Latin square design to evaluate the effect of individual Sweet Bran components on total tract digestibility and rumen fermentation parameters. Three Sweet Bran components (solvent extracted germ meal, dried corn bran, and mixed steep) were included at 40% of diet dry matter in their respective treatment, with a steam-flaked corn control. No differences were observed for dry matter intake between dietary treatments ($P > 0.51$). Dry matter and organic matter digestibility were least for bran (69.0 and 69.6%), intermediate for solvent extracted germ meal (77.5 and 78.6%), and greatest for steep (84.2 and 86.3%) and control (82.2 and 83.0 %; $P < 0.01$). Neutral detergent fiber digestibility (NDF) was least for control (21.0%) and intermediate for bran (37.0%) and steep (37.6%; $P < 0.02$) with a tendency for solvent extracted germ meal to have the greatest NDF digestibility (52.7%; $P = 0.07$). Apparent energy digestibility was greatest for steep (85.6%) and control (81.6%) and least for bran (68.0%) with solvent extracted germ meal being intermediate (76.6%; $P < 0.01$). Overall, steep and SEM have similar energy densities as the SFC control, and bran and SEM are highly digestible NDF sources. The nutrient and physical characteristics of steep, SEM, and bran are complementary and contribute to the higher energy value of Sweet Bran compared to dry-rolled corn.

Key words: corn bran, digestibility, solvent-extracted germ meal, steep

Introduction

Byproducts from the wet corn milling industry are widely utilized in the cattle feeding industry because of their potential for improvements in animal performance and

mitigation of acidosis. Wet corn gluten feed is a common byproduct from the wet corn milling process but can vary in nutrient composition and feeding value based on the level of corn bran, mixed steep, and solvent extracted germ meal (SEM) in the mixture. Corn bran is the highly digestible, fibrous portion of the corn kernel. During the manufacturing of corn gluten feed, wet bran is pressed and may be dried before the addition of steep. Mixed steep is a mixture of heavy steep water and distiller's solubles and contains amino acids, minerals, and vitamins as well as fermentation end products such as lactate. Solvent-extracted germ meal is the fraction remaining after oil is extracted from the germ. In previous research, feed efficiency responded quadratically for bran inclusion with cattle fed 15% having the greatest feed efficiency and cattle fed 0 and 30% bran having similar feed efficiencies (Scott et al., 1997). These data suggest bran has less energy than corn, but when fed at low levels helps mitigate acidosis potential as observed by Sayer et al. (2013) and Scott et al. (1998). Steep improves feed efficiency when replacing 30% corn suggesting steep has greater energy than corn (Scott et al., 1997). Additionally, the addition of steep in a diet has shown to decrease ruminal pH compared to a DRC control (Scott et al., 1998). As the inclusion of SEM increased in DRC based diets, DM and OM digestibility decreased likely due to shorter rumen retention time. Solvent-extracted germ meal has a smaller particle supply compared to DRC, thus increasing passage rate, decreasing digestibility, and consequently ADG and feed efficiency also decreased (Herold et al., 1998). Nutrient composition, performance, physical characteristics vary among bran, steep, and SEM.

Sweet Bran is a branded corn gluten feed consisting of bran, steep, and SEM and recognized for a consistent supply and nutrient composition. Supply of bran, steep, and

SEM can vary resulting in slight changes to ingredient proportions while also meeting the goal of Sweet Bran nutrient composition consistency. Thus, it is important to understand of the impact of these individual components on digestibility and rumen metabolism to better understand performance responses. Therefore, the objective of this digestion study was to evaluate the effect of individual Sweet Bran components, corn bran, SEM, and steep on total tract nutrient digestion and rumen fermentation parameters.

Materials and Methods

All procedures involving animal care and management were approved by the University of Nebraska Lincoln's Institutional Animal Care and Use Committee protocol #1785.

A digestion study was conducted to evaluate the effect of individual Sweet Bran components on total tract digestibility and rumen fermentation parameters. Eight ruminally cannulated, crossbred steers were used in a replicated 4 × 4 Latin square design with 21-d periods consisting of a 16-d adaptation period followed by a 5-d collection period. The study was conducted over 84 days. There were four dietary treatments in an unstructured treatment design: 1) SFC control (CON) consisting of 70% SFC, 2) solvent extracted germ meal (SEM), 3) dried corn bran (BRAN), and mixed steep (STEEP), included at 40% of diet dry matter with 40% SFC (Table 3.1). All the dietary treatments contained 15% corn silage and 5% supplement. All supplements were formulated to include 33 mg/kg of monensin (Rumensin, Elanco Animal Health) and 9.8 mg/kg of tylosin (Tylan, Elanco Animal Health).

Diets were mixed twice weekly in a stationary ribbon mixer (model S-5 Mixer; H.C. Davis, Inc., Bonner Springs, KS) and stored in 200 L barrels. The barrels were stored in a cooler held at 4°C to ensure diet quality was maintained. Diets were offered twice daily in amounts following *ad libitum* intake; 60% was fed at 0700 h and 40% was fed at 1300 h. Feed refusals were removed before feeding at 0700 h. Refusals collected from d 18 and 19 were dried in a forced air oven at 60°C (Model LBB2-21-1, Despatch, Minneapolis, MN) for 48 h (AOAC, 1999, Method 935.29) to determine DM content and then saved for further nutrient analysis. Individual feed ingredients were dried in a 60°C forced air oven weekly to ensure that accurate DMs were used when mixing dietary treatments.

Steers were individually fed in 3.7 m x 1.8 m rubber slatted pens in a 20°C controlled room with 12 h of light and 12 h of dark. The diets differed greatly in nutrient profiles which resulted in difficult transitions from one period to the next in a Latin square design. Therefore, diets were transitioned between periods over the course of 7 d during the adaptation period by mixing the previous treatment diet with the current treatment diet. On day 1 of the period, 75% of the daily DM offered was the previous treatment diet and 25% was the current treatment. On days 2, 3, and 4 a 50/50 blend of the previous treatment diet and current treatment diet was fed. On days 5, 6, and 7, 25% of total DM offered was the previous treatment diet and 75% was the current treatment diet. On day 8 and the remainder of the period, each steer was fed 100% of DM offered as their assigned treatment diet for the period.

Individual ingredient samples were collected before to mixing diets for the collection period, lyophilized (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis,

MO), ground through a Wiley mill using a 1-mm screen, and composited by period. Ort samples were collected on d 16 to 19, weighed, and subsampled to determine nutrient intake. The subsample of orts were dried in a forced-air oven at 60°C (Model LBB2-21-1, Despatch, Minneapolis, MN) for 48 h (AOAC, 1999; Method 4.1.03), ground through a Wiley mill using a 1-mm screen and composited by steer within collection period. Additionally, feed ingredient and ort period composites were ground through a 0.5-mm screen (Cyclotec 1093, Foss, Hillerod, Denmark) for starch analysis and neutral detergent fiber (NDF) analysis for high starch samples. Feed ingredient and ort samples were analyzed for lab DM, organic matter (OM; AOAC, 1999, Method 4.1.10), NDF, and total starch content. (Megazyme International, AOAC International, 2000; Method 996.11; AACC Method 76.13). Lab DM was determined by placing samples in a 100°C forced-air oven for 24 h. Ash was determined by placing samples in a muffle furnace for 6 h at 600°C. Neutral detergent fiber analysis was conducted using the procedure described by Van Soest et al. (1991). All NDF analyses included the addition of 2 doses (0.5 mL/dose) of heat stable alpha amylase (Catalog # FAA, Ankom Technologies, Macedon, NY) and 0.5 g of sodium sulfite during the hour reflux in neutral detergent solution. Additionally, ingredient samples were analyzed for crude protein and gross energy. Crude protein was determined by using a combustion chamber (FlashSmart N/Protein Analyzer CE Elantech, Inc. Lakewood, NJ; AOAC, 1999; method 990.03). Gross energy (GE) was determined by bomb calorimetry (Parr 6400 Automatic Isoperibol Calorimeter, Parr Instrument Co., Moline, IL). Liquid steep samples were sent to a commercial laboratory for DM, OM, starch, and CP analysis (Ward Laboratories, Kearney, NE).

Fecal output was estimated by dosing with a 10 g bolus of titanium dioxide twice daily into the rumen in a gel cap. Cattle were dosed at 0700 and 1700 h on d 7 through d 20 to provide a total of 20 g/d. Fecal grab samples (approximately 300 g) were collected for 2 days (d 19 and 20) at 0700, 1100, 1500, 1900, 2300, and 0300 h. Fecal samples were composited by day (wet weight basis) within steer, lyophilized (Virtis Freezemobile 25ES, Life Scientific, Inc., St. Louis, MO), ground through a Wiley Mill (No. 4, Thomas Scientific, Swedesboro, New Jersey) using a 1-mm screen, and composited by steer within collection period. Period fecal composites were ground through a 0.5-mm screen (Cyclotec 1093, Foss, Hillerod, Denmark) for starch and titanium dioxide analysis. Period fecal samples were analyzed for DM, OM, NDF, starch, and GE using the same procedures as described previously. Furthermore, fecal samples were analyzed for titanium dioxide to determine fecal output (Myers, et al., 2004). Concentration of titanium dioxide was then used to calculate fecal DM output using the following equation: [g marker dosed per day) / (concentration of marker in feces)]. Total tract digestibility was calculated using the following equation: [(g of nutrient fed – g of nutrient refused – g of nutrient in the feces) / (g of nutrient fed – g of nutrient refused)] x 100. Gross energy (GE) was determined by bomb calorimetry (Parr 6400 Automatic Isoperibol Calorimeter, Parr Instrument Co., Moline, IL). Gross energy values from the fecal and ingredient samples were used to calculate digestible energy (DE), by subtracting fecal energy from total energy intake.

Rumen pH was monitored using SmaXtec (Graz, Austria) remote monitoring system. Probes were first activated in a pH 7.00 buffer then submerged into the rumen and then into the reticulum on the first day of the experiment. The probes remained in the

reticulum until the last day of the experiment, a total of 126 d. Ruminal pH was monitored continuously, with one reading every 10 minutes. Recorded data were continuously transmitted to the SmaXtec base station, then transmitted to the SmaXtec software on the computer. Ruminal pH data were analyzed for d 16 through 20 to capture the collection period and get four full days of rumen pH measurements. Measurements for ruminal pH include average pH, minimum and maximum pH, pH magnitude, and pH variance. Ruminal pH variance was calculated using the standard deviation of daily ruminal. Rumination was monitored using sensor ear-tags (Cow Manager, The Netherlands) based on ear movement via a three-dimensional accelerometer. The number of minutes spent ruminating per day and eating per day were predicted using the sensor ear tags.

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc.) with period, treatment, and steer within square as fixed effects. Ruminal pH was analyzed using the MIXED procedure of SAS with treatment, hour, treatment by hour interaction included in the model and hour being considered a repeated measure. Six covariate structures were tested, and the structure with the lowest Bayesian information criterion were determined to be the best fit. The Toeplitz covariate structure provided the best fit for ruminal pH. Probabilities less than or equal to alpha ($P \leq 0.05$) were considered significant, with tendencies acknowledged at *P*-values between 0.05 and 0.10.

Results and Discussion

No dietary treatment effects were observed for DM or OM intake ($P \geq 0.51$; Table 3.3). Scott et al. (1998) also observed no differences in DMI with the addition of bran or steep alone or in combination at inclusions of 15 and 30% of the diet DM in a digestion trial. However, in a prior feedlot trial, Scott et al. (1997) observed an increase in DMI as bran inclusion increased in the diet up to 30% and a reduction in DMI as the steep inclusion increased in the diet up to 30% when replacing DRC. The differences in DMI associated with the addition of bran and steep is likely due to a combination of energy density of the diet and acidosis concerns. The energy density of bran is lower compared to DRC; thus, cattle are consuming more feed to achieve the same energy intake. Additionally, bran displaces rapidly degradable starch with highly digestible fiber, which reduces the acid load and consequently helps control ruminal pH and acidosis. Furthermore, the energy density of steep is greater compared to DRC; therefore, cattle are consuming less feed to achieve the same energy intake. Steep has a low pH (4.0-4.5) and contains appreciable amounts of lactic acid, which increases the potential for acidosis. Due to the higher inclusion of bran and steep in the current study, a difference in DMI would be expected due to differences in digestible energy content of bran (2.92 Mcal/kg) and steep (3.58 Mcal/kg).

Dry matter and OM excreted were greater for BRAN ($P < 0.01$) with no differences among CON, SEM, or STEEP. Thus, DM and OM digestibility for BRAN was lowest, intermediate for the SEM, and greatest for the CON and STEEP ($P < 0.01$). The reduction in DM digestibility of the BRAN treatment has been observed previously and was contributed to corn bran being less digestible than the corn it replaced (Scott et

al., 1998). Additionally, Herold et al. (1998) observed a linear decrease in DM and OM digestibility compared to a DRC control when SEM was included in the diet from 13.7 to 81.8% of diet DM. This was attributed to differences in ruminal digestibility of SEM and DRC due to particle size. Solvent-extracted germ meal is smaller in particle size compared to DRC and therefore rumen retention time could be decreased resulting in less extensive digestion.

Neutral detergent fiber intake was greatest for BRAN, intermediate for SEM, and lowest for CON and STEEP ($P < 0.01$). The difference in NDF intake is related to differences in NDF content of the diets with BRAN having the highest NDF content (32.2%), intermediate for SEM (23.5%), and lowest for CON and STEEP (10.6 and 8.0%). Neutral detergent fiber excreted was greatest for BRAN and not different among SEM, CON, or STEEP ($P < 0.01$). Neutral detergent fiber digestibility was least for CON and intermediate for BRAN and STEEP ($P = 0.02$) with a tendency for SEM to be greater in NDF digestibility ($P = 0.07$). Starch intake was greatest for the CON because of 40% greater SFC inclusion in the diet compared to SEM, BRAN, and STEEP which were not different in starch intake ($P < 0.01$). It is important to note that SEM and bran are not devoid of starch. In fact, bran and SEM is 12.41 and 21.07% starch, respectively (Table 3.2). No differences in starch excretion or starch digestibility were observed among treatments ($P \geq 0.16$). Apparent energy digestibility was greatest for STEEP and CON (85.6 and 81.2%; $P < 0.01$), although there was no difference between CON and SEM (76.6%). The BRAN treatment had the lowest apparent energy digestibility (68.0%; $P < 0.01$). Furthermore, cattle fed STEEP consumed the greatest amount of energy per day, with CON being intermediate, and SEM and BRAN being the lowest ($P < 0.01$).

Digestible energy (Mcal/kg) was greatest for STEEP, CON, and SEM, which were not different and lowest for the BRAN treatment ($P < 0.01$).

Physical and digestion characteristics

The physical characteristics of bran, steep, and SEM are also important to consider in addition to the digestion characteristics, although they were not assessed in the current experiment. Steep is a liquid feed, making it difficult to transport, store, and mix in large quantities. Additionally, high inclusions of steep without corn bran and SEM may cause mineral imbalances due to high levels of phosphorus, magnesium, sulfur, sodium, and potassium. As a result, steep is often formulated at low inclusions when fed as an individual ingredient. Steep has a high energy content and is high in protein, especially rumen degradable protein, but low in fiber content. In contrast, corn bran is relatively low in protein, but a highly digestible NDF source. Corn bran is bulky as a single ingredient but is a useful carrier for liquid ingredients such as steep. Corn bran as a carrier allows for higher proportions of steep to be incorporated into the diet due to a reduction in handling, storage, and mixing concerns, in addition to contributing a highly fermentable fiber source. Although not supported by the current experiment, previous data has established the effectiveness of bran in controlling ruminal pH as well (Scott et al., 1998). Solvent-extracted germ meal is a medium protein, highly digestible fiber source and is comprised of dry, finely ground particles. This results in SEM settling in the bunk and sorting by cattle (Herold et al., 1998). Mixing SEM with corn bran and steep diminishes the separation potential. Overall, the combination of bran, steep, and SEM in Sweet Bran alleviates the handling and sorting concerns when the components are fed individually, resulting in a high protein, highly digestible energy product.

Ruminal pH

No differences were observed for minimum, maximum, average, magnitude of change, or variation of ruminal pH among treatments ($P \geq 0.45$; Table 3.4). This is inconsistent with previous research that observed lower average pH when steep was included at 30% of diet DM and higher average pH when bran was included at 15% of diet DM when compared to the average pH of a DRC control (Scott et al., 1998). It is unclear why there were no differences observed for ruminal pH considering the inclusion of the bran and steep were higher than in previous studies.

Rumination

There was a positive correlation between NDF intake and time spent ruminating (Beauchmin, 2018). This observation is consistent with the current study. Steers fed the BRAN diet (3.51 kg/d NDF) spent the greatest amount of time ruminating (expressed as minutes per day) with SEM and CON (1.09 and 2.33 kg/d NDF) being intermediate, and STEEP (0.82 kg/d NDF) ruminating the least ($P < 0.01$; Table 3.5). There were also dietary treatment differences observed for amount of time spent eating (expressed as minutes per day; $P < 0.01$). Cattle fed the BRAN and SEM treatments spent the greatest amount of time eating, with CON being intermediate, and STEEP spending the least amount of time eating.

Conclusion

Steep and SEM have similar energy densities as the SFC control, while bran is high in NDF and has shown to help control ruminal pH, although not supported by the current experiment. These data suggest the physical and nutrient digestibility

characteristics of bran, steep, and SEM are complementary when fed in combination and contribute to the higher energy value of Sweet Bran compared to DRC.

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Table 3.1 Dietary treatment composition (DM basis) and chemical analysis for finishing steers fed individual Sweet Bran components

	Treatment[1]			
Ingredient	**CON**	**SEM**	**BRAN**	**STEEP**
Steam-flaked corn	79	40	40	40
Solvent extracted germ meal	-	40	-	-
Dried corn bran	-	-	40	-
Mixed steep	-	-	-	40
Corn silage	15	15	15	15
Supplement				
Fine ground corn	-	2.83	1.33	1.86
Soybean meal	2.0	-	-	-
Limestone	1.66	1.66	1.66	2.63
Tallow	0.125	0.125	0.125	0.125
Urea	1.5	-	1.5	-
Salt	0.3	0.3	0.3	0.3
Vitamin A-D-E[2]	0.015	0.015	0.015	0.015
Trace mineral[3]	0.050	0.05	0.05	0.05
Rumensin 90	0.017	0.017	0.017	0.017
Tylan 100	0.0035	0.0035	0.0035	0.0035
Chemical composition, %				
Organic matter	96.82	96.33	96.78	91.75
Neutral detergent Fiber	10.59	23.49	32.16	8.00
Crude protein	12.02	14.58	14.04	18.38
Starch	62.59	43.12	39.68	35.39

[1]Treatments included CON- 79% steam-flaked corn control, SEM- 40% solvent extracted germ meal, BRAN- 40% corn bran, STEEP- 40% mixed steep

[2] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin per gram.

[3]Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.29% Mg, 0.2% I, 0.05% Co.

Table 3.2 Nutrient analysis for individual Sweet Bran components

	Ingredient		
	SEM	**Corn bran**	**Mixed steep**
Analyzed nutrient composition, %			
Organic matter	98.04	99.66	89.69
Crude protein	24.19	11.15	33.85
Neutral detergent fiber	41.27	62.3	-
Starch	21.07	12.41	1.55

Table 3.3 Nutrient intake and digestibility of cattle fed individual Sweet Bran components

	Treatment[1]					
Item	**CON**	**SEM**	**BRAN**	**STEEP**	SEM	*P*-value
DM						
Intake, kg/d	11.2	10.8	11.6	11.6	0.43	0.15
Excreted, kg/d	1.99^{a}	2.44^{a}	3.66^{b}	1.82^{a}	0.30	<0.01
Digestibility, %	82.2^{c}	77.5^{b}	69.0^{a}	84.2^{c}	2.02	<0.01
OM						
Intake, kg/d	10.1	10.0	10.7	9.9	0.59	0.51
Excreted, kg/d	1.71^{a}	2.15^{a}	3.34^{b}	1.34^{a}	0.28	<0.01
Digestibility, %	83.0^{c}	78.6^{b}	69.6^{a}	86.3^{c}	1.75	<0.01
NDF						
Intake, kg/d	1.09^{a}	2.33^{b}	3.51^{c}	0.82^{a}	0.15	<0.01
Excreted, kg/d	0.918^{a}	1.09^{a}	2.27^{b}	0.537^{a}	0.22	<0.01
Digestibility, %	21.0^{a}	52.7^{b}	37.0^{b}	37.6^{b}	6.14	0.02
Starch						
Intake, kg/d	6.91^{a}	4.52^{b}	4.31^{b}	4.00^{b}	0.30	<0.01
Excreted, kg/d	0.0350	0.0400	0.0430	0.0250	0.01	0.45
Digestibility, %	99.5	99.1	99.0	99.4	0.19	0.16
DE						
App. Energy Digestibility, %	81.6^{bc}	76.6^{b}	68.0^{a}	85.6^{c}	2.13	<0.01
DE, Mcal/d	38.5^{b}	35.8^{ab}	33.4^{a}	41.6^{c}	1.52	<0.01
DE, Mcal/kg	3.42^{b}	3.32^{b}	2.92^{a}	3.58^{b}	0.91	<0.01

^{abc}Means in a row with different superscripts are different ($P \leq 0.05$)

[1]Treatments included CON, 79% steam- flaked corn (SFC), 15% corn silage, 6% supplement on a dry matter (DM) basis; SEM, 40% solvent extracted germ meal (SEM), 40% SFC, 15% corn silage, 5% supplement on a DM basis; BRAN, 40% dry corn bran, 40% SFC, 15% corn silage, 5% supplement on a DM basis; STEEP, 40% mixed steep 40% SFC, 15% corn silage, 5% supplement on a DM basis.

Table 3.4 Ruminal pH characteristics of cattle fed individual Sweet Bran components

	Treatment[1]					
Item	**CON**	**SEM**	**BRAN**	**STEEP**	SEM	*P* - Value
Minimum pH	5.56	5.41	5.43	5.51	0.11	0.78
Maximum pH	7.07	6.9	6.83	6.95	0.10	0.45
Average pH	6.29	6.22	6.25	6.27	0.06	0.91
pH magnitude	1.51	1.49	1.39	1.44	0.15	0.91
pH variation[2]	0.330	0.310	0.280	0.300	0.04	0.90

[1]Treatments included CON, 79% steam- flaked corn (SFC), 15% corn silage, 6% supplement on a dry matter (DM) basis; SEM, 40% solvent extracted germ meal (SEM), 40% SFC, 15% corn silage, 5% supplement on a DM basis; BRAN, 40% dry corn bran, 40% SFC, 15% corn silage, 5% supplement on a DM basis; STEEP, 40% mixed steep, 40% SFC, 15% corn silage, 5% supplement on a DM basis.

[2]Standard deviation of daily ruminal pH

Table 3.5 Rumination characteristics of cattle fed individual Sweet Bran components

	Treatment[1]					
Item	**CON**	**SEM**	**BRAN**	**STEEP**	SEM	*P* - Value
Ruminating, min/day	265[b]	230[b]	362[c]	125[a]	25.6	<0.01
Eating, min/day	39.3[b]	65.7[c]	74.8[c]	15.7[a]	8.03	<0.01

[abc]Means in a row with different superscripts are different ($P < 0.05$)

[1]Treatments included CON, 79% steam- flaked corn (SFC), 15% corn silage, 6% supplement on a dry matter (DM) basis; SEM, 40% solvent extracted germ meal (SEM), 40% SFC, 15% corn silage, 5% supplement on a DM basis; BRAN, 40% dry corn bran, 40% SFC, 15% corn silage, 5% supplement on a DM basis; STEEP, 40% mixed steep, 40% SFC, 15% corn silage, 5% supplement on a DM basis.