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EVALUATION OF LIGHTER DENSITY FRACTION FROM DRIED DISTILLERS GRAINS WITH SOLUBLES AS A FEEDSTUFF FOR RUMINANTS

By

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The objective of this study was to evaluate the lighter fraction of DDGS as a possible feedstuff for cattle. To accomplish this, a digestion trial was performed to determine nutrient digestibility and crude protein retention by steers consuming the lighter fraction of DDGS. Steers received **L**, a diet containing the lighter fraction of DDGS, **D**, a diet containing whole DDGS, or **C**, a control diet. Steers receiving L consumed less DM than steers receiving D and C. CP retention and digestibilities of DM, OM, ash, NDF, ADF, HC, and energy did not differ among steers in different treatment groups. Fat digestibility was greatest for steers consuming L and D. Steers consuming L digested more CP than steers receiving C, with steers consuming D being in between. These data suggest that the lighter fraction of DDGS can be effectively fed to cattle without adversely affecting digestibility.

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TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The increased ethanol production during the recent decade caused corn prices to increase, produced an abundance of distillers grains, and caused animal scientists to re-evaluate strategies to efficiently feed cattle. Use of corn for ethanol production produced competition for corn usage: corn, a staple for livestock diets, is now being used for ethanol production, creating a dilemma for many cattle producers. One by product of ethanol production is distillers grains which has traditionally been used as a protein source in ruminant diets; however, with the increase of ethanol production, animal scientists have began to investigate how distillers grains can be effectively used, more specifically how distillers grains can be used as an energy source (Klopfenstein et al., 2008).

As a feedstuff, corn dried distillers grains with soluble (**DDGS**) is a source of non-forage fiber that also provides large quantities of protein and energy, with a digestible energy density of 3.63 Mcal/kg and a protein concentration of 29.5% on a dry matter basis (Jurgens and Bregendahl, 2007). Research has shown that distillers grains are a source of rumen undegradable protein (**RUP**; Stock et al., 2000), meaning the RUP in distillers grains is not utilized or digested by rumen microflora and therefore, enters the small intestine where it is digested and absorbed unaltered. Research has also revealed

that distillers grains is a source of rumen protected fat, implying that unsaturated fatty acids are not hydrogenated in the rumen, allowing them to enter the small intestine as unsaturated fatty acids, which are more digestible than their saturated counterparts (Vander Pol et al., 2007). Investigations have also shown that distillers grains are a viable feedstuff for growing cattle. Larson et al. (1993) reported that diets, which incorporated distillers grains, provided more NE_g than corn based diets. Furthermore, Larson et al. (1993) and Vander Pol et al. (2009) found that cattle consuming distillers grains diets had better gain:feed ratios than cattle receiving corn based diets. Given the research that has been conducted on distillers grains and the information obtained, it is evident that distillers grains are a viable feedstuff for cattle; however, for non-ruminant livestock species, distillers grains may not represent as viable of a feedstuff.

Because of the fiber content, distillers grains cannot be efficiently fed to non-ruminant livestock species, leaving distillers grains to be primarily a ruminant feedstuff. However, recently, techniques have been developed which remove most of the fiber component from distillers grains. These processes attempt to create a less-fibrous distillers grains product that can be fed to non-ruminant species. As a consequence, a fibrous co-product is also created which can be fed to ruminants. One such technique is the Elusieve process which removes a fibrous fraction from DDGS after fermentation, producing an "enhanced DDGS" and "elusieve fiber," also known as the lower density fraction or L-fraction (Srinivasan et al., 2005). The "enhanced DDGS," being less fibrous, has potential for becoming a feedstuff for non-ruminant animals, while the L-fraction might be incorporated in ruminant diets. Before the L-fraction is accepted as a

feedstuff for cattle, research must be conducted to determine if the L-fraction can be successfully incorporated into cattle diets. Therefore, the objective of this study was to evaluate the L-fraction as a feedstuff for cattle. To do this a digestion trial was performed to determine the nutrient digestibility and protein utilization of a diet containing the L-fraction when fed to cattle.

CHAPTER II

LITERATURE REVIEW

Fiber Digestion and Metabolism in Ruminants

Fiber Types

Fiber can be defined as structural carbohydrates and plant cell wall constituents that are resistant to degradation by mammalian enzymes (Van Soest, 1994). When this definition is applied to plant material that is utilized as feedstuffs for ruminant species, it, by strict definition, includes other substances, such as galactans, gums and pectins, which are resistant to mammalian degradation enzymes but are not associated with the plant cell wall (Van Soest, 1994). These non-plant cell wall fibrous carbohydrates are more soluble and, therefore, undergo rapid fermentation in the rumen (Van Soest, 1994). The relatively insoluble carbohydrates and other cell wall constituents which make up the remainder of this definition are hemicellulose, cellulose, and lignin, and it is these three fiber types that are focused upon more in the study of ruminant nutrition.

Hemicellulose is a heteropolysaccharide containing a variety of sugars including xylose, glucose, mannose, arabinose, and galactose that are linked by either α-1,4 or β-1,4 glycosidic linkages, with a chain a xylose molecules forming the backbone and other sugars branching out (Beg et al., 2001; Jurgens and Bregendahl, 2007; Kulkarni et al.,

1999). Located in plant cell walls, hemicellulose is covalently linked to lignin and non-covalently interacts with cellulose, and it is proposed that this arrangement is crucial in maintaining structural integrity within in the cell wall (Uffen, 1997). Hemicellulose is relatively more soluble than cellulose and lignin and is, consequently, more digestible; however, as the plant matures, the hemicellulose becomes less digestible (Van Soest, 1967).

In contrast to hemicellulose, cellulose is a homo-polysaccharide found in plant cell walls that comprises 25% to 30% of fibrous plants and consists of up to 10,000 glucose monomers linked by β- 1-4 glycosidic linkages. These linkages impart structural integrity to cellulose and make it resistant to degradation unless acted upon by cellulase enzymes (Pond et al., 2005; Schwarz, 2001). However, these cellulases are not produced by ruminants, but they are synthesized by microbes found in the rumen (Pond et al., 2005). Cellulose is less soluble and therefore less digestible than hemicellulose, but cellulose is more digestible when compared to lignin. Like hemicellulose, cellulose tends to become less digestible as the plant matures (Van Soest, 1967).

Lignin is a polymer of phenylpropane that is found in the plant cell wall and by definition is a component of plant fiber; however, it is not a carbohydrate, yet it plays a vital role in the digestibility of plant material for ruminants (Jurgens and Bregendahl, 2007; Van Soest, 1994). More specifically, lignin, also known as Klason Lignin, is that fibrous portion of the plant material that remains after all other fibrous carbohydrates have been sequentially extracted by solvents and the plant material has been subjected to treatment with 72 % sulfuric acid (Van Soest, 1994). Lignin that is obtained and

measured via the Klason method will inevitably contain some amount of nitrogen since protein cannot be extracted in this manner (Van Soest, 1994). Nitrogen concentrations in lignin range from 1.5 % to 2% for grasses and legumes even with protease treatment; this nitrogen is trapped within the structure of lignin and unavailable to the animal (Van Soest, 1994). While it has no nutritional value, lignin is an extremely important factor to consider in ruminant nutrition. In the plant cell wall, lignin encases cellulose and hemicellulose to impart structural rigidity to the plant; however, since lignin is indigestible, even by rumen microbes, its presence can severely impair the digestibility of plant based feeds (Jurgens and Bregendahl, 2007; Van Soest, 1994).

Microbial Attachment and Fibrolytic Activity

The ability to effectively utilize fiber as a nutrient source is a characteristic which separates ruminants from most other mammals. However, fiber digestion is not accomplished by the ruminant, but rather, fiber is digested by microorganisms which are present in the rumen compartment of the stomach (Pond et al., 2005).

Microorganisms in the rumen can be roughly separated into three categories: 1) those that are freely suspended in rumen fluid, 2) those that are slightly attached to ingested feed particles, and 3) those are completely associated with the ingested feed particles (McAllister et al., 1994). Microbial attachment to feed particles is vital for fiber digestion, as well as other nutrient digestion. Craig et al. (1987) observed that the majority of microorganisms in the rumen, when alfalfa hay was provided, were associated with feed particles. Similarly, Williams and Strachan (1984) separated rumen microorganisms and reported that microorganisms associated with feed particles had a

greater enzymatic activity compared to those that were freely suspended in the rumen fluid. Furthermore, Minato et al. (1966) demonstrated that feed associated ruminal microorganisms had a greater cellulolytic activity than those not attached to feed particles. The information provided by Craig et al. (1987), Williams and Strachan (1984), and Minato et al. (1966) conveys that the majority of fiber digestion in the rumen is accomplished by microorganisms that are firmly attached to ingested feed particles.

Microbial attachment to feed particles is imperative for fiber digestion to occur in the rumen; however, once microorganisms attach to the feed particles, digestion cannot proceed until barriers on the plant material's surface are compromised and penetrated (McAllister et al., 1994). Once the rumen microbes have penetrated or circumvented the plant material barriers, digestion of fibrous material is accomplished by digestive enzymes which are excreted by the microorganisms. Of the plant fiber components discussed previously, only hemicellulose and cellulose are susceptible to microbial degradation, leaving lignin completely undigested (Van Soest, 1994).

For hemicellulose, multiple enzymes exist and must work concertedly to hydrolyze hemicellulose to yield its monomer components (Beauchemin et al., 2003). Table 2.1 summarizes the enzymes needed to hydrolyze hemicellulose. There are two main categories of hemicellulolytic enzymes: xylanases and side chain enzymes; in the degradation process of hemicellulose, endoxylanase breaks the linkages between the xylose molecules of the xylose backbone to yield shorter xylo-oligosaccharides or acetylated polymers (Juhasz et al., 2005; Kulkarni et al., 1999). As endoxylanase yields shorter xylo-oligosaccharides, the side chain enzymes begin releasing monomer sugars

Table 2.1. Enzymes needed for the degradation of hemicellulose and corresponding Enzyme Commission (**E.C**.) Number.

Types	Enzymes	E.C. Number
Xylanases	**Endoxylanase**	**3.2.1.8**
	β-1,4-xylosidase	**3.2.1.37**
Side Chain Enzymes	**β-mannosidase**	**3.2.1.25**
	α-L-arabinofuranosidase	**3.2.1.55**
	α-D-glucuronidase	**3.2.1.139**
	α-D-galactosidase	**3.2.1.22**
	Acetyl xylan esterases	**3.1.1.72**
	Ferulic acid esterase	**3.1.1.73**

Adapted from Beauchemin et al., 2003.

from the side chains (Beg et al., 2001). The shorter xylo-oligosaccharides and acetylated polymers that are released as a result of the catalytic properties of endoxylanase are hydrolyzed by either β-1,4-xylosidase or acetyl xylan esterase, respectively, to yield free monomer molecules of xylose (Beg et al., 2001; Juhasz et al., 2005).

Just like hemicellulose, cellulose necessitates multiple enzymes (Table 2.2) for its degradation; these enzymes also work together to synergistically yield free glucose from the cellulose molecule (Bayer et al., 1998; Beauchemin et al., 2003; Beguin and Lemaire, 1996; Lynd et al., 2002). All cellulases degrade cellulose by hydrolyzing the β-1,4 bonds that join the glucose monomer units (Schwarz, 2001). However, before hydrolysis can occur, the cellulase must bind to the cellulose substrate via a carbohydrate binding domain (Bayer et al., 1998; Lynd et al., 2002; Schwarz, 2001). The carbohydrate binding domain is a region on cellulase which seemingly acts concertedly with the enzyme's active site to hydrolyze cellulose (Bayer et al., 1998; Lynd et al., 2002; Schwarz, 2001).

Table 2.2. Enzymes involved in the degradation of cellulose and corresponding Enzyme Commission (**E.C.**) Number.

Types	Enzymes	E.C. Number
Endocellulase	**Endoglucanase**	**3.2.1.4**
	Endo-β-1,4-glucanase	
	Carboxymethylcellulase	
	β-1,4-D-glucan -4-glucanohydrolase	
Exocellulase	**β-1,4-D-glucan cellobiohydrolase**	**3.2.1.91**
	Exoglucanase	
	Exo- β-1,4-glucanase	
	β-1,4-D-glucan glucanohydrolase	**3.2.1.74**
β-glucosidase	**Cellobiase**	**3.2.1.21**
	Glucohydrolase	

Adapted from Beauchemin et al., 2003; Lynd et al., 2002; Schwarz, 2001.

In such a proposed mechanism, the carbohydrate binding domain binds to the cellulose substrate, orienting the substrate so that it is in close proximity to the catalytic domain of the enzyme which then hydrolyzes the β-1,4 bond (Bayer et al., 1998; Lynd et al., 2002; Schwarz, 2001). It has been demonstrated that without the carbohydrate binding domain, cellulose hydrolysis would diminish because only the most available binding sites on the substrate could be utilized, and these available binding sites would quickly be exhausted causing cellulase activity to cease (Stahlberg et al., 1991). Just like hemicellulases, cellulases concertedly hydrolyze cellulose to yield free glucose. In this synergistic model of cellulose break down, endocellulases break the internal β-1,4 bonds between glucose molecules of the cellulose chain; this decreases the amount of polymerization present in the chain and releases smaller chains of β-1,4 linked glucose units (Lynd et al., 2002).

The smaller cellulose chains are then bound by an exocellulase which hydrolyzes the β-1,4 linkage at one or both ends of the cellulose chain releasing a molecule of two β-1,4 linked glucose units known as cellobiose, or they release a free unit of glucose (Lynd et al., 2002; Schwarz, 2001). Upon release of cellobiose, β-glucosidases complete the break down of cellulose by cleaving the β-1,4 bond of cellobiose, yielding two free glucose units (Schwarz, 2001).

Microbial Metabolism: Volatile Fatty Acid Production

After cellulose and hemicelloluse are completely hydrolyzed, their monomer components can be utilized as substrates in ruminal microbial metabolism. As a by-product of the microbial utilization of these substrates volatile fatty acids are produced and serve as the primary energy source for ruminant species. Glucose from cellulose and hemicellulose and galactose and mannose from hemicellulose can be used by the rumen microflora as glycolytic substrates. However, arabinose and xylose must first enter the pentose phosphate pathway before entering glycolysis. The end-product of glycolysis is pyruvate which is further metabolized to volatile fatty acids, namely acetate, propionate, and butyrate (Jurgens and Bregendahl, 2007; White, 2000). Pyruvate is a common intermediate for the production of all three primary volatile fatty acids; depending upon the bacterial species present and other environmental conditions, such as the type of feed being digested and pH of the rumen environment, pyruvate can be slanted toward the predominant production of one particular volatile fatty acid (Jurgens and Bregendahl, 2007; White, 2000).

Volatile Fatty Acid Metabolism and Utilization

After rumen microbial populations have utilized the freed monomer carbohydrates from fiber to produce volatile fatty acids, most of the volatile fatty acids are absorbed by the rumen epithelium and enter hepatic circulation (Church, 1988). Once absorbed, propionate enters hepatic circulation where around 80% of the propionate is taken up by the liver, leaving little propionate left in general circulation (Van Soest, 1994). Being that propionate is the only glucogenic volatile fatty acid, most of the propionate that enters the liver is used for gluconeogenesis; however, it may also enter the citric acid cycle (Church, 1988; Van Soest, 1994). To produce glucose, propionate is first converted to propionyl-CoA and then carboxylated to methylmalonyl-CoA leading to the production of succinyl-CoA through carbon rearrangement reactions (Van Soest, 1994). Once propionate has been converted to succinyl-CoA, through a series of reactions, it is converted to oxaloacetate which can then be used for gluconeogenesis. Similarly, if propionate is to be utilized in the citric acid cycle, it must be converted to succinyl-CoA (Church, 1988). Once again, succinyl-CoA is converted, through a series of reactions, to oxaloacetate which can condense with acetyl-CoA to begin a new cycle of the citric acid cycle (Van Soest, 1994). Investigations have revealed that around 50 % of the propionate is utilized for glucose production (Annison and Armstrong, 1970, as reviewed by Van Soest, 1994); however, that estimate is thought to be underestimated and is probably closer to 90 % (Steinhour and Bauman, 1986, as reviewed by Van Soest, 1994).

Acetate is the volatile fatty acid that is produced in the largest quantities through rumen fermentation and is the compound that is absorbed the most through the rumen (Van Soest, 1994). It serves as the major energy source and primary precursor for lipogenesis in the ruminant animal (Van Soest, 1994). After absorption, acetate enters hepatic circulation, traveling to the liver, but most escapes the liver unchanged, leading to 90 % of the volatile fatty acid concentration in peripheral circulation being acetate (Church, 1988; Van Soest, 1994). Once in general circulation, acetate is taken up by tissue cells where it is converted to acetyl-CoA via acetyl-CoA synthase (Church, 1988). Condensing with oxaloacetate, the acetyl-CoA enters the citric acid cycle, where it yields a majority of the energy supply for the ruminant animal (Van Soest, 1994). Given that acetate is the main lipogenic precursor in ruminant animals, the acetyl-CoA, produced from acetate, can be used directly for fatty acid synthesis or carboxylated to malonyl-CoA which also serves as a substrate for fatty acid synthesis (Van Soest, 1994).

Most of the butyrate that is absorbed through the rumen epithelium is converted to ketone bodies by the rumen epithelium, namely acetoacetate and β-hydroxybutyrate with β-hydroxybutyrate representing more than 80% of the ketones that are formed (Church, 1988; Van Soest, 1994). β-hydroxybutyrate can be utilized as an energy source by cardiac and skeletal muscle and as a precursor for fatty acid synthesis in adipose tissue and mammary gland tissue (Church, 1988). The little butyrate that is not converted to ketone bodies by rumen epithelium enters hepatic circulation and metabolized by the liver to yield acetyl-CoA which is used for fatty acid synthesis or energy production via the citric acid cycle (Church, 1988; Van Soest, 1994).

Factors Affecting Fiber Digestion in Ruminants

Ruminal fiber digestion is not the same for all situations. Often times, many factors influence how well fiber is digested and metabolized by rumen microflora. Investigations have demonstrated that pH of the rumen environment, particle size of ingested feed, and the presence of readily fermentable carbohydrates all influence the extent to which fiber is digested in the rumen.

Ruminal pH does not hold constant for extended periods of time. Fluctuations occur depending on the type of diet consumed (Hoover, 1986); however, optimal pH for rumen fermentation has been estimated to range from 6.1 to 6.7 (Cardozo et al., 2000). Deviations from this optimal pH range can negatively impact feed digestion; specifically, depressions in pH have been known to decrease fiber digestion (Hoover, 1986) . Hoover et al. (1984) assessed pH effect on ruminal digestion and found that at pH 4.5 and 5.5 there was little fiber digestion; however, when pH was increased to 6.5, fiber digestion was significantly increased, yet when pH increased to 7.5, fiber digestion was decreased. In 2008, Cerranto-Sanchez et al. noted the effects of pH on fiber digestion. Evaluating the effect of extent and duration of pH shifts on rumen digestion, Cerranto-Sanchez et al. (2008) reported that in dual-flow continuous culture vessels, subjection to 4 h/d of a pH of 5.1 tended to reduce neutral detergent fiber (**NDF**) digestion from 33.8 % (at pH 6.4) to 25.6%. Likewise, Calsamiglia et al. (2008) evaluated the effect that ruminal pH had on fiber digestion in dual-flow continuous culture fermenters. The authors found that when pH was held at 4.9, NDF digestion was less than 5%; however, when the pH was incrementally increased, NDF digestion increased as well, with a pH of 6.7 yielding an

NDF digestion coefficient of 39% (Calsamiglia et al., 2008). When the pH was further increased to 7.0, NDF digestion began to decrease, illustrating that an increased pH may also be detrimental to NDF digestion as well as decreases in pH (Calsamiglia et al., 2008). From these studies, it is evident that ruminal fiber digestion is optimized when the rumen pH is between 6.4 and 6.7, and if the pH is outside of this range, ruminal fiber digestion will suffer.

One cause of ruminal pH decline is the increased presence of readily fermentable carbohydrates (**RFC**), and the increased presence of RFC has also been demonstrated to depress ruminal fiber digestion (Burroughs et al., 1949; Hoover, 1986). Chappell and Fontenot (1968) reported the effects of different amounts of RFC: they found that when the amount of RFC in the diet was 33% or greater, cellulose digestion was decreased; however, at concentrations less than 33% (8%, 16%, and 32%), cellulose digestibility was unaffected, but there was a trend in depression of cellulose digestion at 16% and 32% RFC concentration. Likewise, Brink and Steele (1985) observed a decrease in ruminal NDF digestion when the concentration of corn in the diet increased. The effect of RFC on ruminal fiber digestion can also be influenced by the source of fiber. Stensig and Robison (1997) noted differences in fiber digestion between alfalfa silage and timothy silage when RFC was added to the diet. As RFC concentration increased in a diet containing alfalfa silage, ruminal NDF digestibility numerically increased; however, when RFC was added to timothy silage based diet, ruminal NDF digestibility numerically decreased (Stensig and Robinson, 1997). It is clear that the addition of RFC to diets has an impact on fiber digestion. From the work of Chappell and Fontenot (1968), it is

evident that RFC begin to negatively impact fiber digestion at concentrations greater than one-third of the diet. Also, there appears to be an effect due to the source of fiber as demonstrated by Stensig and Robison (1997) who noted different effects when RFC was added to diets of either alfalfa silage or timothy silage. A major difference between alfalfa silage and timothy silage is the protein content, lending to the idea that protein content of the fiber source may factor into the effects that RFC has on ruminal fiber digestion.

Another factor that influences ruminal fiber digestibility is particle size of the ingested feed. Comparing the ruminal digestion of fine ground and coarse ground hay, Stokes et al. (1988) noted that there was a trend for ruminal NDF digestion to increase as the particle size increased. Proposing an explanation, Stokes et al. (1988) reported that the coarse ground hay stimulated greater remastication which may have led to a greater ruminal fiber digestion. Bowman and Firkins (1993) found that the rate of NDF and acid detergent fiber (**ADF**) disappearance was greater for forages ground to pass through a 2-mm screen compared to a 5-mm screen *in sacco*; however, the extent of NDF and ADF disappearance was greater for the forage ground through a 5-mm screen. Bowman and Firkins (1993) suggested that the decreased particle size may affect structural influences on digestion. While it may be the case for *in sacco* cases, the decreased ruminal fiber digestion associated with decreased particle size (as described by Stokes et al., 1998) may be due to decreased ruminal stimulation caused by smaller particle size. Likewise, a smaller particle sized feed would remain in the rumen for less amount of time, further decreasing its extent of digestion.

In ruminant nutrition, three fiber types are of importance: hemicellulose, cellulose, and lignin, with hemicellulose and cellulose being the two that can provide nutrients to the animal. No matter the fiber type, fiber digestion is accomplished by microbial populations that are present in the rumen. These microbes attach to the ingested feed and secrete enzymes which hydrolyze the fiber and yield the carbohydrate monomer components which the microbes then utilize for energy. As a result of the microbial metabolism, the carbohydrates are fermented and volatile fatty acids are produced which the ruminant animal then absorbs and metabolizes to satisfy its energy demands. There are factors to consider that affect ruminal fiber digestion, such as pH of the rumen, the presence of readily available carbohydrates, and the size of the ingested feed. As observed by numerous studies, the optimal pH for fiber digestion ranges from 6.4 to 6.7, with pH's outside of this range severely impairing ruminal fiber digestion. The presence of RFC may also severly impair ruminal fiber digestion. One thought is that RFC decreases the pH which negatively affects fiber digestion. Also from the work of Chappell and Fontenot (1968), it is evident that RFC begin to impair fiber digestion when they comprise 33% or more of the diet. Furthermore, protein content of the fiber source may determine whether or not the addition of RFC will impair ruminal fiber digestion. Finally, particle size of ingested feed has been shown to affect ruminal fiber digestion. Smaller particle sizes have been associated with a decrease in ruminal fiber digestion. This may be caused by a smaller particle size not being able to properly stimulate rumen function, or it may be that the smaller particle size remains in the rumen for less amount of time, decreasing the extent of ruminal digestion or both. Overall, fiber digestion and

utilization is a characteristic that is unique to the ruminant animal, and it represents a chief source of nutrient supply that cannot be overlooked in the study of ruminant nutrition.

Distillers Grains

Distillers grains are a by-product of ethanol production, whereby the starch from a grain source is subjected to fermentation by yeast. The resultant products from yeast fermentation of this grain starch are ethanol, carbon dioxide, and whole stillage (Waller et al., 1980). At this point, there are two options for the whole stillage: the grain particles can be removed and dried to yield dried distillers grains (**DDG**) or the whole stillage can be condensed and dried to give dried distillers grains with solubles (Waller et al., 1980). In this process, the majority of the starch from the grain is converted to ethanol, leaving protein, fat, fiber, and minerals left in distillers grains (Klopfenstein et al., 2008). Given that corn is approximately two-thirds starch, when the resultant whole stillage is condensed and dried to form DDGS, the remaining nutrients increase in concentration. In general, protein, fat, fiber and phosphorus concentrations increase 3-fold in corn DDGS, with protein increasing from 10% in the grain to 30% in DDGS, fat increasing from 4% in the grain to 12% in DDGS, NDF increasing from 12% in the grain to 36% in DDGS, and phosphorus increasing from 0.3% in the grain to 0.9% in DDGS (Klopfenstein et al., 2008).

Much of the protein coming from corn is zein protein which has been demonstrated to be undegradable in the rumen (Klopfenstein et al., 2008; Little et al., 1968). Moreover, the fermentation of corn necessitates yeast; to this end, a large amount

of the protein in distillers soluble comes from yeast cell protein, which is also somewhat resistant to rumen degradation (Herold, 1999, as reviewed by Klopfenstein et al., 2008). Additionally, the gluten fraction is not removed from DDGS, providing another source of rumen undegradable protein (Stock et al., 2000). Since DDGS contain three sources of rumen undegradable protein, a large quantity of the protein in DDGS is escape protein which passes through the rumen undegraded (Stock et al., 2000). There has also been evidence to support that the fat in distillers products is somewhat protected against rumen hydrogenation. Vander Pol et al. (2007) found that the fat from diets containing wet distillers grains had a greater total tract fat digestibility than a concentrate diet supplemented with corn oil. Moreover, cattle consuming the wet distillers grains diet had greater concentrations of unsaturated fatty acids in the duodenum, namely more 18:1 trans, 18:1, and 18:2 (Vander Pol et al., 2007). This observation led Vander Pol et al. (2007) to conclude that the fat in distillers products is protected from ruminal hydrogenation. Consequently, a greater amount of unsaturated fat, which is more intestinally digestible than saturated fat, enters the small intestine leading to a greater digestibility coefficient for fat in distillers products (Vander Pol et al., 2007). The NDF in distillers products increases in concentration from the fermentation process; however, its digestion coefficient remains about the same. Lodge et al. (1997) found NDF digestibility coefficients of corn wet distillers grains and corn dried distillers grains to be 77.8 % and 71.7 %, respectively, and Hsu et al. (1987) determined that the NDF digestibility of corn fiber was 79.7 %. Given this information on the nutrient content of distillers products, many studies have been conducted to evaluate distillers grains as a feedstuff. Many of the

studies compare distillers grains to other grain products, compare wet and dry distillers grains, or compare distillers grains from different grain sources.

Distillers Grains Diets vs. Other Grain Diets

Given the recent interest in incorporating distillers byproducts into ruminant diets, many studies have been conducted to compare distillers products to other grain based diets and grain based products (Firkins et al., 1985; Larson et al., 1993; Peter et al., 2000; Vander Pol et al., 2009). Recently in 2009, Vander Pol et al. reported a study in which heifers were fed diets consisting of either 0, 20, or 40 % (DM Basis) wet distillers grains plus soluble. Vander Pol et al. (2009) found that the heifers receiving 20 and 40% wet distillers grains plus soluble had greater gain to feed ratio than the heifers receiving 0% wet distillers grains plus solubles. Similarly, a study conducted by Larson et al. (1993) also evaluated the performance of animals fed diets containing distillers grains. When the diet contained 5.2, 12.6 and 40 % wet distillers byproducts (wet distillers grains and thin stillage) yearlings were 5, 10, and 20 % more efficient and calves were 2, 6, and 14 % more efficient, respectively, compared to animals fed a 79% dry-rolled corn diet (Larson et al., 1993). Additionally, the diets containing wet distillers byproducts provided more net energy for gain than the corn based diet, averaging 169% the energy value of corn when fed to yearlings and 128% the energy value of corn when fed to calves (Larson et al., 1993). This led the authors to conclude that the better efficiency associated with the wet distillers byproducts was due to a more efficient use of energy coming from the wet distillers byproducts diet (Larson et al., 1993). Peter et al. (2000) found that diets supplemented with dried distillers grains had a numerically greater total dietary fiber

digestibility than diets containing dried corn gluten feed or modified corn fiber. Moreover, Firkins et al. (1985) compared the *in situ* digestibility of four different corn grain based products: wet distillers grains (**WDG**), DDG, wet corn gluten feed (**WCGF**) and dried corn gluten feed (**DCGF**). Firkins et al. (1985) reported that the corn gluten feeds had a greater DM and NDF disappearance rate than the distillers products; however, at hours 18 and 27, the extent of NDF disappearance was greater for the distillers products. From these studies (Firkins et al., 1985; Larson et al., 1993; Peter et al., 2000; Vander Pol et al., 2009), one can conclude that distillers byproducts are a viable feedstuff for ruminant animals and can have beneficial effects including better gain to feed ratios (Larson et al., 1993; Vander Pol et al., 2009), greater net energy for gain values (Larson et al., 1993), and greater fiber digestibility (Firkins et al., 1985; Peter et al., 2000).

Wet vs. Dry Distillers Grains

Distillers grains can be purchased and utilized in a dry or wet form. Conventionally, distillers grains have been dried before they have been fed to cattle (Ham et al., 1994); however, drying the distillers grains is a costly process (Klopfenstein et al., 2008). For feedlots that are in proximity to the ethanol plant, it is more economical to utilize the wet distillers grains, but for those feedlots that are farther away, it is more economical to dry the distillers grains before shipping (Klopfenstein et al., 2008). Therefore, since some feedlots use wet distillers grains and some use dry distillers grains, animal scientists have conducted studies that compare these two different types of distillers grains. Recently, Depenbusch et al. (2009) conducted a study to evaluate

distillers grains in steam-flaked corn based feedlot diets. The basal diet was steam-flaked corn and 6% alfalfa hay; this diet was supplemented with either 15 % of dry or wet corn or sorghum distillers grains or no distillers grains at all (Depenbusch et al., 2009). Depenbusch et al. (2009) reported that dry matter intake, average daily gain, gain to feed ratio, and apparent total tract digestibility did not differ between the wet and dry distillers grains; however, other studies have found differences to exist. Mateo et al. (2004) supplemented a basal diet with either 20 or 40% of wet or dry distillers grains. The authors reported that the steers receiving the dried distillers grains diets consumed more dry matter than those consuming wet distillers grains with steers fed 40% wet distillers grains consuming the least amount of dry matter (Mateo et al., 2004). Additionally, Mateo et al. (2004) observed that steers consuming wet distillers grains were more efficient than steers consuming dried distillers grains. Likewise, Ham et al. (1994) conducted a finishing trial in which distillers products (wet and dry) replaced 40 % of the dry-rolled corn. Gains were similar among treatment groups; however, Ham et al. (1994) reported that the cattle fed the wet distillers product consumed less feed and were, therefore, more efficient than their counterparts that consumed dried distillers grains. Depenbusch et al. (2009) found no differences for performance of cattle consuming wet or dry distillers grains; however, Mateo et al. (2004) and Ham et al. (1994) found that cattle consuming the wet product were more efficient than cattle consuming the dry product. These differences may be caused by the amount of corn that was present in the diets. Depenbush et al. (2009) fed diets that ranged from 69.6 to 75.2 % steam-flaked corn while Mateo et al. (2004) fed diets ranging from 43.55% to 64% corn, and Ham et

al. (1994) fed diets that were 41 % corn. The presence of readily fermentable carbohydrates has been known to impact fiber digestion (Burroughs et al., 1949; Brink and Steele, 1985; Chappell and Fontenot, 1968; Hoover, 1986; Stensig and Robinson, 1997). Because NDF concentration is increased in distiller grains, the greater amount of corn in the diets used by Depenbusch et al. (2009) may have impacted the digestion of the distillers grains and thus caused differences in performance between wet and dry types to go unnoticed. Ham et al. (1994) suggested an explanation for the difference in animal performance between wet and dry distillers grains diets: wet distillers grains have a greater moisture content than their dry counterpart; this added moisture may increase the physical size and slow rate of passage. This would explain the decrease in dry matter intake (Mateo et al. 2004; Ham et al., 1994) when cattle consumed the wet distillers grains compared to those consuming the dried product. Consequently, because gain was similar (Ham et al., 1994) between steers consuming either wet or dry distillers grains, efficiency would be greater for cattle consuming the wet product because they are consuming less due to the slowed progression through the gastrointestinal tract. Moreover, because the progression through the gastrointestinal tract might be slowed with wet distillers grains, more nutrients may be digested while less feed is consumed, thus presenting another explanation for the increased efficiency seen with cattle consuming wet distillers grains.

Corn Distillers Grains vs. Sorghum Distillers Grains

Any grain can be fermented to yield ethanol and distillers grains, but most commonly, corn and sorghum are used, with corn being the most utilized grain source

(Depenbusch et al., 2009; Klopfenstein et al., 2008). Both grains yield similar amounts of ethanol, but sorghum is less expensive, and therefore, ethanol producers have began using it as a feedstock (Klopfenstein et al., 2008). Consequently, studies have been conducted which compare distillers grains from corn and sorghum. Corn grain has a NEg value of 1.35 Mcal/kg while sorghum grain has a NEg value of 1.09 Mcal/kg (Jurgens and Bregendahl, 2007); this difference in energy is also present in the distillers grains that result from the fermenting these two grains. Al-Suwaiegh et al. (2002) reported NEg values for corn wet distillers grains and sorghum wet distillers grains to be 2.00 and 1.87 Mcal/kg, respectively. The difference in NEg content between corn and sorghum distillers grains may be due to the fact that corn grain has more fat than sorghum grain (Jurgens and Bregendahl, 2007). Corn has an ether extract content of 3.9%, and sorghum has an ether extract content of 2.8% (Jurgens and Bregendahl, 2007), so when distillers grains are formed from these two grain sources, the fat content increases 3-fold, giving corn distillers grains a fat content of approximately 11.7 % and sorghum distillers grains a fat content of 8.4%. This large difference in fat content may explain why corn distillers grains has a greater NEg value than sorghum distillers grains. Using sixteen crossbred lambs, Lodge et al. (1997) compared sorghum distillers grains to corn distillers grains by feeding diets that contain 80% distillers byproducts. When comparing dry products, sorghum dried distillers grains had numerically greater apparent organic matter and NDF digestion coefficients and statistically significant greater apparent nitrogen and true nitrogen digestion coefficients; however, wet corn distillers grains had a numerically greater NDF digestion coefficient and significantly greater apparent organic matter,

apparent nitrogen and true nitrogen digestibility coefficients than wet sorghum distillers grains (Lodge et al., 1997). From this study, it appears that presence of moisture has an effect on which grain source is best: if feeding wet distillers grains, then corn distillers grains may have greater feeding value, but if dried distillers grains are to be used, then sorghum distillers grains will have a greater feeding value. Al-Suwaiegh et al. (2002) also compared wet sorghum and corn distillers grains. Using diets that contained 30% of either wet corn or sorghum distillers grains, Al-Suwaiegh et al. (2002) reported that steers consuming the wet sorghum distillers grains diet had a greater dry matter intake than the steers consuming the wet corn distillers grains diet, but steers fed wet sorghum distillers grains did not gain more and were numerically less efficient. Once again the wet corn distillers grains seems to outperform wet sorghum distillers grains. More recently, Depenbusch et al. (Depenbusch et al., 2009) evaluated corn and sorghum distillers grains fed to steers. Dry matter intake, average daily gain, gain to feed ratio, and apparent total tract digestibility did not differ among steers consuming diets containing 15 % of either corn or sorghum distillers grains (Depenbusch et al., 2009). Considering the 3 studies reported, there appears to be some slight differences between corn and sorghum distillers grains. It seems that when wet distillers grains are to be fed, corn based distillers grains are superior to sorghum based ones, but if dry distillers grains are to be fed, then sorghum distillers grains are better; however, Depenbush et al. (2009) found no differences existed. Moreover, little research has been conducted which directly compares sorghum distillers grains to corn distillers grains, so until further investigations are completed, a

definitive conclusion cannot be made regarding which grain source for distillers grains is superior.

Distillers grains are a byproduct of the ethanol industry, and the production of distillers grains will remain for now and the near future. Therefore, animal scientists are striving to determine how this product can be used correctly and efficiently as a livestock feedstuff. From recent work, distillers grains have been shown to provide certain benefits when included in the diet: better gain to feed ratios (Larson et al., 1993; Vander Pol et al., 2009), greater net energy for gain values (Larson et al., 1993), and greater fiber digestibility (Firkins et al., 1985; Peter et al., 2000). While distillers grains may not be the complete answer to the feed vs. fuel dilemma, they have been proven to be viable feedstuff for ruminant species. Establishing distillers grains as an acceptable feedstuff is only one part of the equation; other questions do exist. When determining whether wet or dry distillers grains are to be used, research has demonstrated that wet distillers grains provide better performance results than their dry counterparts (Ham et al., 1994; Mateo et al., 2004). However, deciding which type of distillers grains, corn or sorghum, is a question that is more complex to answer. Some report differences between corn and sorghum distillers grains (Lodge et al., 1997) while others found no differences to exist (Depenbusch et al., 2009). Given this information and given that the ethanol industry will be present for the near future, research is warranted in the area of distillers grains. Even though much research has been conducted, more research is needed to discover how to properly use this by-product as a feedstuff for ruminants, so that a precise application of this feedstuff can be determined.

Nonforage Based Fiber Sources

Nonforage based fiber sources have been utilized as feedstuffs for ruminants for many years, and while some have once been used as a concentrate for their energy and or protein content, nonforage based fiber sources are now being used as a full or partial forage replacement when forage prices are high or when forage is not readily available (Firkins, 1997). There are many sources of nonforage fiber available for use in ruminant diets, with most being a byproduct from some processing technique (Table 2.3). When discussing fiber sources, it is imperative to consider the effectiveness of the fiber. Fiber effectiveness can be defined as the ability to stimulate appropriate amounts of chewing, salivation, and rumination, as well as the capacity to provide energy to the animal (Grant, 1997). The benefits of fiber in a ruminant diet are well known, and without adequate amounts of effective dietary fiber, metabolic disorders, such as acidosis and abomasal displacement, are the consequence (Clark and Armentano, 1993). Generally, nonforage based fiber sources are considered to possess less effective fiber than their forage based counter parts (Sarwar et al., 1991). Being a less effective source of fiber may stem from the fact that most non-forage based fiber sources are smaller in particle size compared to the larger forage fiber sources, leading to a decreased need for chewing and ruminating (Allen and Grant, 2000). However, current research has demonstrated that nonforage based fiber sources can be effectively included in ruminant diets without severely compromising the nutritional status of the animal.

Much research has been conducted to evaluate the fiber effectiveness of nonforage based fiber sources for dairy cattle diets. In doing so, many dairy nutritionists

Table 2.3. Common nonforage based feedstuffs fed to ruminants and their corresponding source.

Nonforage Fiber Feedstuff	Source
Corn Bran	**Dry Corn Milling**
Corn Gluten Meal	**Wet Corn Milling**
Corn Gluten Feed	**Wet Corn Milling**
Dried and Wet Distillers Grains	**Grain Fermentation**
Wheat Bran	**Wheat Milling**
Wheat Middlings	**Wheat Milling**
Oat Hulls	**Oat Kernel Separation**
Brewer's Dried Grains	**Barley Malt**
Rice Hulls	**Rice Processing**
Soyhulls	**Soybean Processing**
Cotton Gin Mote	**Cotton Ginning**

(Jurgens and Bregendahl, 2007)

have chosen to observe the nonforage fiber source's ability to stimilute chewing and rumination as well as the feedstuff's ability to maintain normal milk fat percentage. Allen and Grant (2000) evaluated diets containing different sources of fiber with respect to chewing and rumination activities. Two diets, a decreased and an increased NDF diet, had alfalfa silage as their source of fiber, another diet had alfalfa silage and wet corn gluten feed as the fiber sources, and the final diet had alfalfa silage, wet corn gluten feed, and alfalfa hay as the fiber sources (Allen and Grant, 2000). Noting differences among dietary treatments, Allen and Grant (2000) reported that the wet corn gluten feed diet was not as successful in stimulating rumination when compared to the increased fiber diet. However, when 47% of the alfalfa silage was replaced with alfalfa hay, the wet corn

gluten feed diet stimulated the same amount of rumination as the all alfalfa silage diet. Likewise, the wet corn gluten feed diet did not stimulate as much chewing activity as the increased fiber diet; however, the addition of hay to the wet corn gluten feed diet did increase chewing activity but not to same magnitude as the high fiber diet (Allen and Grant, 2000). This illustrates that particle size is critical for stimulating rumination and chewing. The decreased particle size of the corn gluten feed did not stimulate as much rumination as the all alfalfa silage diet; however, the addition of alfalfa hay, a feedstuff with larger particle size, was sufficient enough to stimulate rumination in the cows fed the wet corn gluten feed diet. Additionally, Allen and Grant (2000) reported that the wet corn gluten feed diets were able to maintain the same milk fat percentage as the all alfalfa silage diet. Based on wet corn gluten feed's ability to maintain milk fat and somewhat stimulate rumination, Allen and Grant (2000) were able to assign wet corn gluten feed an effective NDF factor of 0.74 when alfalfa silage is considered to be 1.00. Clark and Armentano (1993) also evaluated nonforage based fiber sources by conducting a study during which the effectiveness of whole cottonseed and distillers grains was determined by replacing NDF from alfalfa haylage. In the nonforage fiber diets, 6% of the DM was from either whole cottonseed or distillers grains to yield a diet with 19% DM from NDF; these two diets were then compared to an alfalfa diet (19% DM from alfalfa haylage NDF) and a basal diet (13% DM from alfalfa haylage NDF). When measuring milk fat concentration, Clark and Armentano (1993) reported no differences among the alfalfa haylage and nonforage fiber diets, and suggested that whole cottonseed and distillers grains were viable substitutes for alfalfa haylage in lactating dairy cow diets. Clark and

Armentano (1993) also reported the differences in chewing and ruminating activity: the whole cottonseed diet was more effective in stimulating chewing activity and rumination than the basal diet and the distillers grains diet, but was not different than the alfalfa haylage diet with respect to chewing and rumination activity. This further illustrates the effect that particle size has on chewing time and rumination; distillers grains are smaller in size compared to alfalfa haylage and whole cottonseed, and they were not as effective at stimulating chewing and rumination. However, given that both distillers grains and whole cottonseed were able to maintain milk fat content, they can serve as effective fiber sources in lactating dairy cow diets lacking fiber (Clark and Armentano, 1993). In addition, Depies and Armentano (1995) reported that corn cobs and wheat middlings were not effective at stimulating chewing and ruminating activity but were effective at producing milk fat percentages similar to an alfalfa silage diet.

It has been demonstrated that nonforage fiber sources are slightly effective at stimulating chewing and rumination and exceptionally effective at maintaining milk fat content (Allen and Grant, 2000; Clark and Armentano, 1993; Depies and Armentano, 1995), but work has also been conducted which has yielded the digestibility characteristics of nonforage fiber sources. In 1987, Hsu et al. (1987) evaluated the *in situ* ruminal disappearance of some common nonforage fiber sources: corn fiber, cottonseed hulls, oat hulls, and soyhulls. At 12 hr, the ranking for extent of dry matter disappearance was soyhulls > oat hulls > corn fiber > cottonseed hulls; however, at 27 h and 36 h, the ranking for extent of dry matter disappearance was soyhulls > corn fiber > oat hulls > cottonseed hulls (Hsu et al., 1987). Hsu et al. (1987) suggested that the different rankings

at 12 h compared to 27 and 36 h could be due to the rate at which corn fiber and oat hulls are fermented. Hsu et al. (1987) summarized data and reported that oat starch granules are much finer than corn starch granules; therefore, oat starch granules would be more rapidly fermented during the first 12 hours compared to the corn starch granules. The greater extent of disappearance of oat hulls at 12 h was due to a smaller particle size which fermented at a faster rate than the corn fiber, suggesting that oat hulls ferment to a greater extent than corn fiber only up to 12 hours, but after 12 hours, corn fiber is degraded by the rumen to a greater extent (Hsu et al., 1987). Hsu et al. (1987) also evaluated the total tract dry matter digestibility of corn fiber, soyhulls, oat hulls, and cottonseed hulls and found that corn fiber and soyhulls did not differ but were more digestible than oat hulls which were more digestible than cottonseed hulls. Neutral detergent fiber total tract digestibility did not differ between corn fiber and soyhulls, but corn fiber and soyhulls were more digestible than oat hulls and cottonseed hulls (Hsu et al., 1987).

Still, more research has been conducted to evaluate the effects of replacing forage with nonforage fiber. Using five Holstein heifers with ruminal cannulas and T-cannulas in the proximal duodenum, Sarwar et al. (1991) evaluated the digestion characteristics of corn gluten feed and soyhulls when they replaced 20 and 40 % of the dietary NDF that came from forage. Sarwar et al. (1991) found that replacing forage NDF with either soyhull or corn gluten NDF significantly increased the apparent total tract organic matter digestibility of the diet, even though there were no differences among treatments with respect to ruminal organic matter digestion. Additionally, Sarwar et al. (1991) reported

that total tract organic matter digestibility did not differ between corn gluten feed and soyhulls, but apparent and true ruminal organic matter digestibility were greater for corn gluten feed than soyhulls. Neutral detergent fiber digestion also differed among treatments: replacing forage NDF with corn gluten feed NDF or soyhull NDF significantly increased apparent total tract NDF digestion (Sarwar et al., 1991). Adding to the research which evaluated digestibility of nonforage fiber, Younker et al. (1998) reported the effects of replacing the forage, concentrate, or both portions of the diet with brewers grains. Using four primiparous Holstein cows fitted with a ruminal, proximal duodenal, and distal ileal cannulas, Younker et al. (1998) reported that when brewers grains replaced the concentrate, forage, or both portions of the diet, apparent rumen and apparent total tract organic matter digestibility did not differ. Moreover, ruminal and total tract NDF digestibility were not affected when brewers grains replaced the concentrate, forage, or both portions of the diet, further indicating that brewers grains can successfully replace forage without altering digestibility of the diet. Similarly, Pereira and Armentano (2000) replaced part of the forage and concentrate portions of a forage based fiber diet with wheat middlings, brewers grains, and corn gluten feed and fed this diet to midlactation Holsteins. Compared to the forage based fiber diet, cows consuming the nonforage based fiber diet consumed more dry matter, digested less dry matter, but digested the same percentage of NDF (Pereira and Armentano, 2000), indicating that digestibility of NDF in nonforage fiber sources is comparably to NDF digestibility from forage. In a study that replaced 0, 50 and 100% of the forage with cotton gin mote in a diet fed to steers, Welch (2008) reported differences between nutrient digestibilities.

Organic matter, dry matter, and crude protein digestibility followed a trend in which steers consuming the 0% mote diet digested the most and steers consuming the 50% mote diet digested the least, with steers consuming the 100% mote diet being in between (Welch, 2008). Steers consuming the 0% mote diet digested more NDF and ADF than steers consuming the 50 and 100% mote diets (Welch, 2008). Even though steers consuming the mote diets digested less nutrients than the steers consuming the 0% mote diet, the steers that consumed the 100% mote diet retained the most nitrogen and energy among the treatment groups (Welch, 2008), indicating that cotton gin mote is a viable forage replacement for ruminants. Not only has research been conducted which evaluates the replacement of forage with nonforage fiber, but research has also been conducted which evaluated nonforage fiber sources when replacing the concentrate portion of the diet. Montgomery et al. (2004) compared the effects of replacing approximately half of the concentrate portion of the diet with corn gluten feed. When these diets were fed to Jersey steers, consumption and digestibility of organic matter, NDF, and starch all increased when corn gluten feed replaced the part of the concentrate portion of the diet (Montgomery et al., 2004).

Given the research conducted on nonforage based fiber sources used as feedstuffs for ruminants, the data illustrates that nonforage based fiber sources are viable feedstuffs for ruminants. Even though nonforage based fiber sources may not stimulate chewing and rumination to the degree that forgage fiber does, research has shown that nonforage based fiber does stimulate some chewing and rumination and successfully maintains the milk fat percentage when fed to lactating cows (Allen and Grant, 2000; Clark and Armentano,

1993; Depies and Armentano, 1995), thus establishing nonforage fiber sources as potentially effective sources of fiber for ruminants. Likewise, research has demonstrated that nonforage fiber sources do not negatively impact digestion characteristics when incorporated into ruminant diets. Digestion coefficients for nutrients were either enhanced (Sarwar et al., 1991) or not different (Pereira and Armentano, 2000; Younker et al., 1998) when nonforage fiber replaced dietary fiber from forage sources. More notably, nitrogen retention and energy retention were increased when cotton gin mote was used to replace 100% of the forage in a diet fed to steers (Welch, 2008), thus, further enhancing the argument that nonforage fiber sources are a valuable feedstuff for ruminants. Finally, research illustrated that nonforage fiber sources can replace the concentrate portion of the diet and actually increase certain digestion coefficients (Montgomery et al., 2004). Research has demonstrated that nonforage fiber feedstuffs can be successfully included in ruminant diets. These products have little negative impact on the nutritional status of the animal and, therefore, are a valuable tool for producers to utilize. In situations when forage is limited or not competitively priced, producers can utilize the fiber from these nonforage based products to satisfy the fiber needs of ruminants.

Novel Distillers Grains Processing Techniques

Production of distillers grains increases the fiber concentration of the feedstuff compared to the grain source from which it originated (Klopfenstein et al., 2008); consequently, distillers grains are not as viable of a feedstuff for monogastric animals such as swine and poultry. With ethanol production increasing in popularity, more corn, which is one of the primary feedstuffs for swine and poultry diets, is being used to make

ethanol, leaving less corn for swine and poultry diets and more distillers grains that cannot be as effectively used as a feedstuff for swine and poultry. Because of this paradigm, new technologies have been developed to fractionate distillers grains to yield a less fibrous product that can be effectively fed to poultry and swine (Martinez-Amezcua et al., 2007). Creating these less fibrous distillers grains also creates a by-product which is more fibrous, and this byproduct may provide a new feedstuff for ruminant animals. Three of these novel distillers grains processing techniques are the quick germ, quick fiber (**QGQF**) method, the dry degerm defiber (**3D**) method and the Elusieve process (Martinez-Amezcua et al., 2007). The QGQF process removes fiber from a corn mash prior to fermentation (Singh et al., 1999). The corn is soaked in water to form a mash from which the germ is then removed; then, using density differences, the remaining fiber is separated by increasing the density of the slurry, causing the fiber to float to the top (Singh et al., 1999). After the fiber is removed, the remaining slurry is then subjected to fermentation to produce ethanol and a novel distillers grains product (Martinez-Amezcua et al., 2007). Similarly, the 3D process also removes the fiber from corn before fermentation (Murthy et al., 2006). In this process, corn is first tempered to increase the moisture content which facilitates fractionation; then, the corn is passed through a degerminator which allows for separation of the germ and fiber from the endosperm (Martinez-Amezcua et al., 2007). The mixture is then dried, the fiber and germ are removed using sieving, and the remaining mixture is subjected to fermentation (Martinez-Amezcua et al., 2007).

Contrary to the QGQF and 3D methods which remove the fiber before fermentation, the Elusieve process fractionates dried distillers grains after their production (Srinivasan et al., 2005). The Elusieve process is a combination of two techniques: sieving and elutriation (Srinivasan et al., 2008). Sieving separates the distillers grains particles based on size, while elutriation separates the distillers grains particles based on density, shape, and size by using air (Srinivasan et al., 2005). In this process (Figure 2.1), dried distillers grains are first sieved through a sifter to separate the particles into four different sizes: pan, small, medium and large (Srinivasan et al., 2009). The separated products then enter the elutriation process during which a stream of air is blown up and towards the separated products. At this point, the lighter, less dense, particles are carried up and away, while the heavier, more dense, particles fall downward (Srinivasan et al., 2005). These processes effectively fractionate the dried distillers grains to yield three different products: two less fibrous products (**H-Fraction and Pan DDGS**) and a more fibrous product (**L-Fraction**; Srinivasan et al., 2005). Preliminary laboratory analysis has been performed on the H-fraction , Pan DDGS (Table2.4) and L-fraction (Table 2.5). The initial analysis shows that the three products differ in their nutrient composition: the H-fraction and Pan DDGS contain more crude protein and fat, while the L-fraction contains more fiber from the original distillers grains (Tables 2.4 and2.5). Ultimately, two products can be formed from this process: elusieve fiber and enhanced DDGS (Srinivasan et al., 2008). Elusieve fiber is obtained by mixing all of the L-fractions (small, medium and large) while enhanced DDGS is formed when all three sizes (small, medium and large) of the H-fractions and the Pan DDGS are mixed

together(Srinivasan et al., 2008). Around 30% of the original DDGS is recovered as Pan DDGS, so when the Pan DDGS are mixed with the H-fractions, the less fibrous Pan DDGS helps dilute the NDF content of the H-fractions, creating the less fibrous enhanced DDGS.The enhanced DDGS holds promise in being utilized as feed for poultry and monogastric livestock species due to the decreased NDF content, and preliminary studies

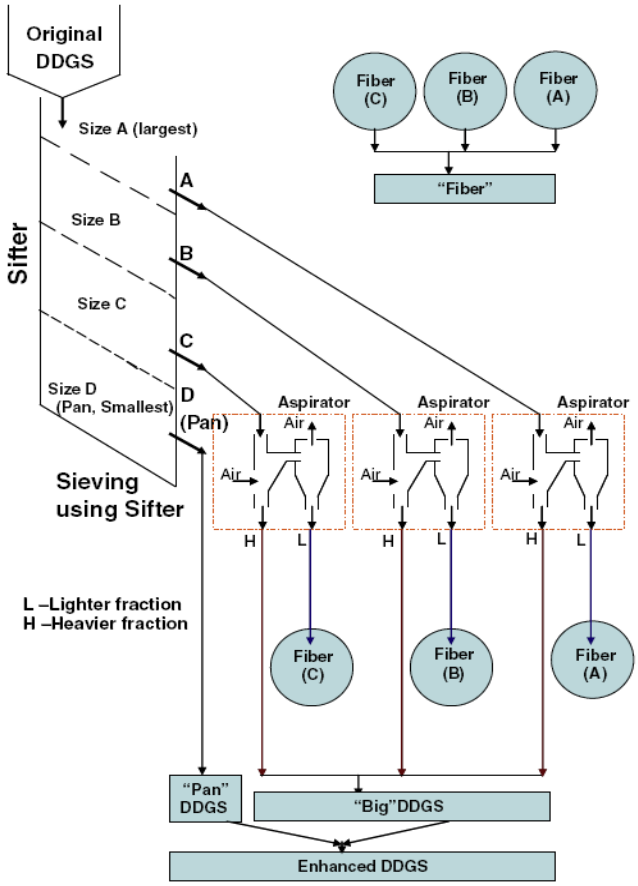

Figure 2.1. A schematic diagram of the Eluseive process.

Dried distillers grains are first separated by size using a sifter. Then, the dried distillers grains are subjected to elutriation which separates the grains based on density, size and shape. Theoretically, the fiber, being less dense, is carried up and away by the air, resulting in a heavy fraction and a lighter fraction (Srinivasan et al., 2005; Reprinted from Srinivasan et al., 2009).

Table 2.4. Preliminary laboratory analysis of H-fractions (Small, Medium, and Large) and Pan DDGS.

Component (%)	Small	Medium	Large	Pan DDGS	Whole DDGS
Ash	**4.98**	**4.90**	**4.78**	**5.20**	**4.99**
CP	**31.92**	**30.48**	**28.95**	**34.72**	**31.27**
NDF	**35.57**	**36.05**	**39.11**	**27.09**	**33.68**
ADF	**10.15**	**8.61**	**10.81**	**7.54**	**8.55**
HC	**25.41**	**27.44**	**28.29**	**19.55**	**25.13**
Fat	**29.95**	**30.06**	**29.61**	**24.69**	**33.49**

Table 2.5. Preliminary laboratory analysis of L-Fraction DDGS.

Component (%)	Small	Medium	Large	Whole DDGS
Ash	**4.59**	**4.41**	**4.23**	**4.99**
CP	**23.52**	**24.13**	**21.11**	**31.27**
NDF	**47.29**	**45.79**	**52.45**	**33.68**
ADF	**12.06**	**12.15**	**13.39**	**8.55**
HC	**35.23**	**33.65**	**39.06**	**25.13**
Fat	**30.94**	**25.56**	**23.29**	**33.49**

have already been conducted with poultry to evaluate this product as a feedstuff (Srinivasan et al., 2008). As for the elusieve fiber, a use is still yet to be determined. Srinivasan et al. (2008) has suggested that the elusieve fiber might be used as a fuel source for ethanol plants or be used as a feedstock for cellulosic ethanol and corn fiber gum production. Given that the elusieve fiber retains much of the fiber from the original DDGS, another possible fate for the elusieve fiber would be to utilize it as a feedstuff for

cattle. It is well established that fiber is an important requirement in the cattle diets, providing such benefits as prevention of metabolic disorders and maintaining healthy gut function (Clark and Armentano, 1993). It is possible that the elusieve fiber may be able to used in cattle diets as a non-forage based fiber source, providing fiber to cattle in times when forage quantity is lacking or during times when it is not economically feasible to provide forage. Nevertheless, elusieve fiber should be evaluated as a feedstuff for cattle to determine if it can be successfully incorporated into cattle diets without impairing digestion or nutrient utilization. If elusieve fiber proves to be a viable feedstuff for cattle, then the elusieve process represents one way in which distillers grains, a feedstuff that is currently only fed to ruminants, can be processed to meet demands of monogastric as well as ruminant animals. Therefore, the objective of this study was to evaluate the L-fraction as a feedstuff for cattle. To do this a digestion trial was performed to determine the nutrient digestibility and protein utilization of a diet containing the L-fraction when fed to cattle.

CHAPTER III

MATERIALS AND METHODS

Digestion Trial

Care and use of animals used in this trial were conducted in accordance with and under the approval of the Institutional Animal Care and Use Committee of Mississippi State University (Protocol # 08-043).

The digestion trial was conducted at the Leveck Animal Research Center (LARC) Metabolism Unit at Mississippi State University during the month of October, 2008. Twelve steers (238 ± 5.7 kg) were used for this trial, consisting of nine Angus and three Hereford. Steers were obtained from the spring calving herd at the LARC Beef Unit, tamed, and halter broke before initiation of the trial. While being halter broke, steers were housed in pens where they received *ad libitum* access to feed and water. Once halter broke, steers were assigned to one of three dietary treatments by breed : low density fraction DDGS diet (**L**), whole DDGS diet (**D**), or a diet without any DDGS (control diet; **C**) which were formulated to be isonitrogenous and isocaloric. Tables 3.1 and 3.2 list the composition and nutrient composition of the experimental diets, respectively. The control diet was formulated to represent an economical diet for cattle in the southeastern United States so that the L diet could be compared to this "standard" diet for cattle. The D diet

Table 3.1. Composition of dietary treatments consumed by steers (n = 4 steers per group).

	Dietary Treatments		
Ingredient (%)	**L[1]**	**D[1]**	**C[1]**
Cotton Gin Mote	**-------**	**30**	**40**
Corn Gluten Feed	**38.5**	**36**	**43.5**
Cotton Seed Meal	**-------**	**2.5**	**15**
Corn DDGS	**-------**	**30**	**-------**
L-Fraction of DDGS	**60**	**-------**	**-------**
Trace Mineralized Salt	**1.5**	**1.5**	**1.5**

[1] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

Table 3.2. Nutrient composition of dietary treatments consumed by steers.

	Dietary Treatments		
Component	**L[1]**	**D[1]**	**C[1]**
DM[3] (%)	**97.34**	**98.03**	**98.36**
Ash[2] (%)	**6.75**	**8.29**	**8.21**
NDF[2,3] (%)	**43.99**	**47.36**	**51.89**
ADF[2,3] (%)	**11.11**	**26.84**	**34.67**
HC[2,3] (%)	**32.88**	**20.52**	**17.22**
Crude Protein[2] (%)	**21.01**	**20.89**	**18.00**
Fat[2] (%)	**7.95**	**7.79**	**5.70**
Gross Energy (cal/g)	**4510.83**	**4417.33**	**4285.01**

[1] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.
[2] Nutrients are given on a dry matter basis.
[3] DM = Dry Matter, NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber, HC = Hemicellulose.

was formulated to determine if differences existed when the lighter fraction DDGS was incorporated in the diet instead of whole DDGS. After the steers were assigned to their dietary treatments, they were placed into pens to keep the treatment groups separate and allowed a two-week adaptation period to acclimate their gastrointestinal tract to their respective diet. During the two-week adaptation period, steers were handled daily to ensure that they remained tame and halter broke.

Following the two-week adaptation period, all steers were relocated to the same room in an indoor facility at the LARC Metabolism Unit where they were randomly placed into individual metabolism crates. The metabolism crates allowed steers to have *ad libitum* access to feed and water and facilitated total urinary and fecal output collection and monitoring of feed intake. Steers were housed in metabolism crates for a 10-day period, the first three days to allow them to become acclimated to their new environment and seven days for data and sample collection. Every day during the seven day collection period, orts from the previous day were weighed and recorded, and fresh feed was weighed, recorded, and offered to the steers. Total feces weight and total urinary volume were also determined and recorded daily. A 5 % sample of feces and orts was collected daily, and a grab sample was taken from the feed offered daily. Urine was sampled at 5% of the total volume and acidified to 2% with 2N H_2SO_4. Feed, orts, and fecal samples were dried at 60 ^oC in a forced air oven. Samples were pooled by animal and stored in sealed containers until analysis. Urine samples were pooled, placed in sealed containers, and stored at -20 ^oC until analysis. After the seven day collection period, steers were removed from crates and returned to the herd at the LARC Beef Unit.

Laboratory Analysis

Feed, orts, and feces were ground to pass through a 2-mm screen using a Thomas Wiley Mill® (Arthor H. Thomas, Philadelphia, PA) and analyzed for dry matter, ash, neutral detergent fiber, acid detergent fiber, crude protein, fat, and gross energy (AOAC, 2003). Urine was thawed and analyzed for crude protein and energy density. For dry matter analysis, 2 g of the sample was placed in an aluminum pan and dried in a 100°C oven for at least 24 hours and weighed again. Ash content was determined by placing the sample from the dry matter analysis in a muffle furnace set at 550°C for five hours, after which ashed samples were allowed to cool to 100°C and then weighed. Fiber analysis was performed by placing 0.5 grams of sample in an Ankom® nylon bag and heat sealing the bag. To determine neutral detergent fiber content, the bag was digested at 100°C for one hour in 2000mL of neutral detergent fiber solution (Goering and Van Soest, 1970), including 20 g of sodium sulfite and 4 mL of α – amylase (4.2 mg / mL). After one hour, the samples were rinsed with two washes of 2000 mL of warm distilled water and 4 mL of α – amylase (4.2 mg / mL), followed by one rinse with 2000 mL of warm distilled water and one rinse with acetone. Samples were then placed in a 100°C oven for at least 24 hours and then weighed. To determine acid detergent fiber content, the same bags containing samples from the NDF analysis were placed in 2000 mL of acid detergent fiber solution (Goering and Van Soest, 1970) and digested at 100°C for one hour. The bags were then rinsed three times with warm distilled water and once with acetone. Samples were then dried at 100°C in an oven for at least 24 hours and weighed. Crude protein was determined using the Kjeldahl nitrogen method (AOAC, 2003); 0.9 grams of

sample, 15 mL of H_2SO_4 (96% w/w), and one FisherTab ™ (Thermo Fisher Scientific Inc., Waltham, MA) were placed in glass tubes and digested at 213^{o}C for 3 hours. The digested samples were then distilled and titrated to calculate crude protein content using a Foss Kjeltec 1035 Analyzer ™ (Foss, Eden Prairie, MN) distillation unit. Fat content was determined by ether extraction; 2 grams of sample were placed in alundum crucibles and placed in a goldfisch ether extraction apparatus with 40 mL of ether. Samples were boiled in ether for four hours, dried at 100^{o}C for at least 24 hours, and weighed. Gross energy was determined using an isoperibol oxygen bomb calorimeter (Parr Instrument Co., Moline, IL). For urine samples, 1 mL of urine and one FisherTab™ (Thermo Fisher Scientific Inc., Waltham, MA) were placed in glass tubes and digested at 213^{o}C for 3 hours. Digested urine samples were then distilled and titrated to calculate crude protein content using a Foss-Tecator Kjeltec 1035™ (Foss, Eden Prairie, MN). To determine the energy density of the urine, first, a blank (no urine added) cellulose powder pellet was placed in an isoperibol oxygen bomb calorimeter (Parr Instrument Co., Moline, IL) and analyzed. Then, 1 mL of urine was pipetted onto 1 g pellet of pelleted cellulose powder which was then placed in an isoperibol oxygen bomb calorimeter (Parr Instrument Co., Moline, IL) and analyzed. Energy density of the urine was calculated by subtracting the energy density of the cellulose pellet from the energy density of the cellulose pellet saturated with urine.

Statistical Analysis

Data for body weight, dry matter intake, nutrient digestibility, digestible energy content of feed, and crude protein retention was analyzed as a completely randomized

design using the general linear model procedure of SAS (Version 9.2). Individual animal was the experimental unit, and there were 4 animals per treatment. Data is reported as least square means. Differences in least square means were determined to be significant when the P-value was less than 0.05. Significantly different least square means were separated using Fisher's Protected Least Significant Difference. Urinary output was analyzed as a repeated measure using the mixed procedures of SAS (Version 9.2), and significantly different least squared means were separated using Tukey's HSD.

CHAPTER IV

RESULTS AND DISCUSSION

Nutrient profiles of dietary treatments are reported in Table 3-2. Even though diets were formulated to be isonitrogenous, differences in actual crude protein content were found for samples of the three diets collected during this trial. Two diets, L and D, had similar crude protein concentrations (21.01% and 20.89%, respectively) but were greater for crude protein content than C (18%). Similarly, L and D also had more fat (7.95% and 7.79%, respectively) than C (5.70%). Fiber content also differed among treatments; NDF and ADF content was greatest for C (51.89% and 34.67%, respectively), intermediate for D (47.36% and 26.84%, respectively), and least for L (43.99% and 11.11%, respectively). Conversely, hemicellulose content was greatest for L (32.88%), intermediate for D (20.52%) and least for C (17.22%). The differences of fiber content are most likely due to the presence or absence of cotton gin mote in the diets. Cotton gin mote has large quantities of NDF(78.78%) and ADF(65.02%) but little hemicellulose (13.76%; Welch, 2008) compared to the L-fraction of DDGS which is 47.04% NDF, 12.20% ADF, and 34.84% hemicellulose. Therefore, it was not surprising that the D and C, which contain cotton gin mote, had more NDF and ADF but less hemicellulose than L. Caloric density was also different among treatments; L and D had more gross energy (4510.83 cal/g and 4417.33 cal/g, respectively) than C (4285.01 cal/g). Differences for

caloric density can be attributed to the differences of fat and protein content. More protein and fat were in L and D than C which would make them more energetically dense. No difference of body weight (P = 0.6253) was detected among steers receiving different dietary treatments (Table 4.1). However, dry matter intake did differ among treatment groups (Table 4.1) expressed as amount consumed (P = 0.0394). Steers receiving L consumed less (4.33 kg/d) than those receiving D and C (5.96 kg/d and 6.50 kg/d, respectively). However, dry matter intake as a percentage of the body weight only tended (P = 0.0532) to follow the same trend as amount. Differences for DMI might be due to diet composition: D and C contained cotton gin mote which has been reported to increase DMI when included in the diet in increasing amounts (Welch, 2008). During the digestion trial, steers appeared to prefer D and C, which contained cotton gin mote, more than L, which contained no cotton gin mote. Also, differences of dry matter intake may be due to the physical characteristics of the L-fraction which is similar to non-pelleted soybean hulls. An unprocessed form of the L-fraction may not be as palatable to cattle compared to a pelleted form. Anderson et al. (1988) found DMI numerically increased when soybean hulls were pelleted rather than fed whole; similarly, DMI of diets containing the L-fraction might have increased if the L-fraction is was pelleted. Therefore, further research is needed to evaluate the L-fraction as a pelleted feedstuff for ruminants.

Average urinary output per day was different (P = 0.0269) for steers in different treatment groups (Table 4.2). Steers consuming C (26.0 L/d) had a greater urinary output than steers consuming L (18.1 L/d), with steers consuming D (21.5 L/d) being

Table 4.1. Body weight of and dry matter intake by steers consuming the three diets.

		DMI[1]	
	BW[1] (kg)	kg/d	%BW[1]/d
L[2]	245	4.33[a]	1.79
D[2]	230	5.96[b]	2.60
C[2]	239	6.50[b]	2.73
SEM	10.43	0.520	0.249
P-value	0.6253	0.0394	0.0532

[a,b] Within a column, means without a common superscript differ (P< 0.05).
[1] DMI = Dry Matter Intake, BW = Body Weight.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

Table 4.2. Average urinary output by steers per day

	L / d	SEM
L[1]	18.1[a]	2.314
D[1]	21.5[ab]	2.599
C[1]	26.0[b]	3.279
P-value	0.0269	

[a,b] Within a column, means without a common superscript differ (P< 0.05).
[1] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

intermediate. The differences in average daily urinary output suggests that, on the average, steers receiving C consumed more water than steers consuming L, and steers receiving D consumed an intermediate amount of water each day. Steers receiving C consuming more water than steers receiving L was not unexpected, because C contained cotton gin mote and L did not. Moreover, the differences in water consumption may have affected rate of passage through the gastrointestinal tract. Consuming more water may

have increased the fluid rate of passage for steers consuming C, and this possible increased fluid rate of passage may have also increased the particulate rate of passage as well. Because consuming more water may have increased rate of passage for steers receiving C, then DMI would be expected to be greater for these steers which was observed in this trial (Table 4.2).

Dry matter (P = 0.1778), OM (P = 0.1748), and ash (P = 0.3125) apparent digestibilties were not different for steers consuming different dietary treatments (Table 4.3). There were also no differences for NDF (P = 0.2674), ADF (P = 0.5073), and hemicellulose (P = 0.2109) apparent digestibilities for steers consuming different dietary treatments (Table 4.4). Given that the hemicellulose content of L (32.88%; Table 3-2) was greater than D and C (20.52% and 17.22%, respectively; Table 3.2), theoretically, the NDF apparent digestibility should have been greater for L, because more of the NDF in L was hemicellulose which is a more digestible form of fiber. However, the fat content of L was greater than the other two diets (Table 4.1). Pavan et al. (2007) reported that linearly increasing fat supplementation decreased NDF digestion by steers, so it is possible that the increased fat, in the current trial, prevented the NDF in L from being digested to optimally. Furthermore, while there were no significant differences, there was a non-significant trend for NDF, ADF, and hemicellulose apparent digestibilities: steers consuming D digested more NDF, ADF, andhemicellulose than those consuming L, with steers consuming C being in between. It is possible that the statistical tests in this current trial were not powerful enough to detect a true difference; therefore, further research is needed to validate this trend. Based on visual appraisal, the particle size of L was smaller

Table 4.3. Apparent digestibility of DM, OM, and ash for diets fed to steers.

	DM[1] (%)	OM[1] (%)	Ash (%)
L[2]	70.01	70.36	65.17
D[2]	71.67	72.19	65.92
C[2]	65.67	66.26	59.00
SEM	2.135	2.079	3.292
P-value	0.1778	0.1748	0.3125

[1] DM = Dry Matter, OM = Organic Matter.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

Table 4.4. Apparent digestibility of NDF, ADF, and hemicellulose for diets fed to steers.

	NDF[1] (%)	ADF[1] (%)	HC[1] (%)
L[2]	54.09	51.28	55.05
D[2]	62.18	57.27	68.27
C[2]	56.42	54.77	55.72
SEM	3.361	3.514	5.463
P-value	0.2674	0.5073	0.2109

[1] NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber, HC = Hemicellulose.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

and more refined than D which may explain the non significant trend for NDF digestibility of L compared to D. Stokes et al. (1988) and Bowman and Firkins (1993) both reported similar results. Stokes et al. (1988) found that increasing the particle size of hay increased ruminal NDF digestion. Likewise, Bowman and Firkins (1993) reported that the extent of NDF disappearance *in sacco* was greater for forages ground to pass through a 5 mm screen than for forages ground to pass through a 2 mm screen,

suggesting that NDF of smaller particles is not digested to the extent that larger particles are digested. While L contained greater amounts of a more digestible form of fiber, the fat content and particle size of the diet prevented NDF digestion from reaching its full potential, necessitating further research to assess and alleviate this problem.

Apparent fat digestibility (P = 0.0036) was different, (Table 4.5) with steers consuming L and D having the greatest apparent fat digestibility (68.52% and 70.61%, respectively) and steers consuming C digesting the least (52.77 %). Treatment diets L and D both contained a form of distillers grains. Whole distillers grains were incorporated in D, while L contained a fraction separated from distillers grains, the L-fraction. Vander Pol et al. (2007) found that the fat in distillers grains is protected from rumen hydrogenation, meaning that unsaturated fatty acids in distillers grains remain unsaturated when exiting the ruminant stomach and entering the small intestine. Furthermore, Plascencia et al. (2003) reported that hydrogenation decreases fatty acid digestion in the small intestine, suggesting that unsaturated fatty acids are more digestible than saturated fatty acids. Possibly, since L and D contained a form of distillers grains, unsaturated fatty acids were protected from rumen hydrogenation, allowing them to remain unsaturated when they entered the small intestine. Consequently, L and D allowed for more unsaturated fatty acids to enter the small intestine, which made the fat in L and D more digestible than the fat in C which contained no distillers grains products.

Apparent energy digestibility (P = 0.1226) did not differ among steers consuming different dietary treatments (Table 4.5). However, the amount of digestible energy (P = 0.0269) in the three experimental diets was different (Table 4.5), with L and D (3.19 and

Table 4.5. Apparent digestibility of fat and energy and digestible energy content for diets fed to steers.

	Fat (%)	Energy (%)	Mcal DE[1] / kg
L[1]	**68.52[b]**	**70.78**	**3.19[b]**
D[1]	**70.61[b]**	**72.32**	**3.19[b]**
C[1]	**52.77[a]**	**65.93**	**2.83[a]**
SEM	**2.912**	**2.038**	**0.0903**
P-value	**0.0036**	**0.1226**	**0.0269**

[a,b] Within a column, means without a common superscript differ (P< 0.05).
[1] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.
[2] DE = Digestible Energy**.**

3.19 Mcal DE / kg, respectively) containing more digestible energy than C (2.83 Mcal DE / kg). Differences in digestible energy content can be attributed to gross energy content of the diets. Since steers receiving the three diets digested the same percentage of energy but L and D had greater energy contents than C, then L and D had a greater amount of digestible energy per kilogram than C. Additionally, the fat content of L and D may have attributed to the difference in digestible energy content. Since L and D both contained more fat (7.95 % and 7.79 %, respectively) than C (5.70%)and since the fat in L and D was more digestible (68.52% and 70.61%, respectively) than the fat in C (52.77 %), L and D contained a greater amount of a more digestible energy source than C, making the digestible energy content of L and D (3.19 and 3.19 Mcal DE / kg, respectively) greater than C (2.83 Mcal DE / kg).

Steers consuming L (78.14%) apparently digested more crude protein (P = 0.0008) than steers consuming C (63.13%) with steers consuming D (72.07%) apparently

digesting less protein than steers consuming L but more than steers consuming C (Table 4.6). Despite apparent protein digestion being different among treatment groups, protein retention values expressed as a percentage of the crude protein being retained (P = 0.5860), as a percentage of the DM being retained (P = 0.4195), or as grams per day (P =0.2452) did not differ among steers in different treatment groups (Table 4.6). Steers consuming L consumed less dry matter than steers in the other treatments groups, and this decreased dry matter consumption might explain the increase for apparent protein digestion observed for the steers consuming L. The decreased DMI may have slowed the rate of passage, causing the ingested feed to remain in the rumen for a longer period of time. This would allow more of the protein to be utilized by the rumen microflora, making the protein digestibility for L greater than the other diets. However, when the protein was utilized by the rumen microflora, there may not have been adequate carbon or energy sources available for the rumen microflora to synthesize their own protein. Possibly, the protein from the diet was deaminated by ruminal microbes to produce ammonia and then excreted as urea, explaining why there were no differences for crude protein retention. Energy retention values could not be determined during this trial. When trying to calculate energy retention, there were difficulties because of the variable data obtained from the urine energy density analysis. Attempts to alleviate this variability were made by repeating the analysis, but the results were still inconsistent. Given the work involved with analyzing urine for energy density, variation is not uncommon. There are multiple sources that may have contributed to the large amount of variation in the current trial. Variation could have come from weighing the cellulose powder pellet,

Table 4.6. Apparent digestibility of crude protein and crude protein retention values for diets fed to steers.

	CP[1] Digested (%)	CP[1] Retained (% of CP)	CP[1] Retained (% of DM)	CP[1] Retained (g/d)
L[2]	**78.14[c]**	**27.41**	**5.71**	**254.49**
D[2]	**72.07[b]**	**33.68**	**7.01**	**424.71**
C[2]	**63.13[a]**	**29.89**	**5.44**	**363.33**
SEM	**1.817**	**4.191**	**0.857**	**67.110**
P-value	**0.0008**	**0.5860**	**0.4195**	**0.2452**

[a,b,c] Within a column, means without a common superscript differ (P< 0.05).
[1] CP = Crude Protein.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

pipetting the urine, or unknown settling of urine particulate prior to pippetting. Also, the time that samples spent in the open air was variable because only one sample could be analyzed at a time. Overall, these sources of variation were compounded and produced inconsistent and non-reportable data.

If the L-fraction is to be accepted as a feedstuff for cattle, a comparative value relative to other feedstuffs must be assigned so that the L-fraction can be compared to other feedstuffs. From the data already presented, it is evident that the L-fraction of dried distillers grains with solubles can be successfully incorporated into a ruminant diet without negatively impacting the digestibility and utilization of the diet. Moreover, the L-fraction comprised 60% of L; this effectively replaced the cotton gin mote and whole DDGS which comprised a total of 60% of D. Given this aspect, it is evident that the L-fraction can be used as a fiber source to replace dietary fiber obtained from cotton gin mote and whole distillers grains without negatively altering digestion.

Furthermore, an economical figure must be assigned to the L-fraction so that producers can determine if it is economically feasible to use the L-fraction instead of whole DDGS. Srinivasan et al. (2009) suggested that since the L-fraction has a similar protein content to corn gluten feed, then its price should be the same as corn gluten feed which at the time was $125.69/tonne. If this same principle is applied to make a comparison between the L-fraction, which is 23.1% protein, and whole corn DDGS, which is 29.5% protein (Jurgens and Bregendahl, 2007), then the L-fraction would be around 78% as valuable as whole corn DDGS. However, because protein digestibility increased when the L-fraction was incorporated into the diet, the value of the L-fraction may increase beyond 78% the value of corn DDGS. Still, depending upon the batch of DDGS and the multiple variables involved in the Elusieve process, such as air velocity and sieving size, protein content of the L-fraction might change, thus changing its value relative to whole corn DDGS.

CHAPTER V

SUMMARY AND CONCLUSIONS

Steers fed L consumed less dry matter than steers in the other treatment groups. Also, steers fed L averaged less daily urinary output than steers fed C, suggesting that steers fed L consumed less water than steers receiving C. A decrease in water consumption may have slowed the rate of passage through the gastrointestinal tract of steers receiving L, explaining why steers fed L consumed less dry matter than steers receiving C. However, DM, OM, ash, NDF, ADF, hemicellulose, and energy digestibility for L, D, and C did not differ among steers in different treatment groups. Also protein retention was similar for steers receiving different dietary treatments. Moreover, protein digestibility and fat digestibility was greater for steers consuming L compared to steers receiving C. Given that L, which utilized the L-fraction of DDGS, produced similar DM, OM, ash, NDF, ADF, hemicellulose and energy digestibilities and protein retention and given that the fat and protein in L was more digestible than C, it can be concluded that the L-fraction of distillers grains is a viable feedstuff for cattle and can be incorporated into diets without negatively impacting digestion.

However, before this feedstuff is mainstreamed, further research is warranted. Due to the decreased dry matter intake by steers consuming L, further investigation should be conducted to determine if dry matter intake can be improved for cattle

consuming the L-fraction. Even though cattle consuming the L-fraction had greater digestibilities for fat and crude protein and similar digestibilites for DM, OM, ash, NDF, ADF, hemicellulose, and energy, they may not receive the same amount of these nutrients, since DMI was reduced. This may pose a problem for beef and dairy operations. If DMI is reduced in beef cattle consuming the L-fractoin, then possibly they will not receive enough nutrients to support gain. Likewise, if a lactating dairy cow consuming the L-fraction experiences a reduction in DMI, then milk production may suffer because the diet is not providing adequate amounts of nutrients to support lactation. Possibly, pelletting the L-fraction will increase the physical size of the L-fraction, making it more palatable to cattle as seen with other feedstuffs such as soybean hulls. Furthermore, research must be conducted to determine how much L-fraction can be incorporated in the diet; it is possible that the amount fed in this trial may have been too little or too much. To determine the proper inclusion rate for the L-faction, trials must be conducted which include the L-fraction at different amounts to determine if any trends for digestion or utilization occur. Additionally, cattle performance, while consuming the L-fraction, must be studied to determine if this feedstuff has potential use as a feedlot feedstuff. The use of the L-fraction as a non-forage based fiber source should also be evaluated. Trials with beef and dairy cattle could be conducted which study how effectively the L-fraction can serve as a replacement for the forage component of the diet without negatively impacting performance. However, before these further investigations are undertaken, the Eluseive process must operate on a much larger scale than what was done for this trial. During this trial, the Elusieve process was only operating on a small

pilot scale; therefore, limited amounts of the L-fraction were available. Fortunately, enough of the L-fraction was provided to obtain data on the digestibility of a diet containing the L-fraction. Regardless, if additional research validates the use of the L-fraction in cattle diets, then the Elusieve process would represent a valuable tool for both the ethanol industry and the animal agriculture industry.

LITERATURE CITED

Al-Suwaiegh, S., K. C. Fanning, R. J. Grant, C. T. Milton, and T. J. Klopfenstein. 2002. Utilization of distillers grains from the fermentation of sorghum or corn in diets for finishing beef and lactating dairy cattle. J Anim Sci 80: 1105-1111.

Allen, D. M., and R. J. Grant. 2000. Interactions between forage and wet corn gluten feed as sources of fiber in diets for lactating dairy cows. Journal of dairy science 83: 322-331.

Anderson, S. J., J. K. Merrill, M. L. McDonnell, and T. J. Klopfenstein. 1988. Digestibility and utilization of mechanically processed soybean hulls by lambs and steers. J. Anim Sci. 66: 2965-2976.

Annison, E.F. and D.G. Armstrong. 1970. Volatile fatty acid metabolism and energy supply. In: Physiology of Digestion and Metabolism in the Ruminant. A.T. Phillipson, ed. Oreil Press, Newcastle upon Tyne, England. Pp 422-437.

AOAC. 2003. Official methods of analysis. 17 ed. Association of Official Analytical Chemists, Arlington, VA.

Bayer, E. A., H. Chanzy, R. Lamed, and Y. Shoham. 1998. Cellulose, cellulases and cellulosomes. Current Opinion in Structural Biology 8: 548-557.

Beauchemin, K. A., D. Colombatto, D. P. Morgavi, and W. Z. Yang. 2003. Use of exogenous fibrolytic enzymes to improve feed utilization by ruminants. J. Anim Sci. 81: E37-47.

Beg, Q. K., M. Kapoor, L. Mahajan, and G. S. Hoondal. 2001. Microbial xylanases and their industrial applications: A review. Applied microbiology and biotechnology 56: 326-338.

Beguin, P., and M. Lemaire. 1996. The cellulosome: An exocellular, multiprotein complex specialized in cellulose degradation. Critical reviews in biochemistry and molecular biology 31: 201-236.

Bowman, J. G., and J. L. Firkins. 1993. Effects of forage species and particle size on bacterial cellulolytic activity and colonization in situ. J. Anim Sci. 71: 1623-1633.

Brink, D. R., and R. T. Steele. 1985. Site and extent of starch and neutral detergent fiber digestion as affected by source of calcium and level of corn. J. Anim Sci. 60: 1330-1337.

Burroughs, W., P. Gerlaugh, B. H. Edgington, and R. M. Bethke. 1949. The influence of corn starch upon roughage digestion in cattle. J. Anim Sci. 8: 271-278.

Calsamiglia, S., P. W. Cardozo, A. Ferret, and A. Bach. 2008. Changes in rumen microbial fermentation are due to a combined effect of type of diet and ph. J. Anim Sci. 86: 702-711.

Cardozo, P.W., S. Calsamiglia, and A. Ferret. 2000. Effects of pH on microbial fermentation and nutrient flow in a dual flow continuous culture system. J. Anim Sci. 83 (Suppl. 1): 265. (Abstr.)

Cerrato-Sanchez, M., S. Calsamiglia, and A. Ferret. 2008. Effect of the magnitude of the decrease of rumen ph on rumen fermentation in a dual-flow continuous culture system. J. Anim Sci. 86: 378-383.

Chappell, G. L. M., and J. P. Fontenot. 1968. Effect of level of readily-available carbohydrates in purified sheep rations on cellulose digestibility and nitrogen utilization. J. Anim Sci. 27: 1709-1715.

Church, D. C. 1988. The ruminant animal : Digestive physiology and nutrition. Prentice-Hall, Englewood Cliffs, NJ.

Clark, P. W., and L. E. Armentano. 1993. Effectiveness of neutral detergent fiber in whole cottonseed and dried distillers grains compared with alfalfa haylage. J. Dairy Sci. 76: 2644-2650.

Craig, W. M., G. A. Broderick, and D. B. Ricker. 1987. Quantitation of microorganisms associated with the particulate phase of ruminal ingesta. J. Nutr. 117: 56-62.

Depenbusch, B. E. et al. 2009. Optimizing use of distiller's grains in finishing diets containing steam-flaked corn. J Anim Sci.

Depies, K. K., and L. E. Armentano. 1995. Partial replacement of alfalfa fiber with fiber from ground corn cobs or wheat middlings. Journal of dairy science 78: 1328-1335.

Firkins, J. L. 1997. Effects of feeding nonforage fiber sources on site of fiber digestion. Journal of dairy science 80: 1426-1437.

Firkins, J. L., L. L. Berger, and G. C. Fahey, Jr. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. Journal of animal science 60: 847-860.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures and some applications). USDA-ARS Agricultural Handbook 379. U.S. Government Printing Office, Washington, D.C.

Grant, R. J. 1997. Interactions among forages and nonforage fiber sources. Journal of dairy science 80: 1438-1446.

Ham, G. A. et al. 1994. Wet corn distillers byproducts compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J Anim Sci 72: 3246-3257.

Herold, D.W. 1999. Solvent extracted germ meal for ruminants. PhD Diss. University of Nebraska, Lincoln.

Hoover, W. H. 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci. 69: 2755-2766.

Hoover, W. H., C. R. Kincaid, G. A. Varga, W. V. Thayne, and L. L. Junkins, Jr. 1984. Effects of solids and liquid flows on fermentation in continuous cultures. Iv. Ph and dilution rate. Journal of animal science 58: 692-699.

Hsu, J. T. et al. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls and soybean hulls as roughage sources for ruminants. J. Anim Sci. 65: 244-255.

Juhasz, T., Z. Szengyel, K. Reczey, M. Siika-Aho, and L. Viikari. 2005. Characterization of cellulases and hemicellulases produced by trichoderma reesei on various carbon sources. Process biochemistry 40: 3519-3525.

Jurgens, M. H., and K. Bregendahl. 2007. Animal feeding and nutrition. 10th ed. Kendall/Hunt, Dubuque, Iowa.

Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. Board-invited review: Use of distillers by-products in the beef cattle feeding industry. J Anim Sci 86: 1223-1231.

Kulkarni, N., A. Shendye, and M. Rao. 1999. Molecular and biotechnological aspects of xylanases. FEMS microbiology reviews 23: 411-456.

Larson, E. M., R. A. Stock, T. J. Klopfenstein, M. H. Sindt, and R. P. Huffman. 1993. Feeding value of wet distillers byproducts for finishing ruminants. J. Anim Sci. 71: 2228-2236.

Little, C. O., G. E. Mitchell, Jr., and G. D. Potter. 1968. Nitrogen in the abomasum of wethers fed different protein sources. J. Anim Sci. 27: 1722-1726.

Lodge, S. L., R. A. Stock, T. J. Klopfenstein, D. H. Shain, and D. W. Herold. 1997. Evaluation of corn and sorghum distillers byproducts. J Anim Sci 75: 37-43.

Lynd, L. R., P. J. Weimer, W. H. van Zyl, and I. S. Pretorius. 2002. Microbial cellulose utilization: Fundamentals and biotechnology. Microbiol Mol Biol Rev 66: 506-577, table of contents.

Mateo, K.S., K.E. Tjardes, C. L. Wright, T.J. Koger, and B.D. Rops. 2004. Evaluation of feeding varying levels of wet distillers grains with solubles as compared to dry distillers grains with solubles to finishing steers. South Dakota Ag. Exp. Sta. Beef Rep. BEEF 2004-03.

Martinez-Amezcua, C., C. M. Parsons, V. Singh, R. Srinivasan, and G. S. Murthy. 2007. Nutritional characteristics of corn distillers dried grains with solubles as affected by the amounts of grains versus solubles and different processing techniques. Poult Sci 86: 2624-2630.

McAllister, T. A., H. D. Bae, G. A. Jones, and K. J. Cheng. 1994. Microbial attachment and feed digestion in the rumen. J. Anim Sci. 72: 3004-3018.

Minato, H., A. Endo, M. Higuchi, Y. Ootomo, and T. Uemura. 1966. Ecological treatise on the rumen fermentation I. The fractionation of bacteria attached to the rumen digesta solids. J. Gen. Appl. Microbiol. 12: 39-52.

Montgomery, S. P. et al. 2004. Effects of wet corn gluten feed and intake level on diet digestibility and ruminal passage rate in steers. J Anim Sci 82: 3526-3536.

Murthy, G. S., V. Singh, D. B. Johnston, K. D. Rausch, and M. E. Tumbleson. 2006. Evaluation and strategies to improve fermentation characteristics of modified dry-grind corn processes. Cereal chemistry 83: 455-459.

Pavan, E., S. K. Duckett, and J. G. Andrae. 2007. Corn oil supplementation to steers grazing endophyte-free tall fescue. I. Effects on in vivo digestibility, performance, and carcass traits. J. Anim Sci. 85: 1330-1339.

Pereira, M. N., and L. E. Armentano. 2000. Partial replacement of forage with nonforage fiber sources in lactating cow diets. Ii. Digestion and rumen function. J Dairy Sci 83: 2876-2887.

Peter, C. M. et al. 2000. The effects of corn milling coproducts on growth performance and diet digestibility by beef cattle. J Anim Sci 78: 1-6.

Plascencia, A., G. D. Mendoza, C. Vasquez, and R. A. Zinn. 2003. Relationship between body weight and level of fat supplementation on fatty acid digestion in feedlot cattle. J Anim Sci 81: 2653-2659.

Pond, W. G., D. C. Church, and K. R. Pond. 2005. Basic animal nutrition and feeding 4th ed. Wiley, New York.

Sarwar, M., J. L. Firkins, and M. L. Eastridge. 1991. Effect of replacing neutral detergent fiber of forage with soyhulls and corn gluten feed for dairy heifers. J. Dairy Sci. 74: 1006-1017.

Schwarz, W. H. 2001. The cellulosome and cellulose degradation by anaerobic bacteria. Applied microbiology and biotechnology 56: 634-649.

Singh, V., R. A. Moreau, L. W. Doner, S. R. Eckhoff, and K. B. Hicks. 1999. Recovery of fiber in the corn dry-grind ethanol process: A feedstock for valuable coproducts. Cereal chemistry 76: 868-872.

Srinivasan, R., F. To, and E. Columbus. 2009. Pilot scale fiber separation from distillers dried grains with solubles (DDGS) using sieving and air classification. Bioresource Technology 100: 3548-3555.

Srinivasan, R., R. A. Moreau, C. Parsons, J. D. Lane, and V. Singh. 2008. Separation of fiber from distillers dried grains (ddg) using sieving and elutriation. Biomass and Bioenergy 32: 468-472.

Srinivasan, R., R.A. Moreau, K.D. Rausch, R.L. Belyea, M.E. Tumbleson, and V. Singh. 2005.A new process for removing fiber from distillers dried grains with soluble. ASAE Annual International Meeting, Tampa, FL. July 17-20, 2005. Paper No. 057044.

Stahlberg, J., G. Johansson, and G. Pettersson. 1991. A new model for enzymatic hydrolysis of cellulose based on the two-domain structure of cellobiohydrolase i. Nat Biotech 9: 286-290.

Steinhour, W.D. and D.E. Bauman. 1986. Propionate metabolism: a new interpretation. In: Aspects of Digestive Physiology in Ruminants. Alan Dobson and Marjorie Dobson, eds. Cornell Univ. Press, Ithaca. P. 238.

Stensig, T., and P. H. Robinson. 1997. Digestion and passage kinetics of forage fiber in dairy cows as affected by fiber-free concentrate in the diet. J. Dairy Sci. 80: 1339-1352.

Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. J. Anim Sci. 77: 1-v-12.

Stokes, S. R., A. L. Goetsch, and K. L. Landis. 1988. Feed intake and digestion by beef steers consuming and receiving ruminal insertions of prairie hay differing in level and particle size. J. Anim Sci. 66: 1267-1274.

Uffen, R. L. 1997. Xylan degradation: A glimpse at microbial diversity. Journal of industrial microbiology & biotechnology 19: 1-6.

Van Soest, P. J. 1967. Development of a comprehensive system of feed analyses and its application to forages. J. Anim Sci. 26: 119-128.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant 2nd ed. Comstock Pub., Ithaca.

Vander Pol, K.J., M.K. Luebbe, G.I. Crawford, G.E. Erickson, and T.J. Klopfenstein. 2007. Digestibility, rumen metabolism and site of digestion for finishing diets containing wet distillers grains or corn oil. Nebraska Beef Cattle Report. MP90: 39-42.

Vander Pol, K. J., G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, and G. I. Crawford. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. Journal of animal science 87: 639-652.

Waller, J., T. Klopfenstein, and M. Poos. 1980. Distillers feeds as protein sources for growing ruminants. Journal of animal science 51: 1154-1167.

Welch, C.M. 2008. Nutrient digestibility and utilization by cattle consuming cotton gin mote as a replacement for forage. M.Sc. Thesis. Mississippi State University, Mississippi State.

White, D. 2000. The physiology and biochemistry of prokaryotes. 2nd ed. Oxford University Press, New York.

Williams, A. G., and N. H. Strachan. 1984. The distribution of polysaccharide-degrading enzymes in the bovine rumen digesta ecosystem. Current microbiology 10: 215-220.

Younker, R. S., S. D. Winland, J. L. Firkins, and B. L. Hull. 1998. Effects of replacing forage fiber or nonfiber carbohydrates with dried brewers grains. J. Dairy Sci. 81: 2645-2656.

APPENDIX A

TOTAL AMOUNT OF NUTRIENTS CONSUMED BY STEERS

A.1. Total amount of DM, OM, and Ash consumed by steers.

	DM[1] (kg)	OM[1] (kg)	Ash (kg)
L[2]	30.3[a]	28.3[a]	2.1[a]
D[2]	41.7[b]	38.3[ab]	3.4[b]
C[2]	45.5[b]	41.8[b]	3.7[b]
SEM	3.363	3.337	0.301
P-value	0.0395	0.0461	0.0072

[a,b] Within a column, means without a common superscript differ (P< 0.05).
[1] DM = Dry Matter, OM = Organic Matter.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

A.2. Total amount of NDF, ADF, and hemicellulose consumed by steers.

	NDF[1] (kg)	ADF[1] (kg)	HC[1] (kg)
L[2]	13.1[a]	3.3[a]	7.6
D[2]	19.6[b]	10.9[b]	8.6
C[2]	23.2[b]	15.6[c]	9.8
SEM	1.790	1.040	0.791
P-value	0.0093	< 0.0001	0.2131

[a,b,c] Within a column, means without a common superscript differ (P< 0.05).
[1] NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber, HC = Hemicellulose.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

A.3. Total amount of crude protein, fat and energy consumed by steers.

	CP[1] (kg)	Fat (kg)	Energy (Mcal)
L[2]	**6.3**	**2.3**	**136.6**
D[2]	**8.7**	**3.3**	**184.5**
C[2]	**8.3**	**2.7**	**195.2**
SEM	**0.749**	**0.255**	**16.008**
P-value	**0.1062**	**0.0539**	**0.0635**

[1] CP = Crude Protein
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

APPENDIX B

TOTAL AMOUNT OF NUTRIENTS DIGESTED BY STEERS

B.1. Total amount of DM, OM, and Ash digested by steers.

	DM[1] (kg)	OM[1] (kg)	Ash (kg)
L[2]	21.3	20.0	1.3[a]
D[2]	29.8	27.6	2.3[b]
C[2]	29.9	27.7	2.2[b]
SEM	2.658	2.445	0.222
P-value	0.0773	0.0860	0.0281

[a,b] Within a column, means without a common superscript differ (P< 0.05).
[1] DM = Dry Matter, OM = Organic Matter.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

B.2. Total amount of NDF, ADF, and hemicellulose digested by steers.

	NDF[1] (kg)	ADF[1] (kg)	HC[1] (kg)
L[2]	7.2[a]	1.7[a]	5.4
D[2]	12.1[b]	6.3[b]	5.8
C[2]	13.1[b]	8.6[c]	4.5
SEM	1.203	0.707	0.579
P-value	0.0144	0.0002	0.3135

[a,b,c] Within a column, means without a common superscript differ (P< 0.05).
[1] NDF = Neutral Detergent Fiber, ADF = Acid Detergent Fiber, HC = Hemicellulose.
[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.

B.3. Total amount of crude protein, fat and energy digested by steers.

	CP[1] (kg)	Fat (kg)	Energy (Mcal)
L[2]	**4.9**	**1.6[a]**	**128.8**
D[2]	**6.3**	**2.3[b]**	**133.2**
C[2]	**5.2**	**1.4[a]**	**97.2**
SEM	**0.563**	**0.180**	**11.900**
P-value	**0.2713**	**0.0121**	**0.1184**

[a,b,c] Within a column, means without a common superscript differ (P< 0.05).

[1] CP = Crude Protein

[2] L = Lighter fraction DDGS diet, D = Whole DDGS diet, and C = Control diet.