NUTRITIONAL IMPACT OF FEEDING LIQUID ETHANOL CO-PRODUCTS AND BARLEY SUPPLEMENTATION TO WEAN-TO-FINISH PIGS ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS

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Abstract

Nutritional Impact of Feeding Liquid Ethanol Co-Products and Barley Supplementation to Wean-To-Finish Pigs on Growth Performance and Carcass Characteristics

The first objective of this study was to compare dry and liquid feeding systems (The Big Dutchman, Holland, MI, USA) on growth performance in nursery pigs. Four-hundred and eighty early weaned pigs (N=480; initial BW 6.1 ± 0.17 kg; 18 d old; Topigs Norsvin female X Compart Duroc boar) were blocked by weight and randomly assigned to one of two dietary treatment groups via a randomized complete block design (n=240; 10 pigs/pen; 24 pens/treatment). Diets were formulated to be isocaloric and isonitrogenous: (1) Dry, corn-soybean meal. (2) Liquid, water and corn-soybean meal (DM 23%). Pig weights were recorded on d0, d14, d28, and d42 indicating the end of the nursery period. Performance parameters average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency measured as gain-to-feed (G:F) were calculated on pen basis. Data were analyzed using PROC-MIXED procedure of SAS. Statistical significance was set at $P \leq 0.05$. Pigs in the dry feeding system had greater ADG, G:F, and final BW ($P<0.01$). Initially, dry diets had greater ADFI ($P<0.01$). By the end of the nursery period, liquid fed pigs had greater ADFI than dry fed pigs ($P<0.01$) In conclusion, feeding nursery pigs dry corn-soybean meal diets resulted in greater ADG and G:F which led to heavier final BW when compared to liquid feeding system pigs ($P<0.01$).

The second objective was to measure nitrogen (N), phosphorus (P), and energy digestibility when feeding the ethanol co-products Dried Distillers Grain with Solubles

(DDGS), Corn Distillers Whole Stillage (CDWS), and Corn Condensed Distillers Solubles (CCDS) to growing swine, and to determine the nutrient profile of manure slurry. Thirty-two crossbred barrows (N=32; Topigs Norsvin females X Compart Duroc boars) were selected with a mean initial body weight of 82.5 kg (Final BW 85.1 kg), housed individually in stainless steel metabolism crates, and were randomly assigned to 1 of 4 dietary treatments (n=8): (1) Dry, control corn-soybean meal (2) Dry, control with 30% DDGS (3) Liquid, control corn-soybean meal and water (4) Liquid, control basemix with 20% CCDS and 30% CDWS. Pigs were allowed 4 days for adaptation to crates with 4 days of sample collection including urine, feces, and slurry. Slurry was pooled and allowed to sit to mimic anaerobic pit conditions. Results from this study found that feeding ethanol co-products attained similar N intake and digestible N levels when compared to conventional corn-SBM diets. Feeding ethanol co-products had greater P intake while liquid diets were greater for digestible P ($P<0.01$). Dry diets were greater for energy intake and DE while feeding CCDS and CDWS reduced energy availability ($P<0.01$). For slurry characteristics, dry diets were greater in total N and P while being similar in K content ($P<0.01$). Pigs fed DDGS had the greatest concentration of sulfur in slurry. In conclusion, feeding liquid ethanol co-products can be an alternative to traditional grains for meeting dietary requirements. Furthermore, pigs fed ethanol co-products yield slurry with comparable nutrient content to corn-SBM and have potential as an alternative to crop fertilizer.

The third objective was to compare feeding DDGS, CDWS, CCDS, and barley to grow-finish swine in terms of growth performance and carcass characteristics. The fourth

objective was to determine the effect of partial replacement of ethanol co-products with barley on belly firmness. Four-hundred and eighty pigs were blocked by weight (25.8 ± 0.43 kg) and randomly assigned to one of six dietary treatment groups via randomized complete block design (N=480; n=80; 10 pigs/pen; 8 pens/treatment). Diets: (1) Dry basal, Control, corn-SBM all phases (2) Dry, DDGS (Phase 1: 20%, Phases 2-4: 30%). (3) Dry, DDGS (Phase 1: 20%, Phases 2 and 3: 30%, Phase 4: 15% DDGS + 15% barley). (4) Liquid basal, control, corn-SBM and water all phases (5) Liquid, Ethanol co-products (Phase 1:16% CCDS + 24% CDWS, Phases 2 and 3: 20% CCDS + 30% CDWS, Phase 4: 24% CCDS + 36% CDWS). (6) Liquid, Ethanol co-products (Phase 1:16% CCDS + 24% CDWS, Phases 2 and 3: 20% CCDS + 30% CDWS, Phase 4: 15% CCDS + 30% CDWS + 15% barley). Pigs were weighed on d0, d28, d56, d84, and d112. Pigs were marketed at 127 kg, therefore liquid fed pigs were allowed two more weeks to meet market weight, and weighed on d126. Growth performance parameters ADG, ADFI, and G:F were calculated on pen basis. Carcasses were measured for hot carcass weight (HCW), fat depth, loin depth, percent lean, and dressing percentage. Across all diets, feeding dry corn-SBM had the greatest performance for final BW, ADG, and G:F ($P<0.01$). Furthermore, pigs fed barley had reduced ADG and ADFI and lesser loin depth ($P<0.01$). Feeding DDGS had similar performance however belly firmness was reduced ($P<0.01$). Feeding liquid ethanol co-products resulted in greater G:F and reduced ADFI when compared to liquid corn-SBM diets ($P<0.01$). For pigs fed ethanol co-products such as DDGS, CCDS, and CDWS, belly firmness was reduced due to the greater level of poly-unsaturated fatty acids (PUFA) and iodine value (IV) leading to softer bellies

($P<0.01$). In conclusion, dry feeding was superior in growth performance and carcass merit as they reached market readiness compared to liquid fed pigs. Feeding ethanol co-products is an effective cost savings strategy, however, belly firmness may become an issue with the current feeding method.
(Key words: pigs, whole stillage, condensed distillers solubles, ethanol co-products, growth performance, nutrient digestibility, carcass characteristics, belly firmness)

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List of Abbreviations

DDGS	Dried Distillers Grain with Solubles
CDWS	Corn Distillers Whole Stillage
CCDS	Corn Condensed Distillers Solubles
DM	Dry Matter
GE	Gross Energy
CP	Crude Protein
ADF	Acid Detergent Fiber
NDF	Neutral Detergent Fiber
EE	Ether Extract
BW	Body Weight
ADG	Average Daily Gain
ADFI	Average Daily Feed Intake
G:F	Gain to Feed Ratio
FCR	Feed Conversion Rate
WDG	Wet Distillers Grains
DMI	Dry Matter Intake
SBM	Soybean Meal
AIA	Acid Insoluble Ash
N	Nitrogen
P	Phosphorus
K	Potassium
S	Sulfur
BUN	Blood Urea Nitrogen
ALA	Alpha Linolenic Acid
SFA	Saturated Fatty Acid
MUFA	Mono-unsaturated fatty acid
PUFA	Poly-unsaturated fatty acid
IV	Iodine Value
NFLF	Non Fermented Liquid Feeding
FLF	Fermented Liquid Feeding
LF	Liquid Feeding

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CHAPTER 1

Literature Review

1.1: Introduction

Modern swine practice encourages producers to maximize production and facility efficiency in order to meet consumer demands while ensuring the sustainability of the production system. This has led to producers weaning pigs early in life, around 3 weeks of age. Producers wean at this time to allow for greater animal performance and sow productivity by increasing the litters per sow per year. The main challenges facing the piglet upon weaning include: a change of diet, shift to a new environment, and withdrawal from sow (Deprez et al., 1987). The transition from a fluid milk diet to dry grain diets results in reduced feed intake as the piglet is not accustomed to the new diet which tends to slow growth and ultimate pig performance. Moving to a new facility and entering a new social hierarchy adds to the stress of the pig.

Weaning at such an early age leads to a phenomena known as the post-wean growth check (Kim et al., 2001). This term refers to the period where pigs have negligible growth while they become familiar with their new surroundings. The post-weaning growth check, despite many nutritional advancements and products, continues to be a significant portion of production focus. Therefore, the newly weaned pig is the primary management challenge among all phases of pork production.

1.1.1: Liquid feeding benefits to weanling pig

Liquid feeding has shown to improve voluntary feed intake in weanlings as a way to ease the transition from sow's milk to a finish diet. Braude and Newport (1977) reported that early weaned pigs fed liquid diets have greater DMI which directly relates to increased gain. The increase in DM intake leads to improved feed utilization, growth performance, and feed digestibility (Choct et al., 2004).

The goal for nutritionists and producers in developing feeding programs for weaned pigs is to recognize the unique needs as wean pigs often encounter digestive upset, diarrhea, and decreased appetite. The goal is to facilitate a smooth transition to solid feed in hopes of resulting in rapid, efficient growth with limited health problems (Han et al., 2006). An important determinant of the performance and health status of weanling pigs is food intake.

Pluske et al., (1996a) found that when liquid diets were fed, the structure and function of the small intestine specifically villous height and crypt depth can be preserved. This suggests a relationship between food type, intake and intestinal morphology such as villous height in determining post-weaning weight gain. In addition, a study by the Pluske et al., (1996b) determined that liquid diets allow early-weaned pigs the greatest capacity for DMI.

1.2: Liquid Feeding

1.2.1: Defining Liquid Feeding Systems

It is important to differentiate between liquid feeding systems as each style has different characteristics which make it useful to a variety of producers. The three different types of liquid feeding systems outlined by Brooks (2001) include: Wet/Dry, Non-fermented, and fermented liquid feeding.

Wet/Dry feeding:

Water is mixed with dry feed in the feeding trough and fed directly to pigs. Feed : Water mixing ratios vary between 1:2 to 1:4 typically. Dry Matter content is important when formulating diets as they reflect nutrient availability of the feedstuffs. Liquid diets regularly have been between 20-30% DM (Geary et al., 1996).

Non-fermented liquid feeding:

Water is added to dry basal feed in the central mixing tank. The liquid co-products are pumped into the central mixing tank. The system mixes for approximately 7 minutes and is immediately dispensed to the feed troughs via high pressured pump lines at 145 psi connected to the feeding troughs in the pen.

Fermented liquid feeding:

Water is mixed with dry feed, and then the liquid co-products are pumped into the mixing tank. After mixing, the feed mixture is pumped to a holding tank with bacterial inoculants for controlled fermentation. The feed typically is fed 24 to 48 hours later via high pressured pipelines connected to the feed troughs in the pen.

Among the various types of liquid feed systems, a common theme is a central feed preparation area that can produce a range of diets to match the nutrient requirements of pigs of different ages and stages of production (Brooks 2001). These systems are designed to handle several different types of feedstuffs and products such as brewer’s yeast, whey product, and bakery co-products.

1.2.2: Design of the modern liquid feeding system

In the wean-to-finish research unit in Waseca, MN at the University of Minnesota Southern Research & Outreach Center, the style of liquid feed system would be classified as non-fermented liquid feeding, (Big Dutchman: Holland, MI, USA.) This system is run by a computer software program which has complete control over preparation of feed as well as dispersal and amount fed. Once the dietary treatment design is input into the program, the computer knows which pens get which treatment. After the diets are formulated, the computer controls and monitors the specific amount of each ingredient being put into the mixing tank for accurate feeding.

Water is added to the central mixing tank followed by feed which is augered in via pipes from the outside bin. The liquid components are connected via pipelines and their respective totes/tanks. After the water and feed are added, the first co-product, in our case being corn distiller's whole stillage, is pumped into the central mixing tank. Followed by the second product, corn condensed distillers solubles is added completing the ration mixture. The feed components are mixed for approximately seven minutes at varying speeds to produce a uniform feed mixture. This feed is automatically dispersed to the corresponding pens depending on the dietary treatment. After each feeding, high pressure water is pumped through the lines for cleaning. At this time, the system begins to prepare the next batch of feed. Each pen can be fed ad libitum or restrict fed while being accurately rationed.

Modern liquid feeding systems are designed to adapt to the producer's needs. They are suitable for frequent diet changes. Furthermore they provide producers an opportunity to utilize step up or phase feeding programs to more accurately meet the pig's requirements throughout the various phases of production while reducing the excreta and environmental impact (Brooks et al., 2001).

1.2.3: Liquid feeding worldwide

Since the industrialization of pork production in the mid-1900s, market hogs have been primarily fed dry-grain based diets with corn and soybeans as the main ingredients in the United States. A smaller portion of livestock producers had access to cheaper, liquid products available to feed pigs. Liquid feeding technologies were first developed in the latter 20th century as a means to recycle the growing supply of human food production co-products in Europe at a lower cost to the producer. These systems were first developed in Western Europe. Swine liquid feeding research has been conducted largely in this area with barley and wheat based diets due to nearby feedstuff availability. In the Netherlands, approximately 70% of finish pigs are fed liquid diets (Jensen and Mikkelsen, 1998). In Canada, close to 20% are finished on liquid diets as well (SLFA, 2012).

In the United States, the bulk of hog producing states are located in areas dominated by corn and soybean production. With ample supply of these feedstuffs in the nearby geographic area, a lower number of producers use liquid feeding systems. Although the prevalence of liquid feeding is low in the Midwest, it is slowly gaining interest given the benefits it has over conventional dry diet programs. At times of increased grain prices and more co-products becoming available, there has been a growing interest and research into evaluating the various co-products to determine their value in livestock finishing diets.

1.2.4: Perceived benefits over dry feeding

Given that liquid feeding systems is an emerging technology in the United States, less research has been done using these systems due to practical limitations. The majority of the research for liquid feeding has been conducted in the Netherlands, England, and Canada. Two unique features that the liquid feeding system allow are that a new batch of liquid feed is prepared for each feeding and for individual troughs, and that liquid feed is moved to the feeders using high-pressure air.

Research conducted at the University of Guelph has utilized the Big Dutchman system and from their experience, growth performance and feed efficiency of growing-finishing pigs on the liquid feeding system are at least as good as those achieved on a conventional feeding system where pigs are fed pelleted feed (Columbus et al., 2006). Their liquid feeding design is suited for fermented liquid feeding.

A review of previous studies focused on liquid feeding compared to dry feeding have produced more desirable parameters such as improved performance, carcass traits, and health. The following are some of the benefits of utilizing liquid feeding:

Summary of the benefits of liquid feeding systems

1. Improved nutrient utilization and animal performance
2. Utilization of inexpensive liquid co-products
3. Flexibility in raw material use and ease of delivery
4. Improvement in environment and gut health with reduction of dust
5. Reduction of feed loss during handling and feeding
6. Computer control of feeding program and monitor intake
7. Increased DM intake in wean pigs and lactating sows

Kim et al., (2001) showed that liquid feeding to wean pigs accelerates performance which is maintained to market weight. Pigs fed liquid diets showed favorable growth with increased average daily gain and feed conversion rate when compared to pigs fed dry diets (Scholten et al., 1999). However, not all studies have shown similar results when studying liquid feeding. Lawlor et al., (2002) reported no significant advantage in liquid feeding in terms of growth performance and carcass merit.

Like any livestock feeding system, liquid feeding systems also can present challenges to producers as well. Typical challenges producers face include high cost of the system, variability of nutrient content of liquid co-products, lifespan of co-product and uncontrolled fermentation, and maintenance of the system.

Consistency of liquid co-product remains a central issue within liquid feeding systems. With the high moisture content of the liquid products, variability reduces quality of feedstuffs which can negatively affect animal performance (Braun and de Lange, 2004). Feed samples should be routinely taken as a measure to ensure consistent product quality. High capital cost has also been associated with liquid feeding systems. When compared to conventional dry systems, maintenance and up keep of liquid systems may be increased.

Another major drawback that can be associated with liquid feeding is the advanced technology involved with these systems. Since the system is controlled electronically, more advanced training is required for barn staff. In addition, system maintenance costs are typically higher compared to conventional dry feeding systems due to automation (Squire, 2005). Furthermore, more management time is involved in maintaining liquid feed systems due to feeding line blockages and mechanical breakdowns. If not continuously monitored, these systems may shut down leading to out of feed events in the barn.

Given the high moisture content of co-products commonly used in liquid feeding systems, lifespan and shelf life can pose problems to producers. Liquid co-products often times need to be circulated every few hours to avoid settling in the storage tank. Rosentrater and Lu (2015) reported that without proper storage, liquid co-products can spoil from excess mold growth and become unviable as a feedstuff from uncontrolled fermentation. Uncontrolled fermentation can result from improper management or storage and result in undesired fermentation of proteins and amino acids. This can result in reduced feed palatability and can potentially be harmful to pigs (Brooks et al., 2003).

1.3.1: Utilization of common liquid co-products:

Liquid feeding systems are designed to utilize many different types of by-products. The systems allow for by-products to be recycled from human food factory production and used to feed livestock. Common by-products used in the livestock industry were described by Braun and de Lange (2004) including corn distillers soluble, liquid whey, buttermilk, bakery waste, brewer's wet yeast, and candy syrup. The biofuel, food production, and fermentation industries all contribute a wide variety of by-products that can be used in liquid feeding systems.

Bakery Waste products:

Bread co-products are a palatable, high energy food product often times with wheat origins. Co-products include expired bread, cookies, crackers, biscuit meal, cake, and breakfast cereals. These products can be fed to both pigs and ruminants as a high energy source due to a high level of dietary fat (Crawshaw 2001).

Brewing co-products:

The main co-products include brewer's wet grains and yeast. Wet grains are the solid residue leftover after the extraction of malt in the production of beer. These are typically fed to ruminants as a high energy and protein source. Brewer's yeast is the liquid portion that brewers use to ferment sugars into alcohol. Typically a highly flavored ingredient suitable for swine liquid diets, Kornegay et al., (1995) reported brewer's yeast has a lysine content similar to soybean meal making it a suitable alternative as a digestible protein source.

Grain and Vegetable processing by-products:

Corn steep liquor, the concentrated liquid formed during the early stages of wet-milling ethanol production, is a rich protein source with typically low oil and fiber contents. Corn gluten feed and corn gluten meal differ by moisture content (25% vs.

65%, respectively) however these by-products have been reported to be good sources of energy and protein and are usually fed to ruminants (Crawshaw 2001).

Potato steam peel, a high moisture by-product from french fry production, has been utilized as a liquid feedstuff for growing swine. Nicholson et al., (1988) reported potato steam peel to be a good source of digestible protein and could be included up to 25% of the diet for finishing pigs. Potato chips and crisps have also been found to be an excellent source of energy and fat for all categories of swine (Pettigrew, 1981; Seerley, 1984)

Milk processing co-products:

Whey is a liquid co-product from the cheese making process that has been extensively used in swine diets. Being high in lactose, whey has been used primarily in early age pig diets as it is a good source of calcium and phosphorus. Yogurt, buttermilk, and ice cream have also been studied as alternatives in liquid feeding systems for swine. Yogurt is typically used as a protein source while Braun and de Lange (2004) reported buttermilk and ice cream to be a highly digestible energy source from the high fat level.

1.3.2: Fermented Liquid Feeding Benefits

Fermenting liquid feed is known to have beneficial effects on the gut microflora of pigs as well as enhance the nutrient availability (Columbus et al., 2006). Specifically using lactic acid inoculants has greatly reduced the prevalence of Salmonella on farms in the Netherlands (Brooks et al., 2001). These bacteria are successful in eliminating the enteropathogens thus promoting pig health and alleviating antibiotic use.

Fermented liquid feed has been studied to determine if it could be used as a possible alternative to antibiotics (Plumed-Ferrer and von Wright, 2008; Canibe et al., 2007). van Winsen et al., (2001) demonstrated that fermenting liquid feed significantly lowered the population of enterobacteriaceae in the digestive tract when compared to pigs fed dry diets.

1.3.3: Uses of Liquid Feeding

Inexpensive:

When managed properly and used responsibly, feeding liquid co-products can be a suitable replacement for common feedstuffs as they typically provide a low cost alternative. Scholten et al., (1999) reported feeding costs decreased by 10 to 17% when liquid co-products were fed compared with dry diets. An economic analysis of co-product use in Eastern Europe validated the advantage in terms of cost to the producer. A study by Spajic et al., (2010) showed a savings of $6.89 per pig over a 90-day period in Croatia when pigs were fed brewer's yeast along with whey. The possibility of using cheaper liquid ingredients with current fluctuations in feed prices makes liquid feeding an intriguing feeding strategy to any producer.

Recycle human food:

Grow-finishing pigs are suitable to recycle human food and biofuel production by-products as they are omnivores able to consume liquid co-products inedible to humans while converting them into animal protein for consumption (Zjilstra and Beltranena 2013). Feeding these co-products typically provides a cheaper way to attain similar growth performance and carcass characteristics while greatly reducing the environmental output and load. Incorporation of liquid co-products eliminates the need for drying and handling processes, thus reducing energy need and expenditure.

Environment:

Many reports have outlined the perceived benefits to the environment from utilizing liquid co-products as a way to reduce environmental load (Canibe and Jensen, 2003; Brooks et al., 2001). Added environmental benefits include the use of co-products from the human food industry which would likely incur a disposal cost, and Brooks et al., (2001) reported a reduction in nitrogen output through use of a phase feeding program. These programs are designed to more accurately adjust to the protein, more specifically lysine, requirement for growing swine. Gill (1998) reported these programs reduce the amount of excess protein fed. Typically the protein supplied in excess would have to be deaminated, and consequently more N being excreted in the urine thus increasing effluent output. With environmental policies aimed at decreasing disposal of waste, promoters can utilize liquid co-products from the food, pharmaceutical, and biofuel industry for liquid feeding purposes (Gill 1998).

One of the major limitations of the corn to ethanol conversion process is stillage handling. Eskicioglu et al., (2010) reported that drying DDGS and stillage evaporation accounts for approximately 30% and 16% of total energy consumption of an ethanol plant, respectively. Feeding higher moisture liquid co-products such as CDWS and CCDS to pigs could have major impacts on reducing the cost of disposal via drying, dumping or burning, making those processes no longer necessary. Subsequently, the use of fossil energy and the negative effects on the environment are reduced (Scholten et al., 1999). Yang and Rosentrater (2015) later reported that the increased demand for whole stillage and syrup products may decrease environmental impacts like greenhouse gas emissions as these products require much less processing and energy expenditure to produce.

Antibiotic reduction:

As of January 1st, 2006, antibiotic use as a growth promotant was banned in the European Union citing food safety and public health issues (European Union). Globally, it is the wish of many consumers to see a decrease in the use of antibiotics in pig production. With this in mind, liquid feeding programs have been investigated in order to compensate the use of antibiotics as growth promoters in swine production. Several studies conducted in Holland and Canada found reduced levels of *Salmonella spp.* when liquid co-products were fed (Tielen et al., 1997; van der Wolf et al., 1999; Farzan et al., 2006).

Therefore, liquid feeding has been proposed as a means to improve the public perception of pork production and meat safety by having the potential to reduce the use of antibiotic use (Braun and de Lange 2004). Fermenting the liquid feed with specific lactic acid bacteria inoculants reduces the pathogenic bacteria load in the gut and subsequently on the farm from the drop in pH during fermentation (Brooks et al., 2001).

1.3.4: Summary of Liquid Feeding on Growth Performance and Carcass Characteristics

Reference	Feed Source	ADG	FCR	Carcass Quality
Braude and Newport, 1977	Liquid milk	+	0	N
Brooks et al., 1996	Liquid whey + yogurt	+	-	N
Brooks et al., 2001	Liquid Wheat bottom stills + Potato Peel	+	+	N
Canibe & Jensen, 2003	Dry, NFLF, and FLF	+	+	N
Chae et al., 2000	Dry vs. Wet	+	+	0
Choct et al., 2004a	Liquid vs. Dry	+	+	N
Han et al., 2006	Liquid whey	+	-	N
Jensen and Mikkelsen, 1998	Liquid vs. Dry	+	+	N
Kim et al., 2001	Liquid whey	+	+	0
Lawlor et al., 2002	Dry, NFLF, FLF, and Acidified LF	0	0	N
Meried et al., 2014	CCDS + CDWG	+	+	N
Moon et al., 2004	Liquid food products	+	+	0
Partridge et al., 1992	Liquid vs. Dry	+	+	0
Patterson et al., 1991	Wet vs. Dry	-	-	N
Russell et al., 1996	Dry vs. Liquid	+	-	N
Zoric et al., 2015	Dry vs. Wet	0	0	0

+ : Liquid feeding better, - : Dry feeding better, 0 : no difference, N : no data provided

Table 1.3.4 reviewed common performance parameters including ADG, FCR, and carcass quality associated with liquid feeding. Overall in the studies examined, using various liquid co-products including whey product, potato steam peel, and bakery waste and found that liquid feeding often times improved ADG and FCR. However not all studies have found similar results in terms of performance. Lawlor et al., (2002) found no differences in growth performance when liquid diets were compared with dry fed diets. Patterson et al., (1991) found reduced growth when wet diets were fed. In terms of carcass and meat quality, feeding liquid co-products yielded similar quality as no differences were found in studies examining carcass output and meat quality (Chae et al., 2000; Moon et al., 2004; Partridge et al., 1992).

1.4: Ethanol Production

1.4.1: By-products of the ethanol production industry

With the rise in biofuel production topping over 50 billion liters in the last decade, many more by-products have become available. With the increased availability, many research institutions have gained interest in identifying any by-products with potential as livestock feed. The by-products produced from the ethanol process include corn distiller's whole stillage, corn distiller's thin stillage, corn distiller's wet grains, corn condensed distiller's solubles, and dried distillers grain with solubles (DDGS). Guardian Energy, LLC outlined the dry-grind ethanol process found in Appendix 1 showing how each co-product is produced.

Most research over the past decade has been evaluating the various types of DDGS, the final product in the ethanol by-product process. DDGS is similar compositionally to traditional corn-soybean meal diets versus its contemporary co-products. Given that the other co-products have greater moisture contents when compared to DDGS, most research units are not properly equipped to handle and feed the liquid by-products. Therefore, less research has been done evaluating their efficacy in livestock production.

1.4.2: Dry-grind ethanol process

The typical bioethanol process can be divided into processes including milling, hydrolysis, fermentation, and distillation. After being unloaded from the grain cart, the whole corn kernel goes through a hammer or roller mill and becomes corn flour. This flour is mixed with water in a slurry tank to produce a corn mash. The mash moves into a slurry tank where alpha-amylase enzymes are added to convert the starch to a simple sugar via hydrolysis. Ammonia is added at this point to control the pH. The mash goes through a jet cooker to reduce levels of bacteria before the fermentation process. After going through the cooker, the hydrolyzed substrate liquid pools into the fermentation tank where yeast is added to convert the starch sugars to produce ethanol and carbon dioxide. Once fermentation is complete, the carbon dioxide rises to the top of the tank and exits the system via a water scrubber to remove any leftover ethanol and to reduce emissions (Sartori and Leder, 1978). The liquid goes through distillation to produce ethanol.

The leftover liquid is separated from the remaining corn-residue stillage to yield the first product known as corn distiller's whole stillage. Typically, the fermentation residue goes through a centrifuge to separate the remaining liquid from the corn particles. The liquid portion is known as corn distiller's thin stillage while the corn particles is known as corn distiller's wet grains or cake. The thin stillage goes through an evaporator to be concentrated, and the result is the second co-product termed corn condensed distillers soluble or syrup. Typically, the wet cake and syrup are mixed together and tumble dried to produce DDGS to be sold as livestock feed. For each bushel of corn (25.4 kg) processed through a dry-mill ethanol facility, approximately 7.7 kg DDGS are produced.

1.4.3: Corn Distillers Whole Stillage

The first co-product from the dry-grind ethanol process used is corn distillers whole stillage (CDWS). After ethanol is distilled from the fermentation tanks, the leftover corn residue fluid is whole stillage. Typically the mixture is near 10% DM. Little research has been conducted using this product in livestock diets. Before mainstream biofuel production in the 1940s, Lane (1980) found feeding whole stillage to swine yielded a soft meat product. However carcass quality improved with inclusion of dry corn.

1.4.4: Corn Condensed Distillers Solubles

The second co-product used is corn condensed distillers solubles (CCDS). This product is a result of the thin stillage going through an evaporator yielding the syrup. Syrup compositions vary widely from within and among ethanol plants but typically is reported to be around 30% DM. This co-product has been used as a source of energy and reported to have crude protein levels between 20-30%.

Lardy and Anderson (2014) reported that for beef cattle, condensed distillers solubles can be added up to 10% in the diet to reduce dust and enhance dry rations. It also can be added to low-quality forages to improve palatability and protein utilization. Squire et al., (2005) fed varying levels of CCDS at 0, 7.5, 15.0, and 22.5% to swine and found that above 15% of the diet, growth rate, feed intake, and feed conversion was reduced when compared to corn-SBM diets. They also found that up to 15% inclusion of fermented CCDS in the diet resulted in similar performance while non-fermented CCDS had slightly reduced performance.

Minimal research has been done to evaluate liquid feeding whole stillage and syrup together to growing swine. Baidoo (2014) found that when CDWS and CCDS were fed in liquid diets to swine, growth performance, carcass weight, and belly firmness were reduced when compared to corn-SBM. Yang (2017) reported reduced growth and carcass performance when compared to dry feeding similar co-products.

1.4.5: Potential issues with liquid feeding ethanol co-products

Factors to recognize when considering including ethanol co-products in diet formulations are ration palatability, nutritional composition, variability and consistency among products, and impact on pork quality (Plain 2006).

Inclusion Rates and Ration Palatability:

Several studies have been conducted to see the ideal inclusion level of the various ethanol co-products. For DDGS, Stein (2007) reported maximum inclusion values for all categories of swine. Lactating sows, nursery, and finish pigs levels are up to 30% DDGS with gestating sows able to be 50% of their diet containing DDGS. Feeding beyond these levels leads to reduced FI which compromises growth performance. Baidoo (2014) reported that combined levels of CDWS and CCDS should not exceed 50%. Meried et al., (2014) also found that CDWS and WDG can be included up to 20% of the diet. Beyond the recommended inclusion levels for ethanol co-products, ration palatability and acceptability can suffer, resulting in reduced performance (Whitney et al., 2006).

Impact on pork quality:

A common issue with feeding high levels (up to 30%) has been soft meat products such as bacon due to a different fatty acid composition of DDGS than traditional corn-

SBM diets. This is a result of a higher level of poly-unsaturated fatty acids from the DDGS which leads to an increased iodine value of the meat yielding a softer pork product (Wood et al., 2003). Carcass fat firmness is directly related to dietary fat composition in addition to the ratio of saturated fatty acids to poly-unsaturated fatty acids (Wood et al., 2003). The ratio of these fatty acids determines iodine value and overall unsaturation level of the fat (US Grains Council, 2012).

Since it is known that DDGS has a greater concentration of PUFAs than conventional corn-soybean meal diets, pigs fed DDGS result in greater levels of PUFAs in carcass adipose tissue. With the degree of unsaturation increased, meat products are softer as a result of the melting point being closer to room temperature (US Grains Council, 2012). Upon harvest, meat processors have demonstrated that softer cuts leads to more difficult processing.

Nutritionists have developed different ways of dealing with the softer pork product in order to retain product firmness including dietary supplements, withdrawal of DDGS in late finishing, and alternative cereal grain source in order to ameliorate the effects of DDGS inclusion (US Grains Council, 2012). Even still, research has shown that consumers cannot detect a difference in flavor in terms of sensory taste panels (Baidoo et al., 2014).

Variability:

Variability of ethanol co-products within and among plants also remains to be a main issue facing producers who feed these products (Braun and de Lange, 2004). When nutritional composition and consistency issues arise, animal performance drops leading to delayed growth and subsequent marketing time. An agreement between supplier and producer is imperative to maintain and ensure quality and consistency of products in order to meet production goals. Spiehs (2002) found large variability of ethanol co-products among several Midwestern ethanol plants. Furthermore, when samples of the same product have been taken from the same plant at various points throughout the year, variability existed.

1.5: Purpose and Objectives

Much research has been done since DDGS has been identified with potential in livestock diets yet less research has been done to evaluate feeding high moisture, liquid co-products in swine diets due to the logistical and production restrictions with these systems. Therefore, the purpose for conducting the study was to evaluate the effect of feeding liquid CCDS and CDWS in terms of growth performance and carcass merit, and to determine the value of replacing a portion of the late finishing diet with barley to grow-finish swine.

The hypothesis of these studies are that feeding ethanol co-products to wean-to-finish pigs would not influence pig performance.

The objectives of this thesis are:

(1) Evaluate the growth performance of nursery pigs fed dry and liquid corn-SBM diets

(2) Determine the nutrient digestibilitys of DDGS, CDWS and CCDS

(3) Evaluate the growth performance and carcass characteristics of growing-finishing pigs fed ethanol co-products

(4) Determine the effect of supplementing barley in ethanol co-product diets on belly firmness

CHAPTER 2

Effect of Feeding Systems on Growth Performance of Nursery Pigs

Abstract

The objective of this study was to compare dry versus a liquid feeding corn-soybean meal (The Big Dutchman, Holland, MI, USA) on growth performance in nursery pigs. Four-hundred and eighty early weaned pigs (N=480; initial BW 6.1 ± 0.17 kg; 18 d old; Topigs Norsvin female X Compart Duroc boar) were blocked by weight and randomly assigned to one of two dietary treatment groups via a randomized complete block design (n=240; 10 pigs/pen; 24 pens/treatment). Diets were formulated to be isocaloric and isonitrogenous: (1) Dry, corn-soybean meal. (2) Liquid, water + corn-soybean meal (DM 23%). Pig weights were recorded on d0, d14, d28, and d42 indicating the end of the nursery period. Performance parameters ADG, ADFI, and G:F were calculated on pen basis. Data were analyzed using the PROC-MIXED procedure of SAS. Statistical significance was set at $P \leq 0.05$. Pigs in the dry feeding system had greater ADG, G:F, and final BW when compared to liquid diets ($P<0.01$). Initially, dry diets had greater ADFI ($P<0.01$). In phase 3, liquid fed pigs had greater ADFI than dry fed pigs ($P<0.01$) In conclusion, feeding nursery age pigs dry corn-soybean meal diets resulted in higher ADG and G:F which led to heavier final BW versus liquid feeding system pigs ($P<0.01$).

(Key words: dry feeding, liquid feeding, corn, soybean meal, nursery pigs, growth performance)

Introduction

Corn and soybean have dominated Midwest grain production for over a century due to the ideal growing conditions. With the ample supply of feedstuffs in the nearby geographic area, farmers began to grow their swine production capacity to meet the increasing demand. Before intensive swine production began, liquid feeding was a common feeding method for swine in the 1950s. After modernization of swine production in the United States, farmers began utilizing corn and soybean meal as staples in all diets.

The Netherlands was the first to adopt the modern liquid feeding system in the early 1990s as they were identifying many food processing by-products with potential in swine diets (de Haas, 1998; Brooks et al., 2003). After showing many advantages in terms of performance and efficiency with a variety of co-products, liquid feeding started gaining interest in North America with farmers and research institutions.

The majority of research conducted in Europe had barley and wheat as the staples in the diet with less knowledge on liquid feeding other grains (Scholten et al., 1999).

The hypothesis for the nursery trial determining the effect of feeding dry and liquid corn-soybean meal diets was that liquid feeding would improve the performance of early weaned pigs.

With little knowledge on liquid feeding corn and soybean meal to growing swine, and the known benefits of feeding similar feedstuffs, our purpose for conducting the nursery trial was to:

(1) Determine the effect of liquid feed corn-soybean meal based diets to early weaned pigs on growth performance.

Materials and Methods

The University of Minnesota Institute of Animal Care and Use Committee reviewed and approved the experimental protocol which was conducted at the Southern Research and Outreach Center in Waseca, MN.

Early weaned pigs (N=480; 18 ± 3 d; Topigs Norsvin females X Compart Duroc boars), identified by ear tag, blocked by initial weight (6.1 ± 0.17 kg), and randomly assigned to 1 of 2 different diet treatments: (1) Dry, corn-SBM (2) Liquid, corn-SBM with water (n = 240; 10 pigs/pen; 24 pens/treatment). Pens provide 0.74 sq. m. per pig at a stocking density of 10 pigs per pen.

Within each phase, the experimental diets were formulated to meet or exceed nutrient requirements for wean to finish pigs (NRC, 2012). The diets were formulated to be isocaloric and isonitrogenous. All pens had concrete slats and a water bowl for free access. On the liquid feeding side, each pen had a single feed trough with sensor connected to a pipeline system from the computer automated command center. On the dry feeding side, each pen had standard metal hog feeders which were manually filled by barn staff with a Mosdal feed cart (Mosdal Scale Systems, Inc. Broadview, MT) and auger system. For each phase, diet samples were collected and stored at -20°C until analyzed.

The dietary composition is shown in Table 2.1. A basal diet, stored in a feed bin, provided vitamins, minerals, corn, soybean meal, choice white grease, and essential amino acids. This basal diet was added to water, mixed and pumped to the individual pens. All these processes were controlled by a computer system in the liquid feeding room. The computer system controls diet preparation, feed mixing for individual pens, and monitor weight changes of the tank. The tank mixes for approximately 7 minutes at varying speeds to produce a uniform feed mixture. Immediately after mixing, the pressurized pump lines would disperse the liquid feed to the corresponding pens.

After each feeding, the pipes were rinsed with high pressure water to clear any remaining feedstuffs prior to preparation for the next batch. Feed allowance was increased based on the feed curve that was related to the estimated BW. Pigs were fed up to 10 times a day using the computerized liquid feeding system.

Pigs were weighed every 14 days (d0, d14, d28, and d42) signaling a switch to the next phase. From these measures, the performance parameters average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) were determined. Growth performance parameters were calculated per pen on a weekly basis. Pigs were observed daily for signs of morbidity and mortality, feed and water outages, and environmental temperature. Daily minimum and maximum temperatures were recorded in the morning. Experimental diets were analyzed for proximate analysis including DM, GE, EE, NDF, ADF, and CP.

Results

Growth performance results are reported in Table 2.2. Initial body weights (6.1 ± 0.17 kg) did not differ between treatments at the beginning of the trial ($P>0.05$). In phase 1, dry fed pigs consumed more than liquid fed pigs post-wean (0.41 vs. 0.34 kg/d respectively, P<0.01). Furthermore, dry fed pigs were more efficient as they had a greater G:F ratio than those fed liquid diets (0.83 vs 0.71 respectively, P<0.01). This resulted in the dry fed pigs gaining more than liquid fed pigs (0.34 vs. 0.24 kg/d respectively, P<0.01). With the advantage in growth performance, pigs fed dry corn-SBM weighed heavier than those fed liquid diets (10.96 vs. 9.53 kg, respectively, P < 0.01).

In phase 2, dry fed pigs had greater ADG than liquid fed pigs (0.53 vs 0.45 kg/d respectively, P<0.01). Dry fed pigs had greater gain efficiency ratios than liquid fed pigs (0.64 vs 0.53 respectively, P<0.01). No difference was found for ADFI in phase 2 (P>0.05). At the end of phase 2, dry corn-SBM fed pigs gained more than liquid corn-SBM fed pigs (18.39 to 15.86 kg, respectively, P<0.01).

In the final phase of the nursery trial, ADG were similar between dry and liquid treatments (P>0.05). During phase 3, liquid fed pigs had greater ADFI than dry diets (1.28 vs. 1.18 kg/d respectively, P<0.01). Dry fed pigs had greater G:F ratios than liquid fed pigs (0.53 vs. 0.47 respectively, P<0.01).

For the entire nursery period, dry fed pigs had greater ADG (0.50 vs. 0.44 kg/d, respectively, P<0.01). Dry fed pigs had a greater G:F ratio (0.62 vs 0.53 respectively, P<0.01) than liquid fed pigs. Pigs liquid diets had greater ADFI than those fed dry diets (0.59 vs. 0.54 kg/d respectively, P<0.01). As a result of greater ADG and G:F, dry fed pigs were heavier than liquid fed pigs resulting in final BW (27.20 kg vs. 24.26 kg respectively, P<0.01).

Discussion

In the present study, no liquid co-products were fed, only a basal corn-soybean meal diet plus water. Contrary to Kim et al., (2001) reporting liquid feeding increasing ADFI and ADG, our study showed that early weaned pigs performed better on dry based diets. These findings more closely align with those found by Lawlor et al., (2002). Lawlor (2002) also showed dry based diets being superior in terms of growth performance. The reduced growth may be associated with taking more time to accept the dietary form and high moisture diet. Previous studies showing favor to liquid feeding systems fed liquid co-products including whey product and potato steam peel.

The DM content of the liquid diet used in the study (23%) was within acceptable ranges of liquid diets previously determined by Brooks et al., (2003). However, the fast settling nature presumably affected diet acceptability and subsequent gain. Once in the feed trough corn settled easily to the bottom making it more difficult for pigs to consume although the feed was mixed for a uniform solution.

By the final phase of the nursery trial, liquid feeding pigs began to perform better than dry fed pigs specifically with increased ADFI. These results are consistent with Braude and Newport (1977) concluding that liquid feeding is a way to improve intake for young pigs. Feed conversion rate favored dry diets likely as a result of the greater feed wastage by liquid fed diets. With the feedstuff settling easily, the water portion created a barrier the pigs had to encounter to obtain the required nutrition. This increased feed wastage since the pigs had to sift for feed.

Similar to the results reported by Han et al., (2001) and Woods et al., (2008), our study showed liquid feeding corn-soybean meal has little benefit in terms of growth performance immediately post-wean when compared to contemporary dry diets. Dry fed pigs had improved ADG and G:F which resulted in heavier final BW at the end of the trial. As a result of compensatory growth, liquid fed pigs were able to show adequate performance. However when evaluating feeding system for optimal growth, the present study suggests dry feeding corn-soybean meal to be the preferred option over feeding a similar liquid diet.

Conclusion

From the present findings of the trial studying different feeding programs in the nursery period for growing pigs, dry feeding corn-SBM had the advantage in ADG and G:F which resulted in heavier final BW over liquid feeding corn-SBM. Contrary to some reports claiming that liquid feeding has greater initial FI, our study showed that early weaned pigs consumed dry corn-SBM at higher levels rather than liquid corn-SBM.

The studies where young pigs had greater performance on liquid diets used co-products from the food processing industry. Liquid feeding did improve ADFI however it also had reduced performance when compared to dry feeding. Phase 1 was by far the most efficient for G:F when compared with the other time points in this study.

Liquid feeding programs typically have been utilized as a cost savings strategy in hog production. Performance may have been improved within liquid diets if a highly palatable liquid co-product, like whey product, would have been used. Through compensatory gain, liquid fed pigs were able to be comparable in growth parameters. Yet in this trial, dry feeding pigs proved to be superior.

Table 2.1: Dietary composition of nursery pigs fed dry or liquid feed

Ingredients	**Dry Basal**	**Liquid Basal**
Corn	70.62	70.62
Soybean meal,CP 47.5%	24	24
Choice white grease	1.57	1.57
Limestone, ground	0.55	0.55
Calcium phosphate (dicalcium)	1.7	1.7
L-Lys-HCL	0.44	0.44
DL-Met	0.17	0.17
L-Thr	0.15	0.15
Sodium chloride	0.3	0.3
Vitamin-trace mineral premix	0.5	0.5
Total	**100.00**	**100.00**
Calculated nutrients (%)		
ME (kcal/kg)	3350	3350
SID Lys	1.10	1.10
SID Met	0.40	0.40
SID Met+Cys	0.64	0.64
SID Thr	0.69	0.69
SID Trp	0.18	0.18
Total crude protein	17.17	17.17
Total P	0.59	0.59
ATTD P	0.33	0.33
Ca	0.71	0.71
Analyzed Values (% unless noted)		
GE (kcal/kg)	3650	3261
CP	17.0	16.9
NDF	14.1	14.6
ADF	4.1	4.9
Ether Extract	4.5	4.4
DM	89.0	20.2

Table 2.2: Effect of feeding system on growth performance of nursery pigs

Body Weight (kg)

Time Period	Liquid	Dry	SEM	P-value
D0	6.13	6.14	0.17	0.97
D14	9.53^{b}	10.96^{a}	0.22	0.01
D28	15.86^{b}	18.38^{a}	0.35	0.01
D42	24.46^{b}	27.20^{a}	0.43	0.01

Average Daily Gain (kg/d)

Phase	Liquid	Dry	SEM	P-value
1	0.24^{b}	0.34^{a}	0.01	0.01
2	0.45^{b}	0.53^{a}	0.01	0.01
3	0.61	0.63	0.01	0.34
Overall	0.44^{b}	0.50^{a}	0.01	0.01

Average Daily Feed Intake (kg/d)

Phase	Liquid	Dry	SEM	P-value
1	0.34^{b}	0.41^{a}	0.01	0.01
2	0.85	0.83	0.01	0.19
3	1.29^{a}	1.19^{b}	0.02	0.01
Overall	0.59^{a}	0.54^{b}	0.01	0.01

Gain : Feed Intake

Phase	Liquid	Dry	SEM	P-value
1	0.71^{b}	0.83^{a}	0.01	0.01
2	0.53^{b}	0.64^{a}	0.01	0.01
3	0.48^{b}	0.53^{a}	0.01	0.01
Overall	0.53^{b}	0.62^{a}	0.01	0.01

^{ab} Means (a, b) within a row with different superscripts are significantly different at ($P<0.05$)

CHAPTER 3

Nutrient Digestibility of Dried Distillers Grains with Solubles (DDGS), Corn Distillers Whole Stillage (CDWS), and Corn Condensed Distillers Solubles (CCDS) in Growing Swine

Abstract

Thirty-two crossbred barrows (N=32; Topigs Norsvin females X Compart Duroc boars) were selected with a mean initial body weight of 82.5 kg (Final BW 85.1 kg), individually housed in stainless steel metabolism crates and randomly assigned to 1 of 4 dietary treatments (n=8): (1) Dry, control corn-soybean meal (2) Dry, control with 30% DDGS (3) Liquid, control corn-soybean meal and water (4) Liquid, control basemix with 20% syrup and 30% whole stillage. Pigs were allowed 4 days for adaptation to the crates with 4 days of sample collection including urine, feces, and slurry. Slurry, a mixture of urine and feces, was pooled and allowed to sit to mimic anaerobic pit conditions. The objective of this study was to measure N, P, and energy digestibility when feeding ethanol co-products including DDGS, CDWS, and CCDS to growing swine, and to determine the nutrient profile of slurry when feeding ethanol co-products. Results from this study found that feeding ethanol co-products attained similar N intake and digestible N levels when compared to conventional corn-SBM diets ($P>0.05$). Ethanol co-products were greater for P intake while liquid diets were greater for digestible P. Dry diets were far greater for energy intake and DE while feeding CCDS and CDWS reduced energy availability ($P<0.01$). For slurry characteristics, dry diets were greater in total N and P while being similar in K ($P<0.01$). Pigs fed DDGS had the greatest concentration of S content in slurry. In conclusion, feeding liquid ethanol co-products can be a viable alternative for meeting dietary requirements as well as produce slurry with potential as an alternative to crop fertilizer.

(Key words: whole stillage, syrup, ethanol co-products, digestibility, metabolism)

Introduction

With the rise in biofuel production over the past decade, many ethanol co-products have become available (Stein, 2007) including DDGS, CDWS, CDWG, and CCDS (US Grains Council, 2012). The bulk of research that has been conducted has focused on DDGS with much less on the other co-products. Since corn is the basis for dry-grind ethanol production, researchers began finding ways to utilize the ethanol co-products in livestock diets. The majority of ethanol co-products have much higher moisture contents versus typical feedstuffs making them more suitable for liquid feeding systems.

Normally these high moisture co-products go through drying cycles to yield DDGS which has been studied extensively in swine (Spiehs et al., 2002; US Grains Council, 2012). Much less information is known about feeding CDWS and CCDS to growing swine due to practical research limitations with these liquid ethanol co-products. Squire (2005) determined that inclusion of CCDS above 15% reduced growth performance. Similarly, Baidoo (2014) reported that including CDWS in finish swine diets also reduced performance. Few studies have been conducted feeding both ingredients together in terms of growth performance and carcass merit. Furthermore, few have studied CDWS and CCDS digestibility and efficacy of feeding.

The hypothesis of the nutrient balance trial was that feeding liquid ethanol co-products would not influence N, P, and energy digestibility.

With the availability of these co-products from a nearby ethanol plant (Guardian Energy, Janesville, MN) and the facility research capacity, our purpose for conducting the balance metabolism study was to

(1) Evaluate the nutrient digestibility of DDGS, CDWS and CCDS in growing swine

Materials and Methods

The University of Minnesota Institute of Animal Care and Use Committee reviewed and approved the experimental protocol which was conducted at the Southern Research and Outreach Center in Waseca, MN.

Animals and Housing

Thirty-two crossbred barrows (N=32; Topigs Norsvin females X Compart Duroc boars) were selected with a mean initial body weight of 82.5 kg (Final BW 85.1 kg). Pigs were individually housed in stainless steel metabolism crates (2.0 m x 0.7 m) equipped with slatted floors with free access to nipple waterers. These waterers had meters attached to monitor daily water intake. The metabolism crates had metal pans installed underneath with spouts which funneled into plastic buckets for total urine collection. These buckets contained 10 mL of 6 N HCl to maintain urine quality. Mesh screens were placed atop the steel pans for total fecal collection. The screens separated the feces from the urine.

Pigs were fed twice daily at 0800 h and 1600 h. Upon entry into the metabolic facility, 32 barrows were randomly assigned to 1 of 4 dietary treatments (n=8). Diet Nutrient Compositions are presented in Table 3.1: (1) Dry, control corn-soybean meal (2)

Dry, control with 30% DDGS (3) Liquid, control corn-soybean meal and water (4) Liquid, control basemix with 20% syrup and 30% whole stillage.

Liquid feed diets were mixed with a manual concrete mixer as they contained dry feed with liquid co-products. Pig BW was measured at the beginning and end of the trial. The amount of feed given was calculated, which was 4% of the initial BW. The amount of feed provided to animals was recorded at each feeding time. Rations were mixed right before all feedings and dispensed immediately. Room temperature was maintained at 20 ± 1°C.

Sample Collection

Pigs were allowed 4 days for adaptation to the crates with 4 days of sample collection. Fecal grab samples were collected twice daily after feeding by anal palpation. Samples were directly placed into aluminum pans and stored at -20°C. Depending on the initial collection volume of urine, 5 or 10% was sub-sampled at the end of each day and stored at -20°C. Weight and volume of urine samples were measured. At the end of each day, all feces from the screens and non-sub-sampled urine from each pig were pooled into 5 gallon buckets and covered. At the end of the collection period, these buckets of feces and urine mixture, termed slurry, were allowed to sit for 3 weeks to mimic pit conditions in typical finishing barns. After the 3 weeks, the slurry samples were stirred to create a uniform mixture. Two liter sub-samples were collected and stored in -20°C. Feed samples were collected on the day 1 before the first feeding and stored at -20°C. Laboratory analyzed compositions for the diets fed are provided in Table 3.5. Feed refusals were collected and weighed at the end of the study to reflect intake.

Sample Preparation and Chemical Analysis

All diet samples were analyzed for GE, CP, NDF, ADF, EE, ash content, and DM. All samples were done in duplicate to ensure accuracy.

Feed, fecal, urine, and slurry samples were thawed and mixed for uniform quality. 50 mL of urine and slurry were sub-sampled for nutrient analysis. Fecal samples were dried in a forced oven blower at 56°C for 48 h, and ground into a fine powder with a blender to a particle size of 1 mm. Feces was measured and calculated for CP, N, P, GE, DM, Ash, and AIA. Urine was measured for CP, N, P, GE, and DM. Slurry was measured for CP, N, P, K, S, and DM.

Feed samples were dried at 56 °C for 48h in a forced oven. The total ash content of the samples was weighed before and after ashing in a high temperature muffle furnace at 600 °C for 6h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc., Hampton, New Hampshire).

Nitrogen (N) in all samples was determined using the Kjeldahl method (method 976.05, AOAC, 2000; Kjeltec 2300 Analyzer, Foss, Höganäs, Sweden). Crude protein (CP) was found by multiplying the N value by 6.25. Gross energy (GE) was determined via bomb calorimetry with the IKAR-WERKE c2000 bomb calorimeter (IKA Werke GmbH & Co. KG, Staufen, Germany). Dry matter was analyzed by AOAC (2000) method 939.01. Dry matter (DM) was by heating the samples at 105°C for 4 h. Fiber samples were analyzed for NDF and ADF via a filter bag technique (ANKOM2000 fiber analyzer, methods 12 & 13, respectively, ANKOM Technology, Macedon, NY). Crude fat was analyzed by the ether extract method (AOCS, 2009 method Am 5-04) using

ANKOM XT15 extraction system (ANKOM Technology, Macedon, NY). Ether extract was found using the ANKOM XT15 extraction system and ANKOM hydrolysis system. For ash content, feed and feces samples were digested for 30 minutes at 150°C using the FOSS Tecator digestion system. Tube contents were filtered through ash less filter paper via a funnel. The pH of the leftover residue was measured with litmus paper to ensure neutrality. The drained filter paper was subjected to ashing after being burned in a muffle furnace at 650°C for 6 h. Ash content was found by calculating the difference in weight of samples before and after. Acid insoluble ash (AIA) content of feed, and feces was calculated by the method of McCarthy et al., (1974).

Calculation and Statistical Analysis

Normality and homogeneity of variance of variables were determined using the UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Data were analyzed by ANOVA using the PROC Mixed SAS in a randomized complete block design with the individual pig as the experimental unit. The statistical model included treatment as the fixed effect and block as a random effect. When diet was a significant source of variation, treatment means were separated using the LSMEANS statement and multiple comparison was done by Tukey correction of PROC GLM. Statistical significance was considered at $P < 0.05$ and trends were considered at $P < 0.10$.

Results

Four diets (Table 3.1) with some containing ethanol co-products (Liquid ethanol co-products Nutrient profiles: Table 3.2) were fed to growing pigs housed in metabolism crates to measure Nitrogen, Phosphorus, and energy digestibility along with urine and fecal output to measure slurry characteristics.

Apparent Nutrient Digestibility (AND) was calculated according to the following equation adapted from Zhang et al., (2016):

$$AND_{Nutrients} = 1 - \{(Nutrient_{Feces} / Nutrient_{Diet}) \text{ X } (AIA_{Diet} \text{ X } AIA_{Feces})\}$$

Results from the metabolism balance study for Nitrogen, Phosphorus, and energy digestibility are reported in Table 3.3. For Nitrogen digestibility, feeding liquid corn-SBM significantly reduced both percent of N intake and percent of digestible N when compared to all other diets ($P < 0.01$). Dry corn-SBM, DDGS, and CCDS + CDWS were similar in terms of N intake and utilization ($P > 0.05$).

In terms of Phosphorus digestibility, liquid feeding corn-SBM resulted in the greatest percent of P intake while dry feeding corn-SBM resulted in the lowest percent P intake ($P < 0.01$). Dry diets reduced P intake and percent digestible P when compared to liquid diets ($P < 0.01$). Regardless of dietary form, no difference was found between feeding DDGS and CCDS + CDWS as they were similar in percent P intake ($P > 0.05$). For digestible P, both liquid diets were significantly greater than contemporary dry diets indicating greater P utilization associated with liquid feeding ($P < 0.01$).

For energy digestibility, dry fed diets were far greater in terms of percent of GE intake than liquid diets ($P < 0.01$). Following a similar pattern, dry diets were significantly higher in percent of digested energy than liquid diets ($P < 0.01$). Within liquid diets, liquid feeding CDWS + CCDS resulted in greater percent GE intake and percent digestible energy than liquid corn-SBM ($P < 0.01$). Feeding dry diets allowed for greater energy retention and utilization for pigs when compared to the contemporary liquid diets ($P<0.01$). When comparing feeding dry versus liquid ethanol co-products, feeding DDGS resulted in greater energy intake and percent digestible energy ($P<0.01$).

From the metabolism trial, slurry samples were collected to measure nutrient composition. The slurry nutrient profile is presented in Table 3.4. To obtain slurry, urine and feces from the metabolism trial were pooled in plastic buckets and allowed to sit to mimic typical pit conditions. Slurry, a mixture of urine and feces that pool in a pit underneath finishing barn pen floors, are typically spread on fields to be used as crop fertilizer.

On a fresh, as-is basis, liquid diets were higher in slurry moisture content than dry diets ($P<0.01$). For total Nitrogen and Phosphorus content, dry diets were much greater in concentration of N and P than liquid diets ($P<0.01$). Liquid feeding corn-SBM reduced potassium concentration ($P<0.01$). Dry corn-SBM, DDGS, and CCDS + CDWS were similar in K concentration ($P>0.05$). For Sulfur concentration, feeding DDGS resulted in the greatest concentration among the diets ($P<0.01$) while feeding dry corn-SBM and liquid ethanol co-products resulted in similar levels ($P>0.05$). Liquid feeding corn-SBM resulted in a significantly lower concentration of S when compared to the other diets ($P<0.01$).

On DM basis, liquid corn-SBM had the greatest total N content among the diets ($P<0.01$). Dry corn-SBM, DDGS, and CCDS + CDWS were similar in N content ($P>0.05$). No difference was found for P content across all diets ($P>0.05$). For both K and S content, liquid feeding CCDS + CDWS resulted in the highest concentration when compared to the other diets (P<0.01). Feeding DDGS resulted in the lowest K concentration among the diets (P<0.01). Feeding dry corn-SBM, DDGS, and liquid corn-SBM were similar in S concentration on a DM basis (P>0.05).

Discussion

Pigs fed liquid corn-SBM fell behind in terms of performance as they had reduced N intake and digestible N along with much lower GE intake and digestible energy. This most likely can be attributed to the high moisture content of the feed mixture. High moisture co-products can sometimes be variable in quality due to greater liquid portion when compared to contemporary diets (Shurson, 2006).

Dry fed diets resulted in greater dietary energy utilization, and were similar to values reported for DDGS energy digestibility by Pahm et al., (2008). As previously reported by Shurson et al., (2000), DDGS is a viable replacement for corn-SBM as it is comparable in energy content, nitrogen, and digestible P values. Spiehs et al., (2000) fed DDGS and also found increased N and GE intake when compared to a basal corn-SBM diet.

Liquid feeding ethanol co-products resulted in similar performance for N utilization to both dry diets. Soares et al., (2011), fed liquid condensed solubles and found a CP digestibility around 41.7, similar to the levels found in the present study. Scholten et al., (1999) reported that feeding liquid co-products can result in highly digestible CP values meaning these co-products are viable in swine diets. Feeding liquid ethanol co-products CCDS and CDWS resulted in lower values than Scholten (1999) reported.

However, feeding CCDS and CDWS is still viable to growing swine in terms of meeting their N intake levels.

Liu et al., (1997) and Zhu et al., (2011) showed that soaking feed in liquid solution improves P utilization. Similarly the present study demonstrated greater P intake and percent digestible P in liquid diets when compared to dry diets. These findings are slightly contradictory to the results reported by Pedersen and Stein (2010) stating that mixing water and feed at a 3:1 ratio showed no difference for ATTD of P. In the study by Pedersen and Stein (2010), feed was allowed to steep for 24 hours with minor fermentation allowed. In the present study, liquid fed diets were mixed immediately before feeding with no fermentation being allowed.

An issue with liquid feeding corn-SBM was settling and diet acceptability. Although feed was immediately dispersed, the solid corn particles tended to settle more easily in the liquid solution within the feeder. Furthermore, at times the water used in the diet mixture was colder than room temperature. These issues led to less acceptability and consumption for pigs fed liquid control corn-SBM.

As outlined by Sutton et al. (2001), manure composition largely depends on dietary composition of rations fed to livestock. Fertilizer quality is typically evaluated by the content of N, P, K along with crop system and source (Massey 2007). Livestock manure can be used as a substitute for fertilizer and is an efficient way to recycle nutrients from plant sources. Swine manure has been reported to be effective in increasing crop yield and specifically N, P, and K concentration of plant nutrients

(Choudhary et al., 1996). The main nutrients available to the plant from manure include total N, P, K, and S.

On a fresh basis from the present study, dry diet slurry was greater in total N and P content when compared to liquid diets. When looking within dry diets, no differences were found for total N, P, or K. These findings are similar to the results reported by Widyaratne and Zjilstra (2007) where no differences were found for N and P excretion output content when compared to contemporary DDGS diets.

Other than liquid corn-SBM, feeding liquid ethanol co-products produced slurry lower in N and P concentration while being similar in K and S content when compared to dry diets. Similar results were reported by Gralapp et al., (2002), supporting the result of the present study that feeding DDGS increased the rate of S content in slurry.

On an as-is basis for N and P, dry fed diets were greater in total N and P content. Spiehs et al., (2000) also simulated anaerobic manure conditions and found that feeding DDGS slightly increased N excretion. The present study did not see a similar rise in N excretion via slurry when feeding DDGS which may be attributed to variability between plants. Liquid feeding ethanol co-products resulted in comparable K content to dry diets. However, liquid feeding ethanol co-products reduced the level of total N and P. Brooks et al., (2003) reported similar reduced N levels when liquid feeding co-products.

Conclusion

Liquid feeding the ethanol co-products CDWS and CCDS can attain similar performance to contemporary dry diets for N digestibility in terms of similar N intake and percent digestible N values. For P utilization, feeding ethanol co-products had greater levels of P intake and digestible than dry diets. However in terms of energy intake and utilization, liquid fed diets were greatly reduced. If properly managed, liquid feeding ethanol co-products can be a viable source of N and P. Special attention should be noted for the lower energy value and be taken into account upon formulation when considering feeding these co-products.

Swine manure has long been used as an alternative for crop fertilizer and typically can increase yield 10-15% from the high levels of N, P, and K within the slurry. Although lower in N and P, liquid feeding ethanol co-products yields slurry that is comparable in K and S, and therefore is a viable alternative for potential as fertilizer use. Feeding these co-products are viable alternatives.

Table 3.1: Ingredients and nutrient composition of experimental diets for nutrient balance (as fed basis)

Ingredients	[1]DC	[2]DT	[3]LC	[4]LT
Corn	74.26	54.54	74.26	31.88
Soybean meal (CP 47.5%)	20	10	20	12
Corn condensed distillers solubles				20
Corn whole stillage				30
DDGS		30		
Choice white grease	1.77	1.46	1.77	2.65
Limestone, ground	0.75	1.08	0.75	2.1
Calcium phosphate (dicalcium)	1.82	1.4	1.82	
L-Lys-HCL	0.37	0.54	0.37	0.38
DL-Met	0.12	0.05	0.12	0.05
L-Thr	0.11	0.1	0.11	0.13
L-Trp		0.03		0.01
Sodium chloride	0.3	0.3	0.3	0.3
Vitamin-trace mineral premix	0.5	0.5	0.5	0.5
Total	**100.00**	**100.00**	**100.00**	**100.00**
Calculated nutrients				
ME (kcal/kg)	3350	3350	3350	3350
SID Lys (%)	0.95	0.95	0.95	0.95
SID Met (%)	0.33	0.32	0.33	0.31
SID Met+Cys (%)	0.55	0.55	0.55	0.55
SID Thr (%)	0.59	0.59	0.59	0.59
SID Trp (%)	0.16	0.16	0.16	0.16
Total P (%)	0.60	0.60	0.60	0.93
ATTD P (%)	0.34	0.35	0.34	0.52
Ca (%)	0.80	0.80	0.80	0.80
Analyzed Value (% unless noted)				
GE (kcal/kg)	3497	3489	3352	3583
CP	15.2	16.5	17.1	17.7
NDF	13.6	16.8	15.4	16.2
ADF	4.1	6.8	5.5	6.4
Ether Extract	4.7	6.8	7.3	8.5
AIA	0.30	0.30	0.33	0.34
DM	89.4	88.9	20.2	21.5

[1]DC = Dry Control, corn-SBM, [2]DT = Dry Test, corn-SBM + 30% DDGS, [3]LC = Liquid Control, corn-SBM + Water, [4]LT = Liquid Test, corn-SBM + 30% CDWS + 20% CCDS

Table 3.2: Analyzed nutrient composition of Liquid Ethanol Co-Products (g/kg, dry matter basis unless otherwise indicated)

Nutrients	Corn condensed distillers solubles (CCDS)	Corn distillers whole stillage (CDWS)
Dry matter (as-fed basis)	332.6	92.2
Gross energy (MJ/kg)	18.9	21.8
Crude Protein	219.3	269.2
Acid-hydrolyzed ether extract	66.4	156.7
Neutral detergent fiber	30.3	269.5
Acid detergent fiber	15.6	96.1
Phosphorus	32.0	11.5
Starch	25.2	27.9
Indispensable amino acids		
Arginine	10.6	11.8
Histidine	6.7	7.3
Isoleucine	6.5	9.6
Leucine	15.9	28.7
Lysine	10.2	9.7
Methionine	3.3	5.0
Phenylalanine	9.4	13.6
Threonine	7.9	10.1
Tryptophan	1.6	2.2
Valine	9.7	13.1
Dispensable amino acids		
Alanine	12.4	17.7
Aspartate + asparagine	12.9	16.8
Cysteine	4.5	5.4
Glutamate + glutamine	22.5	36.4
Glycine	10.6	11.3
Proline	14.3	19.9
Serine	9.0	12.3
Tyrosine	6.2	9.4

Table 3.3: Effect of ethanol co-products on Nitrogen, Phosphorus, and Energy digestibilities in growing pigs

Item (%)	[1]DC	[2]DT	[3]LC	[4]LT	SEM	P-value
N Intake	40.3^{a}	40.8^{a}	25.0^{b}	39.4^{a}	2.2	<0.0001
Digested N	58.9^{a}	59.7^{a}	35.2^{b}	61.0^{a}	3.1	<0.0001
P Intake	24.2^{c}	30.3^{bc}	45.6^{a}	38.4^{ab}	2.5	<0.0001
Digested P	71.7^{b}	65.6^{b}	82.8^{a}	84.1^{a}	2.0	<0.0001
Energy Intake	49.6^{a}	45.9^{a}	8.4^{c}	27.9^{b}	3.3	<0.0001
Digested Energy	71.2^{a}	71.0^{a}	15.1^{c}	43.5^{b}	5.5	<0.0001

[1]DC = Dry Control, corn-SBM
[2]DT = Dry Test, corn-SBM + 30% DDGS
[3]LC = Liquid Control, corn-SBM + Water
[4]LT = Liquid Test, corn-SBM + 30% CDWS + 20% CCDS

[abc] Means (a, b, c) within a row with different superscripts are significantly different at (P<0.05)

Table 3.4: Effects of ethanol co-products on characteristics of pig slurry

	Dietary Treatment					
	[1]DC	[2]DT	[3]LC	[4]LT	SEM	P-value
	As-is basis					
Moisture, %	94.7[b]	94.5[b]	98.6[a]	97.3[a]	0.33	<.0001
Total nitrogen, %	1.08[a]	1.09[a]	0.45[b]	0.57[b]	0.07	<.0001
Phosphorus as P_2O_5, %	0.59[a]	0.54[a]	0.18[b]	0.27[b]	0.04	<.0001
Potassium as K_2O, %	0.63[a]	0.54[a]	0.23[b]	0.56[a]	0.03	<.0001
Sulfur, ppm	1228[b]	1591[a]	440[c]	1198[b]	75	<.0001
	Dry matter basis					
Total nitrogen, %	20.4[b]	20.2[b]	31.7[a]	21.7[b]	1.3	<.0001
Phosphorus as P_2O_5, %	11.2	9.8	12.4	10.6	0.7	0.0945
Potassium as K_2O, %	12.8[bc]	9.9[c]	16.1[b]	21.3[a]	1.2	<.0001
Sulfur, ppm	24929[b]	29453[b]	31325[b]	45354[a]	2413	<.0001

[1]DC = Dry Control, corn-SBM
[2]DT = Dry Test, corn-SBM + 30% DDGS
[3]LC = Liquid Control, corn-SBM + Water
[4]LT = Liquid Test, corn-SBM + 30% CDWS + 20% CCDS

[abc] Means (a, b, c) within a row with different superscripts are significantly different at (P<0.05)

CHAPTER 4

Influence of Ethanol Co-Products and Barley Supplementation on Growth Performance and Carcass Characteristics of Growing-Finishing Pigs in Dry and Liquid Feeding Systems

Abstract

The objective of this study was to compare feeding dried distiller grains with solubles (DDGS), liquid feeding corn distillers whole stillage (CDWS), corn condensed distillers syrup (CCDS), and barley to grow-finish swine on growth performance and carcass characteristics and to determine if partial replacement of ethanol co-products with barley would have an effect on meat quality. Four-hundred and eighty pigs (N=480) were blocked by weight (25.8 ± 0.43 kg) and randomly assigned to one of six dietary treatment groups via a randomized complete block design (n=80; 10 pigs/pen; 8 pens/treatment). Diets, formulated to be isocaloric and isonitrogenous, were: (1) Dry, Control, corn-SBM phases 1 through 4. (2) Dry, DDGS (Phase 1: 20%, Phases 2-4: 30%). (3) Dry, DDGS (Phase 1: 20%, Phases 2 and 3: 30%, Phase 4: 15% DDGS + 15% barley). (4) Liquid, control, corn-SBM and water phases 1-4. (5) Liquid, Ethanol co-products (Phase 1:16% CCDS + 24% CDWS, Phases 2 and 3: 20% CCDS + 30% CDWS, Phase 4: 24% CCDS + 36% CDWS). (6) Liquid, Ethanol co-products (Phase 1:16% CCDS + 24% CDWS, Phases 2 and 3: 20% CCDS + 30% CDWS, Phase 4: 15% CCDS + 30% CDWS + 15% barley). All pigs were weighed d0, d28, d56, d84, and d112. Pigs were marketed at 127 kg, therefore liquid feeding pigs were allowed two more weeks on feed to meet market weight. Growth performance parameters ADG, ADFI, and G:F were calculated on pen basis. Carcasses were measured for HCW, fat depth, loin depth, percent lean, and dressing percent. Data were analyzed using PROC-MIXED procedure of SAS. Statistical significance was set at $P \leq 0.05$. Across all diets, feeding dry corn-SBM had the greatest performance in terms of final BW, ADG, and G:F ($P<0.01$). Furthermore, pigs fed barley had reduced ADG and ADFI which yielded lighter HCW and shallower loin depth (P<0.01). Feeding DDGS had similar performance to dry corn-SBM however belly firmness was significantly reduced (P<0.01). Feeding liquid ethanol co-products resulted in greater G:F and reduced ADFI when compared to liquid corn-SBM diets (P<0.01). Upon harvest, no differences were found among liquid diets. Pigs fed dry corn-SBM and DDGS had greater loin depths than those fed liquid ethanol co-products and barley (P<0.01). For pigs fed DDGS, CDWS, and CCDS, belly firmness was reduced due to the greater level of PUFA and IV leading to softer bellies (P<0.01). In conclusion, dry feeding was superior in growth performance and carcass characteristics as they reached market readiness than compared to liquid fed pigs. Feeding ethanol co-products is an effective cost savings strategy, however belly firmness may be an issue with the current feeding method.

(Key words: pigs, whole stillage, condensed distillers solubles, growth performance, carcass characteristic, liquid feeding, ethanol co-products, barley, iodine value, belly firmness)

Introduction

Many research trials for liquid feeding have used barley and wheat as the majority of ration with varying inclusion levels of co-products. European swine research institutions have studied several different co-products including: whey, brewer's yeast, corn steep water, vegetable peels, and bakery products (Crawshaw, 2001). By feeding these co-products to growing swine, researchers demonstrated improved animal performance and carcass merit at a lower cost to the producer (Braun and de Lange, 2004). From these results interest grew in North America after seeing the perceived benefits and recognizing liquid feeding success in Europe.

The rise in ethanol production in the Midwest led to the arrival of new co-products with potential in livestock diets (Spiehs et al., 2002). Research began immediately throughout the Midwest on determining the value of these co-products in swine diets as the ethanol plants began marketing the co-products to producers. As liquid feeding in the United States was a novelty, the majority of leftover product after the ethanol was distilled ultimately ended up as DDGS in order to make it as close compositionally to feedstuffs regularly found in rations.

Many research trials were conducted on evaluating and finding the effects of feeding DDGS. Many reports (Beltranena et al., 2009; Lampe et al., 2006; US Grains Council, 2012) found the maximum inclusion level to be up to 30% to attain similar performance with conventional corn-SBM diets, however encountered softer meat end-products with feeding DDGS. The process of drying DDGS greatly increases the energy expenditure and cost of the ethanol process. To offset the energy cost, nutritionists and producers fed the high-moisture co-products as-is knowing it was a possible way to feed livestock.

As interest grew in liquid feeding systems in the Midwest, researchers began to evaluate the high moisture liquid ethanol co-products like CDWS, CWDG, and CCDS including Baidoo (2014) and Meried (2014). Feeding these co-products required different storage and feeding systems making it more difficult to research without the proper equipment.

The hypotheses of this trial are:

(1) Feeding ethanol co-products will not influence growth performance and carcass characteristics of grow-finish pigs

(2) Partial replacement of ethanol co-products with barley in late finishing will improve belly firmness

With limited knowledge of feeding CDWS and CCDS to growing swine, our purpose was to:

(1) Evaluate the ethanol co-products and measure growth performance and carcass characteristics

(2) The effect of replacing a portion of the ethanol co-products with barley in the late-finishing phase diet on carcass characteristics

Materials and Methods

The University of Minnesota Institute of Animal Care and Use Committee reviewed and approved the experimental protocol which was conducted at the Southern Research and Outreach Center in Waseca, MN.

Experimental Design

This study was conducted in the wean-to-finish barn at the Southern Research & Outreach Center, located in Waseca, MN in environmentally controlled rooms. The barn contains 4 rooms with 2 designed for each set-up, with 16 pens in each room. Four hundred and eighty pigs (N=480; Topigs Norsvin females X Compart Duroc boars) were weaned at 18 ± 3 d of age with an average BW of 6.1 ± 0.17 kg. Pigs were ear-tagged for identification at weaning, blocked by body weight, and randomly assigned to 6 dietary treatments with 8 pens per treatment and 10 pigs (5 barrows and 5 gilts) per pen using a completely randomized block design (n=80). During the nursery phase, all pigs were fed the similar corn-soybean meal diets differing between dry and liquid systems. At the end of the nursery phase on d 42, the pigs began receiving their dietary treatments for the finishing phase. Average BW at the beginning of the grow-finishing period was 25.7 ± 0.43 kg.

Diets: (1) Dry, Control, corn-SBM phases 1 through 4. (2) Dry, DDGS (Phase 1: 20%, Phases 2-4: 30%), with corn-SBM basemix. (3) Dry, DDGS (Phase 1: 20%, Phases 2 and 3: 30%, Phase 4: 15% DDGS + 15% barley), with corn-SBM basemix. (4) Liquid, control, water with corn-SBM phases 1-4. (5) Liquid, Ethanol co-products (Phase 1:16% WS + 24% Syrup, Phases 2 and 3: 20% WS + 30% syrup, Phase 4: 24% WS + 36%

syrup). (6) Liquid, Ethanol co-products (Phase 1:16% WS + 24% Syrup, Phases 2 and 3: 20% WS + 30% syrup, Phase 4: 20% WS + 15% syrup + 15% barley). Table 4.6 provides the Liquid Feeding Trial Ingredient Compositions. Phase Dietary composition values are presented in Table 4.7 (Phase 1), Table 4.8 (Phase 2), Table 4.9 (Phase 3), and Table 4.10 (Phase 4).

Within each phase, the experimental diets were formulated to meet or exceed nutrient requirements for wean to finish pigs (NRC, 2012). The diets were formulated to be isocaloric and isonitrogenous. All pens had concrete slats and a water bowl for free access. On the liquid feeding side, each pen had a single feed trough with sensor connected to a pipeline system from the computer automated command center. On the dry feeding side, each pen had standard metal hog feeders which were manually filled by barn staff with a Mosdal feed cart and auger system (Mosdal Scale Systems, Inc. Broadview, MT).

Pigs in the dry feeding system were fed on trial for 112 days during the finishing period before marketing at the goal weight of 127 kg. The liquid feeding pigs required 14 more days to reach the goal weight resulting in 126 days on trial. In this study, the Big Dutchman (Big Dutchman, Holland, MI, USA) computerized liquid feeding system was used to feed the pigs. This system is controlled by computer software, therefore feeding was managed automatically. The feeding amount and times were determined and programmed based on feed curves related to pig BW. The software controlled feeding was automatically managed based on sensor information of the individual trough. Data on amount of feed disappearance was also recorded.

Description of Liquid Feeding System

A basal diet, stored in a feed bin, provided vitamins, minerals, corn, soybean meal, choice white grease, and essential amino acids. This basal diet was added to water, mixed and pumped to the individual pens. All these processes were controlled by a computer system in the liquid feeding room. The computer system controlled diet preparation, feed mixing for individual pens, and monitored weight changes of the tank. The tank mixed for approximately 7 minutes at varying speeds to produce a uniform feed mixture. The ratio of water to feed was set in the program. Immediately after mixing, the pressurized pump lines would disperse the liquid feed to the corresponding pens. After each feeding, the pipes were rinsed with high pressure water to clear any remaining feedstuffs prior to preparation for the next batch. Feed allowance was increased based on the feed curve that was related to the estimated BW. Pigs were fed up to 8 times a day using the computerized liquid feeding system.

Sample and Data Collection

For each phase, diet samples were collected of all different feedstuffs. Pig BW were measured at the beginning and end of the trial, and at the end of each phase (d0, d28, d56, d84, and d112). From these measures, the performance parameters average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) were determined. Growth performance parameters were calculated per pen on a weekly basis. Pigs were observed daily for signs of morbidity and mortality, feed and water outages, and environmental temperature. Daily minimum and maximum temperatures were recorded in the morning.

Carcass Evaluation

At day 112, the dry feeding pigs were shipped to a commercial Tyson Meats packing plant in Waterloo, IA where data on standard carcass measurements including HCW, dressing percentage, fat depth, loin depth, and lean percent were collected. 18 of these pigs were retained for belly flop testing at a smaller butcher shop. Prior to shipping, blood was collected from the 18 pigs to obtain serum for BUN analysis.

The 18 pigs retained were sent to Morgan's Meats in New Richland, MN, for harvest where leaf fat samples were collected. Leaf fat samples were collected from each carcass for fatty acid profile analysis via gas chromatography (Agricultural Utilization Research Institute, Marshall, MN)

Iodine value equation:

$$= [C16:1] \times 0.95 + [C18:1] \times 0.86 + [C18:2] \times 1.732 + [C18:3] \times 2.616 + [C20:1] \times 0.785 + [C22:1] \times 0.723$$

After sitting in the cooler for 4 days, the carcasses were processed at which time the belly flop test was conducted. The belly flop test determines the firmness and overall quality of the belly. Once the belly is removed from the carcass, the lateral length was measured on a flat surface. Then the belly was placed over a steel rod and allowed to naturally flop. Once the sides were level, the vertical and lateral flexes were measured. These three measurements (length, vertical flex, and lateral flex) were input into an equation to determine the angle of belly flop. The same test was conducted for all 18 carcasses. Belly firmness scores were calculated according to Whitney et al., (2006) with the equation below:

Belly firmness score = cos-1{[0.5(L2) − D2] / [0.5(L2)]}

*Where L = belly length measured on a flat surface and D = the distance between the 2 ends of a suspended belly; greater belly firmness scores indicate firmer bellies

At day 126, a similar timeline took place for the liquid feeding pigs. All but 18 pigs were shipped to Tyson Meats in Waterloo, IA. Similar carcass measurements were collected. The retained 18 had blood collected before being sent to Morgan's Meats. Upon harvest, leaf fat samples were collected. 4 days later the belly flop test was conducted for all 18 carcasses.

Chemical Analysis

All diet samples were analyzed for DM, gross energy, CP, ether extract by acid hydrolysis, neutral detergent fiber, acid detergent fiber, and ash content. All the analyses were done in duplicate. Feed samples were dried at 56 °C for 48h in a forced oven. Dry matter was analyzed by AOAC (2000) method 939.01. The CP was determined using Kjeldahl method (method 976.05, AOAC, 2000; Kjeltec 2300 Analyzer, Foss, Höganäs, Sweden). Gross energy was determined by bomb calorimetry with a IKA WERKE c2000 basic bomb calorimeter (IKA Werke GmbH & Co. KG, Staufen, Germany). Crude fat was analyzed by the ether extract method (AOCS, 2009 method Am 5-04) using ANKOM XT15 extraction system (ANKOM Technology, Macedon, NY). Samples were analyzed for NDF and ADF using a filter bag technique (ANKOM2000 fiber analyzer, method 12 and 13, respectively; ANKOM Technology, Macedon, and NY). The total ash content of the samples was weighed before and after ashing in a high temperature muffle furnace at 600 °C for 6h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc., Hampton, New Hampshire).

Blood urea nitrogen (BUN) was measured with the Liquid Urea Nitrogen Reagent Set manufactured by Pointe Scientific, Inc (Canton, MI, USA). Blood samples were taken from eighteen pigs from both dry and liquid feeding systems. The blood was centrifuged at 1500 rpm for 15 minutes to obtain the serum for BUN analysis. To read absorbance, a thermos scientific Genesys 20 spectrophotometer was used. The spectrophotometer was calibrated at 340 nm with deionized water at zero absorbance. After reaching 37°C in a water bath, the tubes were placed directly in the spectrophotometer. Absorbances were measured at 30 s, and again 60 s after the first reading. Changes in absorbance were recorded to calculate the change in BUN.

Serum BUN was calculated by using the equation in mg/dL :

$$= (\Delta A \text{ serum} / \Delta A \text{ standard}) \times 30 \text{ (the concentration of the standard)}$$

Where Δ A serum is the change/decrease in the absorbance of the serum sample, Δ A standard is the change/decrease in the absorbance of the standard. 30 is the concentration of the standard used.

Statistical Analysis

Pen was used as experimental unit. Data were subjected to analysis of variance (ANOVA) based on the general linear model of procedure of SAS, version 9.4 (SAS Institute Inc., Cary, NC). Treatment and block were considered as a source of variation. Initial body weight was used as a covariant for growth performance data. Least squares means were separated by the PDIFF and Tukey's test option. Repeated measures test was conducted for growth performance data with four different time points. Statistical significance was determined at the $P < 0.05$.

Results

Results for growth performance from the grow-finish trial are presented in Table 4.1. In the initial phase, all dry fed diets had greater ADG when compared to the liquid diets ($P<0.01$). No differences were found within dry and liquid diets ($P>0.05$). Liquid feeding ethanol co-products CDWS + CCDS reduced ADFI when compared to all dry diets ($P<0.01$). Dry feeding corn-SBM and DDGS resulted in greater G:F efficiency than liquid feeding corn-SBM ($P<0.01$).

For the second finish phase, no difference was found across all diets for ADG ($P>0.05$). Pigs fed DDGS consumed more than those fed CCDS + CDWS ($P<0.01$). Feeding dry corn-SBM and liquid feeding CDWS + CCDS resulted in greater efficiency when compared to feeding DDGS ($P<0.05$). At the end of phase 2, pigs fed dry corn-SBM were heavier than all liquid fed diets. Within liquid diets, feeding liquid corn-SBM resulted in heavier pigs ($P<0.01$).

For the third finish phase, no difference was found across all diets for ADG ($P>0.05$). Feeding DDGS and liquid corn-SBM resulted in similar intake ($P>0.05$). Across all diets, feeding ethanol co-products CCDS + CDWS reduced intake ($P<0.01$). No difference was found for G:F efficiency across all diets ($P>0.05$). At the end of the third phase, all dry fed pigs were heavier than all liquid fed pigs ($P<0.01$). Within dry and liquid diets, no differences were found for BW ($P>0.05$).

For the final finish phase, it is important to note that barley replaced 15% of DDGS in diet 3, and 15% of CCDS in diet 6. Across all diets, partial barley replacement reduced ADG (P<0.01). Within dry diets, feeding barley reduced ADG (P<0.01). Within liquid diets, those fed CCDS + CDWS showed greater gain than those fed CCDS + CDWS + barley (P<0.01).

For ADFI, liquid corn-SBM fed pigs consumed the most at 3.70 kg/d across all diets (P<0.01) while pigs fed dry DDGS + barley consumed the least amount across all diets at 2.75 kg/d (P<0.01). Within liquid diets, pigs fed liquid corn-SBM had greater intake than both diets containing liquid ethanol co-products (P<0.01). Within dry diets, those fed DDGS consumed more than those fed corn-SBM and DDGS + barley (P<0.01). Barley replacement significantly reduced ADFI in dry diets (P<0.01).

Gain efficiency was reduced for pigs fed liquid corn-SBM and CCDS + CDWS + barley when compared to dry corn-SBM and DDGS + barley (P<0.01). In dry diets, efficiency was similar for phase 4 (P>0.05). Final BW was significantly reduced for those fed DDGS + barley when compared to dry control and DDGS (P<0.01). Similarly within liquid diets, those fed CCDS + CDWS + barley were lighter in weight (P<0.01).

Over the entire grow-finish period, feeding dry corn-SBM and DDGS resulted in greater ADG than liquid feeding corn-SBM, CCDS + CDWS, and CCDS + CDWS + barley (P<0.01). Feeding DDGS and liquid corn-SBM resulted in the greatest intake while feeding DDGS + barley, CCDS + CDWS, and CCDS + CDWS + barley reduced ADFI (P<0.01). Feeding dry corn-SBM resulted in the greatest efficiency while feeding liquid corn-SBM was the least efficient across the diets (P<0.01). Barley slightly reduced efficiency in liquid diets when compared to dry diets (P<0.01).

Data on carcass characteristics for the grow-finish trial are reported in Table 4.2. No differences were found for carcass characteristics across all diets for HCW, fat depth or dressing percentage (P>0.05). Loin depth was significantly greater for pigs fed dry diets when compared to liquid diets (P<0.01). Within liquid diets, those fed ethanol co-products resulted in shallower loin depths when compared to control corn-SBM (P<0.01). Pigs fed dry corn-SBM and DDGS yielded leaner carcasses when compared to liquid corn-SBM and CCDS + CDWS fed pigs (P<0.01).

Data for blood urea nitrogen (BUN) levels are presented in Table 4.3. No difference was found across all diets for blood urea nitrogen level (P>0.05).

Data for belly thickness and firmness scores are presented in Table 4.4. No difference was found across all diets for belly thickness (P>0.05). Feeding ethanol co-products DDGS and CCDS + CDWS significantly reduced belly firmness when compared to control corn-SBM diets (P<0.01). Within test diets containing ethanol co-products, no differences were found for belly firmness (P>0.05). No statistical difference was found when replacing DDGS with barley in dry diets (P>0.05). Similarly, no difference was found when 15% of CCDS was replaced with barley for liquid diets (P>0.05). Feeding corn-SBM, regardless of dietary form, greatly increased belly firmness scores.

Data for Leaf Fat Fatty Acid Profiles are presented in Table 4.5. Liquid corn-SBM had a higher concentration of myristic acid than CCDS + CDWS + barley (P<0.01).

Leaf fat samples from pigs fed liquid ethanol co-products had significantly reduced levels of palmitic acid (P<0.01). Pigs fed CCDS + CDWS had greater levels of margaric acid than those fed dry corn-SBM (P<0.01). Feeding liquid ethanol co-products resulted in decreased levels of stearic acid (P<0.01). No differences were found for arachidic acid among the diets fed (P>0.05). Liquid ethanol co-products resulted in reduced levels of palmitoleic acid (P<0.01). Feeding dry corn-SBM resulted in greater levels of oleic acid than those fed only CCDS + CDWS (P<0.01). Dry diets were greater in oleic acid concentration when compared to those fed liquid ethanol co-products (P<0.01). Dry corn-SBM diets were greater in gondoic acid than those fed CCDS + CDWS + barley (P<0.01).

For linoleic acid, dry based diets were lower in concentration than liquid diets (P<0.01). Pigs fed liquid ethanol co-products had greater levels of linoleic acid across all diets (P<0.01). Similarly for α-linolenic acid, dry diets were lower than liquid diets (P<0.01). Liquid ethanol co-products levels were also higher for ALA (P<0.01). Feeding liquid ethanol co-products resulted in greater levels of eicosadienoic acid than dry corn-SBM (P<0.01). Across all diets, feeding dry corn-SBM reduced levels of arachidonic acid in leaf fat of pigs (P<0.01).

Feeding liquid ethanol co-products reduced the level of saturated fatty acids (P<0.01). Similarly, MUFA levels were reduced for liquid ethanol co-products when compared to dry corn-SBM (P<0.01). PUFA levels were significantly increased with the inclusion of ethanol co-products when compared to corn-SBM diets (P<0.01). Omega-6 fatty acid, omega-3 fatty acid, and the ratio of omega-6 to omega-3 were all increased with feeding ethanol co-products (DDGS, CDWS, and CCDS) when compared to control corn-SBM within both dry and liquid diets (P<0.01). Liquid feeding CCDS + CDWS increased trans-fatty acid levels when compared to dry corn-SBM and DDGS (P<0.01). Iodine values were significantly increased for pigs fed ethanol co-products within dry and liquid feeding systems when compared to control corn-SBM (P<0.01).

Discussion

The aim for conducting this study was to determine the value of feeding ethanol co-products and barley to grow-finish swine on growth performance, carcass characteristics, and meat quality. Furthermore to compare them to conventional diets used in the Upper Midwest as less information is known about feeding CDWS and CCDS. Results from previous liquid feeding trials from the Netherlands and Canada (Braun and de Lange, 2004) noted beneficial effects on growth performance specifically increased DMI and nutrient utilization leading to adequate gain and carcass output (Canibe and Jensen 2003; Braun and de Lange, 2004). Previous studies used barley and wheat primarily instead of corn for the basemix to go along with the liquid portion as they are more readily accessible.

Findings from the present study indicate that liquid feeding ethanol co-products CDWS and CCDS up to 30% in diets to finishing swine led to reduced performance when compared to conventional corn-SBM diets. This may be attributed to the low energy and high moisture content of CDWS and CCDS when compared to typical DDGS and corn-SBM based diets fed. Yang et al., (2017) found similar reduced performance results when feeding the same co-products to growing swine. Furthermore, Squire et al.,

(2005) reported that inclusion of CCDS above 15% DM in the diet had decreased gain and intake when compared to corn-SBM diets.

Initially in phase 1, pigs fed dry diets had greater ADG over the liquid diets. As the trial progressed, liquid fed pigs rebounded and began growing at a similar rate until the final phase as pigs became more accustomed to the diet. Inclusion of barley in the final phase reduced gain for both dry and liquid systems. It appears barley was less accepted by pigs in the present study.

Contrary to previous liquid feeding findings (Canibe & Jensen, 2003; Kim et al., 2001), in the present study liquid feeding ethanol co-products reduced ADFI for the first two phases of the grow-finish trial. Furthermore into phase 3, feeding CCDS + CDWS lowered ADFI when compared to dry diets and liquid corn-SBM. As the pigs entered the late-finishing period, liquid fed pigs maintained similar intake levels as dry diets. Replacing a portion of DDGS with barley greatly reduced ADFI. Che et al., (2014) also found reduced performance when feeding barley to growing swine. Pigs fed barley sometimes experience gut fill as a result of the high fiber content of the feedstuff. Gut fill slows the rate of passage through the intestinal tract signaling satiety. This tends to reduce intake and subsequent gain when compared to corn or wheat based diets (Whittemore et al., 2001).

Gain-to-feed efficiencies were somewhat close in the early phases (up to 56 days) between dry and liquid systems. Choct et al., (2004) reported similar findings in terms of efficiency for liquid feeding with d 50 to 55 being the greatest. However throughout the entire finish period, liquid diets had reduced G:F when compared to dry diets.

Lu and Rosentrater (2015) claimed that high moisture fed products can separate easily. Liquid feeding corn-SBM was lowest in terms of efficiency. This can likely be due to the rapid settling nature of corn when combined with water, ultimately leading to the decrease in efficiency. In addition with the rapid settling nature of corn in liquid solution, feed wastage and spoilage increased as pigs encountered more difficulty in consuming the mixture in the feed trough.

Many strategies including withdrawal of ethanol co-product, specific diet formulation for lower IV, and use of alternative grain source have been used to reduce the impact of feeding ethanol co-products on pork fat firmness (U.S. Grains Council, Ch. 23). According to Harper (1996), barley is used primarily as an alternative grain source when contemporary feedstuffs like corn and wheat are higher in price. Barley has been praised for its elevated levels of total protein and lysine. However, the high fiber and lower metabolizable energy content can hinder the performance potential when compared to corn based diets (Zjilstra and Beltranena, 2013).

Dry fed pigs were heavier than liquid fed diets at the end of most phase showing favorable growth. In the final finish phase, replacing a portion of DDGS with barley also reduced final BW. Since barley reduced gain and intake, final BW was reduced. In terms of carcass characteristics, HCW and percent lean were reduced for those fed barley within dry diets. This can be attributed to the high fiber content associated with barley. The fiber content leads to reduced passage rate of digesta and subsequent increase in gut fill within the intestinal tract pre-harvest. Zjilstra and Beltranena (2013) had similar findings when feeding barley in terms of carcass traits for percent. In addition, feeding dry corn-SBM had the greatest loin depth while those fed barley were shallower.

Since the goal market weight was set at approximately 127 kg, liquid fed pigs had to be on feed and trial for two weeks longer than dry pigs to attain market readiness. These pigs demonstrated compensatory growth during the growing-finishing period due to the inclusion of liquid ethanol co-products and barley. Upon harvest, liquid fed pigs were comparable in carcass output across all diets. Yang et al., (2017) found similar carcass traits when feeding CCDS + CDWS. As expected from previous reports with feeding ethanol co-products (Shurson, 2007; Squire et al., 2005; Whitney et al., 2006), pigs fed DDGS, CCDS, and CDWS greatly reduced belly firmness even with barley replacement.

Barley was included in the diet as a potential way to retain belly firmness given its low fat nutrient profile when compared to DDGS (2.1 vs 10.4%, respectively). Previous studies (Carr et al., 2005; Opapeju et al., 2005) also fed barley to examine carcass characteristics. They saw no difference in meat or fat quality attributes with barley when compared to corn and wheat based diets. In the current study, barley was somewhat successful in slightly retaining belly firmness when implemented in the last 28 days for dry diets. A trial by Kim et al., (2014) also studied barley supplementation on pork quality and found similar results in terms of minimal retention of fat firmness along with reduced gain. Kim (2014) also showed that the longer barley was fed, total PUFA values decreased. Therefore belly firmness may improve if barley is implemented for earlier period.

Corresponding with previous knowledge on feeding ethanol by-products (Yang et al., 2017; Beltranena, 2012), the present study showed that pigs fed DDGS, CDWS, and CCDS resulted in carcasses with higher iodine values which led to softer meat product. High iodine values reflect the level of saturation in the fat sample, specifically the ratio of saturated and poly-unsaturated fatty acid (Wood et al., 2003). The iodine value calculation focuses on the level of double bonds present (Kellner, 2014). The main fatty acids of focus are oleic (18:1), linoleic (18:2), ALA (18:3) and gondoic acid (20:1). From the leaf fat fatty acid profiles, feeding ethanol co-products resulted in greater levels of linoleic, ALA, eicasadienoic fatty acids. Furthermore increased levels of PUFAs and omega fatty acids. Even with replacing a portion of ethanol co-products with barley, PUFA and IV levels were greater when compared to traditional corn-SBM diets.

Since ethanol co-products have higher levels of PUFAs when compared to traditional corn diets, carcass fat quality can be compromised as a result of dietary fat composition from the high concentration of linoleic acid present in corn oil in DDGS (Stein and Shurson, 2009). The altered fatty acid composition of the ethanol co-products yielded higher levels of poly-unsaturated fatty acids and omega fatty acids in leaf fat. For reference, as the degree of saturation in the fatty acid increases so does the iodine value. Thus the melting point is reduced and fats become liquid at room temperature (Wood et al., 2003). This was confirmed by the belly flop test as pig's fed ethanol co-products also had reduced belly firmness scores. Baidoo (2014) had similar findings as the belly flex and firmness scores were vastly decreased when pigs were fed ethanol co-products when compared to corn-SBM.

In the present study, barley was included in the diet as an alternative cereal grain source to reduce the carcass effects of feeding ethanol co-products. Previous studies comparing barley and corn based diets showed that barley diets had much lower levels of PUFA and subsequently lower IV (Beltranena et al., 2009; Lampe et al., 2006). Other studies have outlined different methods to counter the adverse effects of feeding DDGS on pork fat quality including nutritive additives, alternative grain source replacement, and withdrawal at various times throughout the grow-finish period (US Grains Council, 2012). While not all are successful in retaining belly firmness, these strategies have been implemented for producers using DDGS in ration formulation.

The present study showed no difference in PUFA level or IV when a portion of the ethanol co-product portion (DDGS typically 30%, phase 7: 15% DDGS + 15% barley) of the final phase diet was replaced with barley for both dry and liquid diets. Therefore, there was no significant retention in belly firmness or flex with barley supplementation. When evaluating overall as a system, dry feeding seemed to have superior growth performance and carcass characteristics over liquid feeding.

Blood urea nitrogen levels were similar across all diets suggesting that feeding ethanol co-products and barley are acceptable when compared to conventional finish diets used today. These findings are consistent with Meried (2014) who also fed CCDS along with other ethanol co-products. In a broad sense, this tests examines protein quality. In terms of N utilization, low blood urea levels is related to greater feed protein quality through blood plasma concentration (Kohn et al., 2005).

Conclusion

Feeding ethanol co-products in livestock diets will continue as the biofuel industry continues to grow. Common co-products from the ethanol industry with potential in livestock diets include DDGS, CDWS, CDWG, and CCDS. Extensive research has been conducted feeding DDGS while much less have been done to evaluate the efficacy of feeding the higher moisture co-products due to practical research limitations with liquid feed systems.

Findings from the present study report mixed results on the use of ethanol co-products in swine diets. Feeding DDGS resulted in similar growth performance and carcass characteristics to traditional corn-soybean meal diets. However upon harvest, the altered fatty acid profile of ethanol co-products yielded softer meat products. Feeding liquid ethanol co-products to pigs was able to attain similar performance to control, liquid corn-SBM. However as expected, these high moisture ethanol co-products also yielded softer meat products. Supplementation of barley in the late-finishing phase did not improve retention of belly firmness.

Producers will have to decide whether to maximize pig performance or utilize a cost savings strategy for diet formulation. From the present study's findings, feeding dry corn-SBM resulted in the best combination of growth performance and carcass characteristics. Economically speaking, utilizing liquid ethanol co-products is an effective cost savings strategy.

Table 4.1: Effect of feeding ethanol co-products and barley on growth performance in grow-finishing pigs

Item	[1]Dry Basal	[2]DDGS	[3]DDGS + Barley	[4]Liquid Basal	[5]CCDS + CDWS	[6]CCDS + CDWS + Barley	SEM	P-value
Phase 1								
ADG	0.95[a]	0.94[a]	0.90[a]	0.78[b]	0.77[b]	0.76[b]	0.02	<0.0001
ADFI	2.07[a]	2.06[a]	2.09[a]	1.93[abc]	1.84[bc]	1.81[bc]	0.03	0.0003
G:F	0.46[a]	0.46[a]	0.43[ab]	0.41[b]	0.42[ab]	0.42[ab]	0.01	0.0037
BW	52.3	52.1	50.8	48.0	47.5	47.2	0.59	0.0349
Phase 2								
ADG	1.11	1.03	1.06	1.04	1.02	1.01	0.02	0.1083
ADFI	2.84[ab]	2.98[a]	2.95[a]	2.71[bc]	2.58[c]	2.60[c]	0.05	<0.0001
G:F	0.39[a]	0.35[b]	0.36[ab]	0.38[ab]	0.40[a]	0.39[a]	0.01	0.0103
BW	83.5[a]	81.0[ab]	80.6[abc]	77.1[bc]	76.0[bc]	75.3[c]	0.98	0.0005
Phase 3								
ADG	1.03	1.03	1.03	0.96	0.95	0.93	0.03	0.0254
ADFI	3.08[ab]	3.28[a]	3.15[a]	3.20[a]	2.88[b]	2.90[b]	0.07	<0.0001
G:F	0.34	0.32	0.33	0.30	0.33	0.32	0.01	0.1616
BW	115.7[a]	113.2[a]	112.5[a]	106.6[b]	105.3[b]	104.1[b]	1.36	<0.0001
Phase 4								
ADG	0.89[a]	0.87[a]	0.73[bc]	0.82[abc]	0.86[a]	0.74[bc]	0.03	<0.0001
ADFI	3.13[c]	3.35[b]	2.75[d]	3.70[a]	3.30[bc]	3.33[bc]	0.04	<0.0001
G:F	0.29[a]	0.26[ab]	0.27[a]	0.22[b]	0.26[ab]	0.22[b]	0.01	<0.0001
BW	134.5[ab]	131.5[abc]	128.0[c]	135.1[a]	135.3[a]	129.9[bc]	1.90	0.0003
Overall								
ADG	1.01[a]	0.98[a]	0.95[ab]	0.90[bc]	0.90[bc]	0.85[c]	0.02	<0.0001
ADFI	2.76[ab]	2.90[a]	2.74[b]	2.94[a]	2.69[b]	2.70[b]	0.04	<0.0001
G:F	0.36[a]	0.34[ab]	0.35[ab]	0.30[c]	0.33[ab]	0.32[bc]	0.01	<0.0001

[abcd] Means (a, b, c, d) within a row with different superscripts are significantly different at ($P<0.05$). Growth performance units: BW (kg), ADG (kg/d), ADFI (kg/d)

[1]Dry Basal=control, Corn-soybean meal

[2]DDGS=20% DDGS phase 1, 30% DDGS phases 2-4

[3]DDGS+Barley=20% DDGS phase 1, 30% DDGS phases 2 and 3, 15% DDGS + 15% barley phase 4

[4]Liquid Basal=Control, Corn-soybean meal + water

[5]CCDS+CDWS=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 24% syrup + 36% whole stillage phase 4

[6]CCDS+CDWS+Barley=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 15% syrup + 30% whole stillage + 15% barley phase 4

Table 4.2: Effect of feeding ethanol co-products and barley to pigs on carcass characteristics

Carcass	[1]Dry Basal	[2]DDGS	[3]DDGS + Barley	[4]Liquid Basal	[5]CCDS + CDWS	[6]CCDS + CDWS + Barley	SEM	P-value
HCW (kg)	103.7	100.8	98.0	100.4	100.2	95.7	1.81	0.07
Fat depth (cm)	2.15	2.01	2.03	2.20	2.16	1.97	0.07	0.13
Loin depth (cm)	7.57[a]	7.39[ab]	7.20[bc]	7.02[c]	6.92[d]	6.83[d]	0.07	<0.01
%, Lean	55.61[a]	55.65[a]	55.29[ab]	54.55[c]	54.47[c]	54.80[bc]	0.19	<0.01
Dressing, %	76.13	75.67	75.61	75.21	74.89	74.68	0.41	0.14

[abcd] Means (a, b, c, d) within a row with different superscripts are significantly different at ($P<0.05$)

[1]Dry Basal=control, Corn-soybean meal

[2]DDGS=20% DDGS phase 1, 30% DDGS phases 2-4

[3]DDGS+Barley=20% DDGS phase 1, 30% DDGS phases 2 and 3, 15% DDGS + 15% barley phase 4

[4]Liquid Basal=Control, Corn-soybean meal + water

[5]CCDS+CDWS=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 24% syrup + 36% whole stillage phase 4

[6]CCDS+CDWS+Barley=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 15% syrup + 30% whole stillage + 15% barley phase 4

Table 4.3: Effect of feeding ethanol co-products and barley on Blood Urea Nitrogen levels

	[1]Dry Basal	[2]DDGS	[3]DDGS + Barley	[4]Liquid Basal	[5]CCDS + CDWS	[6]CCDS + CDWS + Barley	SEM	P-value
BUN value	10.7	12.9	10.8	11.2	11.7	10.0	1.18	0.59

Values in (mg/dL)
[1]Dry Basal=control, Corn-soybean meal
[2]DDGS=20% DDGS phase 1, 30% DDGS phases 2-4
[3]DDGS+Barley=20% DDGS phase 1, 30% DDGS phases 2 and 3, 15% DDGS + 15% barley phase 4
[4]Liquid Basal=Control, Corn-soybean meal + water
[5]CCDS+CDWS=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 24% syrup + 36% whole stillage phase 4
[6]CCDS+CDWS+Barley=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 15% syrup + 30% whole stillage + 15% barley phase 4

Table 4.4: Effect of feeding ethanol co-products and barley to pigs on belly firmness score and thickness

Belly	[1]Dry Basal	[2]DDGS	[3]DDGS + Barley	[4]Liquid Basal	[5]CCDS + CDWS	[6]CCDS + CDWS + Barley	SEM	P-value
Thickness (cm)	4.09	3.84	4.27	3.56	3.86	3.61	0.11	0.45
Firmness Score	65.6[a]	24.3[b]	32.4[b]	69.0[a]	25.5[b]	20.9[b]	4.95	<0.01

[ab] Means (a, b) within a row with different superscripts are significantly different at ($P<0.05$)

[1]Dry Basal=control, Corn-soybean meal
[2]DDGS=20% DDGS phase 1, 30% DDGS phases 2-4
[3]DDGS+Barley=20% DDGS phase 1, 30% DDGS phases 2 and 3, 15% DDGS + 15% barley phase 4
[4]Liquid Basal=Control, Corn-soybean meal + water
[5]CCDS+CDWS=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 24% syrup + 36% whole stillage phase 4
[6]CCDS+CDWS+Barley=16% syrup + 24% whole stillage phase 1, 20% syrup + 30% whole stillage phases 2 and 3, 15% syrup + 30% whole stillage + 15% barley phase 4

Belly Thickness = Fresh belly thickness, measured at the midpoint

Belly firmness score = cos-1{[0.5(L2) − D2]/[0.5(L2)]}

where L = belly length measured on a flat surface and D = the distance between the 2 ends of a suspended belly; greater belly firmness scores indicate firmer bellies.

Belly firmness score adjusted for belly thickness.

Table 4.5: Effect of feeding ethanol co-products and barley to pigs on Leaf Fat Fatty Acid Profile

Fatty Acid	Dry Basal	DDGS	DDGS + Barley	Liquid Basal	CCDS + CDWS	CCDS + CDWS + Barley	SEM	P-value
C14:0	1.55[ab]	1.60[ab]	1.60[ab]	1.65[a]	1.45[ab]	1.37[b]	0.06	0.0161
C16:0	28.20[a]	27.63[a]	27.37[a]	28.40[a]	24.10[b]	23.50[b]	0.46	<0.0001
C17:0	0.32[b]	0.40[ab]	0.37[ab]	0.42[ab]	0.45[a]	0.40[ab]	0.03	0.0259
C18:0	19.25[a]	17.50[a]	17.97[a]	18.93[a]	15.25[b]	14.98[b]	0.47	<0.0001
C20:0	0.30	0.25	0.27	0.27	0.22	0.22	0.02	0.0601
C16:1	1.80[a]	1.80[a]	1.67[a]	1.80[a]	1.22[b]	1.23[b]	0.10	<0.0001
C18:1	39.80[a]	35.92[b]	36.18[b]	35.67[bc]	32.77[d]	33.53[cd]	0.62	<0.0001
C20:1	0.77[a]	0.63[ab]	0.65[ab]	0.63[ab]	0.62[ab]	0.57[b]	0.04	0.0160
C18:2	6.52[c]	12.35[b]	11.83[b]	10.13[bc]	21.37[a]	21.50[a]	0.98	<0.0001
C20:2	0.27[c]	0.45[b]	0.42[bc]	0.40[bc]	0.72[a]	0.68[a]	0.04	<0.0001
C18:3	0.37[b]	0.43[b]	0.45[b]	0.48[ab]	0.60[a]	0.62[a]	0.03	<0.0001
C20:4	0.12[b]	0.18[a]	0.20[a]	0.18[a]	0.20[a]	0.20[a]	0.02	0.0053
SFA	49.62[a]	47.38[a]	47.57[a]	49.67[a]	41.47[b]	40.47[b]	0.79	<0.0001
MUFA	42.37[a]	38.35[b]	38.50[b]	38.10[bc]	34.60[d]	35.33[cd]	0.66	<0.0001
PUFA	7.27[c]	13.42[b]	12.93[b]	11.20[bc]	22.88[a]	23.07[a]	1.05	<0.0001
n-6	6.90[c]	12.98[b]	12.48[b]	10.72[bc]	22.28[a]	22.45[a]	1.02	<0.0001
n-3	0.37[b]	0.43[b]	0.45[b]	0.48[ab]	0.60[a]	0.62[a]	0.03	<0.0001
n-6/n-3	19.01[c]	30.03[b]	27.87[b]	22.05[c]	37.04[a]	36.48[a]	0.75	<0.0001
Trans	0.42[c]	0.45[c]	0.48[bc]	0.53[abc]	0.62[a]	0.57[ab]	0.03	<0.0001
Iodine value	48.79[c]	55.62[b]	54.88[b]	51.70[bc]	68.40[a]	69.31[a]	1.44	<0.0001

[abcd] Means (a, b, c, d) within a row with different superscripts are significantly different at (P<0.05)

Note: C14:0 – myristic acid, C16:0 – palmitic acid, C17:0 – margaric acid, C18:0 – stearic acid, C20:0 – arachidic acid, C16:1 – palmitoleic acid, C18:1 – oleic acid, C20:1 – gondoic acid, C18:2 – linoleic acid, C20:2 – eicosadienoic acid, C18:3 – alpha-linolenic acid, C20:4 – arachidonic acid, SFA - saturated fatty acids; MUFA - monounsaturated fatty acids; PUFA - poly unsaturated fatty acids; n-6, omega-6 fatty acid; n-3, omega-3 fatty acid; trans - trans fatty acids; IV – Iodine value.

Table 4.6: Ingredient composition of base-mixes in the grow-finish study feeding liquid ethanol co-products

	Phase 1			Phase 2			Phase 3			Phase 4		
Treatment	1	2	3	1	2	3	1	2	3	1	2	3
Ingredient (%)												
[1]Basal Diet	100	60	60	100	50	50	100	50	50	100	40	55
[2]CCDS	---	16	16	---	20	20	---	20	20	---	24	15
[3]CDWS	---	24	24	---	30	30	---	30	30	---	36	30

[1]Basal Diet = Corn, soybean meal, vitamins, and minerals
[2]CCDS = Corn Condensed Distillers Solubles
[3]CDWS = Corn Distillers Whole Stillage

Table 4.7: Dietary compositions of ethanol co-products in grow-finish study (Phase 1)

Ingredients	**[1]Dry Basal**	**[2]DDGS**	**[3]Liquid Basal**	**[4]CCDS + CDWS**
Corn	70.62	56.86	70.62	39.41
Soybean meal (CP 47.5%)	24	18	24	15
Corn condensed distillers solubles				16
Corn whole stillage				24
DDGS		20		
Choice white grease	1.57	1.37	1.57	2.17
Limestone, ground	0.55	0.78	0.55	1.83
Calcium phosphate (dicalcium)	1.7	1.38	1.7	
L-Lys-HCL	0.44	0.53	0.44	0.52
DL-Met	0.17	0.12	0.17	0.11
L-Thr	0.15	0.14	0.15	0.14
L-Trp		0.02		0.02
Sodium chloride	0.3	0.3	0.3	0.3
Vitamin-trace mineral premix	0.5	0.5	0.5	0.5
Total	**100.00**	**100.00**	**100.00**	**100.00**
Calculated nutrients				
ME (kcal/kg)	3350	3350	3350	3350
SID Lys (%)	1.10	1.10	1.10	1.10
SID Met (%)	0.40	0.39	0.40	0.37
SID Met+Cys (%)	0.64	0.64	0.64	0.64
SID Thr (%)	0.69	0.69	0.69	0.69
SID Trp (%)	0.18	0.18	0.18	0.18
Total crude protein (%)	17.17	18.86	17.17	20.39
Total P (%)	0.59	0.59	0.59	0.73
ATTD P (%)	0.33	0.33	0.33	0.39
Ca (%)	0.71	0.71	0.71	0.71
Analyzed Values (% unless noted)				
GE (kcal/kg)	3475	3482	3207	3542
CP	16.9	18.6	17.2	18.3
NDF	13.9	14.4	15.1	18.1
ADF	4.2	5.5	4.7	6.6
Ether Extract	5.1	6.0	7.2	8.5
DM	88.9	88.6	20.9	20.5

[1]Dry Basal=control, Corn-soybean meal, [2]DDGS=20% DDGS, [3]Liquid Basal=Control, Corn-soybean meal + water, [4]CCDS+CDWS=16% syrup + 24% whole stillage

Table 4.8: Dietary compositions of ethanol co-products in grow-finish study (Phase 2)

Ingredients	[1]Dry Basal	[2]DDGS	[3]Liquid Basal	[4]CCDS + CDWS
Corn	74.26	54.54	74.26	31.88
Soybean meal (CP 47.5%)	20	10	20	12
Corn condensed distillers solubles				20
Corn whole stillage				30
DDGS		30		
Choice white grease	1.77	1.46	1.77	2.65
Limestone, ground	0.75	1.08	0.75	2.1
Calcium phosphate (dicalcium)	1.82	1.4	1.82	
L-Lys-HCL	0.37	0.54	0.37	0.38
DL-Met	0.12	0.05	0.12	0.05
L-Thr	0.11	0.1	0.11	0.13
L-Trp		0.03		0.01
Sodium chloride	0.3	0.3	0.3	0.3
Vitamin-trace mineral premix	0.5	0.5	0.5	0.5
Total	**100.00**	**100.00**	**100.00**	**100.00**
Calculated nutrients				
ME (kcal/kg)	3350	3350	3350	3350
SID Lys (%)	0.95	0.95	0.95	0.95
SID Met (%)	0.33	0.32	0.33	0.31
SID Met+Cys (%)	0.55	0.55	0.55	0.55
SID Thr (%)	0.59	0.59	0.59	0.59
SID Trp (%)	0.16	0.16	0.16	0.16
Total P (%)	0.60	0.60	0.60	0.93
ATTD P (%)	0.34	0.35	0.34	0.52
Ca (%)	0.80	0.80	0.80	0.80
Analyzed Values (% unless noted)				
GE (kcal/kg)	3562	3489	3338	3552
CP	15.0	16.5	15.2	17.1
NDF	16.1	16.8	17.1	18.6
ADF	5.3	6.8	6.2	6.7
Ether Extract	6.1	6.8	5.9	7.5
DM	89.1	88.9	20.1	20.7

[1]Dry Basal=control, Corn-soybean meal, [2]DDGS=30% DDGS, [3]Liquid Corn=Control, Corn-soybean meal + water, [4]CCDS+CDWS=20% syrup + 30% whole stillage

Table 4.9: Dietary compositions of ethanol co-products in grow-finish study (Phase 3)

Ingredients	[1]**Dry Basal**	[2]**DDGS**	[3]**Liquid Basal**	[4]**CCDS + CDWS**
Corn	78.42	59.72	78.42	38.74
Soybean meal (CP 47.5%)	17	6	17	6
Corn condensed distillers solubles				20
Corn whole stillage				30
DDGS		30		
Choice white grease	1.27	0.9	1.27	2.13
Limestone, ground	0.72	1.18	0.72	1.87
Calcium phosphate (dicalcium)	1.48	0.9	1.48	
L-Lys-HCL	0.34	0.54	0.34	0.44
DL-Met	0.1	0.05	0.1	0.07
L-Thr	0.12	0.12	0.12	0.18
L-Trp		0.04		0.02
Sodium chloride	0.3	0.3	0.3	0.3
Vitamin-trace mineral premix	0.25	0.25	0.25	0.25
Total	**100.00**	**100.00**	**100.00**	**100.00**
Calculated nutrients				
ME (kcal/kg)	3350	3350	3350	3350
SID Lys (%)	0.85	0.85	0.85	0.85
SID Met (%)	0.30	0.30	0.30	0.30
SID Met+Cys (%)	0.51	0.51	0.51	0.51
SID Thr (%)	0.56	0.56	0.56	0.56
SID Trp (%)	0.14	0.14	0.14	0.14
Total P (%)	0.52	0.49	0.52	0.90
ATTD P (%)	0.28	0.28	0.28	0.51
Ca (%)	0.70	0.70	0.70	0.70
Analyzed Values (% unless noted)				
GE (kcal/kg)	3610	3587	3326	3405
CP	13.9	15.8	14.1	15.5
NDF	17.5	19.6	18.4	19.8
ADF	7.1	5.4	6.7	7.2
Ether Extract	5.9	3.4	6.1	7.7
DM	89.0	89.2	20.0	19.4

[1]Dry Basal=control, Corn-soybean meal, [2]DDGS=30% DDGS, [3]Liquid Corn=Control, Corn-soybean meal + water, [4]CCDS+CDWS=20% syrup + 30% whole stillage

Table 4.10: Dietary compositions of ethanol co-products in grow-finish study (Phase 4)

Ingredients	[1]Dry Basal	[2]DDGS	[3]DDGS + Barley	[4]Liquid Basal	[5]CCDS + CDWS	[6]CCDS + CDWS + Barley
Corn	79.89	61.22	57.06	79.89	34.7	32.37
Barley			15			15
Soybean meal (CP 47.5%)	16	5	8	16		2
CCDS					24	15
CDWS					36	30
DDGS		30	15			
Choice white grease	1.13	0.76	1.87	1.13	2.2	2.58
Limestone, ground	0.8	1.22	1.05	0.8	1.78	1.76
Calcium phosphate	1.2	0.65	0.85	1.2		
L-Lys-HCL	0.28	0.48	0.44	0.28	0.49	0.48
DL-Met	0.06		0.04	0.06	0.04	0.04
L-Thr	0.08	0.08	0.11	0.08	0.19	0.18
L-Trp	0.01	0.04	0.03	0.01	0.05	0.04
Sodium chloride	0.3	0.3	0.3	0.3	0.3	0.3
Vitamin-trace mineral premix	0.25	0.25	0.25	0.25	0.25	0.25
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Calculated nutrients						
ME (kcal/kg)	3350	3350	3350	3350	3350	3350
SID Lys (%)	0.78	0.78	0.78	0.78	0.78	0.78
SID Met (%)	0.26	0.25	0.25	0.26	0.26	0.25
SID Met+Cys (%)	0.46	0.46	0.46	0.46	0.46	0.46
SID Thr (%)	0.51	0.51	0.51	0.51	0.51	0.51
SID Trp (%)	0.14	0.14	0.14	0.14	0.14	0.14
Total P (%)	0.47	0.44	0.45	0.47	1.02	0.80
ATTD P (%)	0.24	0.24	0.24	0.24	0.59	0.45
Ca (%)	0.65	0.65	0.65	0.65	0.65	0.65
Analyzed Values						
GE (kcal/kg)	3507	3555	3544	3393	3633	3705
CP (%)	13.8	15.6	13.9	13.6	16.6	16.2
NDF (%)	18.5	28.4	23.3	17.9	22.1	20.8
ADF (%)	7.2	8.0	6.1	6.3	7.1	6.8
Ether Extract (%)	3.9	3.6	3.7	5.5	6.7	6.3
DM (%)	88.7	88.5	89.1	20.7	21.5	18.9

[1]Dry Basal= Corn-soybean meal, [2]DDGS=30% DDGS, [3]DDGS+Barley=15% DDGS + 15% barley, [4]Liquid Basal= Corn-soybean meal + water, [5]CCDS+CDWS=24% syrup + 36% whole stillage, [6]CCDS+CDWS+Barley=15% syrup + 30% CDWS + 15% barley

CHAPTER 5

Conclusion

5.1 Summary

The goal of the studies provided in this thesis were to evaluate dry and liquid feeding systems with ethanol co-products and barley in terms of growth performance, nutrient digestibility, and carcass merit. The ethanol co-products including DDGS, CDWS, and CCDS provide a cost savings strategy to producers looking for alternatives at times of increased grain prices. From the present findings, feeding ethanol co-products can be a viable alternative to contemporary feedstuffs and have the potential to provide adequate growth and nutrient requirements along with acceptable carcass characteristics when using a cost savings strategy.

From the nursery trial studying feeding program, liquid fed diets had reduced performance. When evaluating nutrient digestibility, feeding DDGS and liquid ethanol co-products was similar to conventional corn-SBM diets in N and therefore CP utilization. For P utilization, liquid diets surpassed dry diets which meant that they are a valuable source of P for growing pigs. The main issue found with feeding liquid ethanol co-products was the large difference in GE intake and DE as liquid diets were much lower when compared to dry diets. This issue may be attributed to the high moisture content leading to variable quality of liquid co-products. If managed properly, these issues can be handled and pig performance can be optimized.

From the grow-finish trial studying ethanol co-products and barley within dry and liquid feeding systems, dry fed pigs showed favorable growth performance over liquid fed pigs as they reached market readiness fourteen days earlier. Feeding DDGS proved to increase intake while decreasing efficiency, however the pigs grew at a similar rate when compared to conventional corn-SBM diets. Replacing a portion of barley in the late-finishing phase decreased intake due to the high fiber nature. Barley was implemented in the diet as an alternative grain source in hopes of retaining belly firmness upon harvest as it is known that feeding DDGS compromises belly pork fat quality. For dry fed pigs, barley slightly retained belly firmness showing it is possible to improve belly quality by feeding low fat alternatives. In the present study, this method was only in place for the last twenty-eighty days before harvest. Although all bellies were acceptable for industry standards for belly flex and IV values, earlier replacement or complete withdrawal may be more effective methods to improve belly fat quality.

Liquid fed pigs showed acceptable growth performance and carcass characteristics despite being on feed for a longer period. This can be attributed to the low dietary energy associated with the liquid ethanol co-products CCDS and CDWS found in our metabolism balance study. When compared to control liquid corn-SBM, feeding liquid ethanol co-products to pigs can attain similar performance while reducing feed costs as these co-products are economic alternatives. Replacing a portion of liquid ethanol co-products in late finishing with barley did not improve belly firmness. If a producer utilizing a liquid feeding system with ethanol co-products would like to improve belly quality, other methods may need to be implemented.

On a slurry basis, swine manure has been used as a valuable alternative to crop fertilizer as it contains adequate N, P, and K concentrations. From the present study, dry feeding DDGS results in similar N and P content when compared to conventional corn-SBM diets. While liquid ethanol co-products of N and P are lower, K concentrations are similar among dry and liquid diets. As these co-products were likely used as an economic alternative, consequently the slurry could be used as a similar alternative for crop producers as fertilizer.

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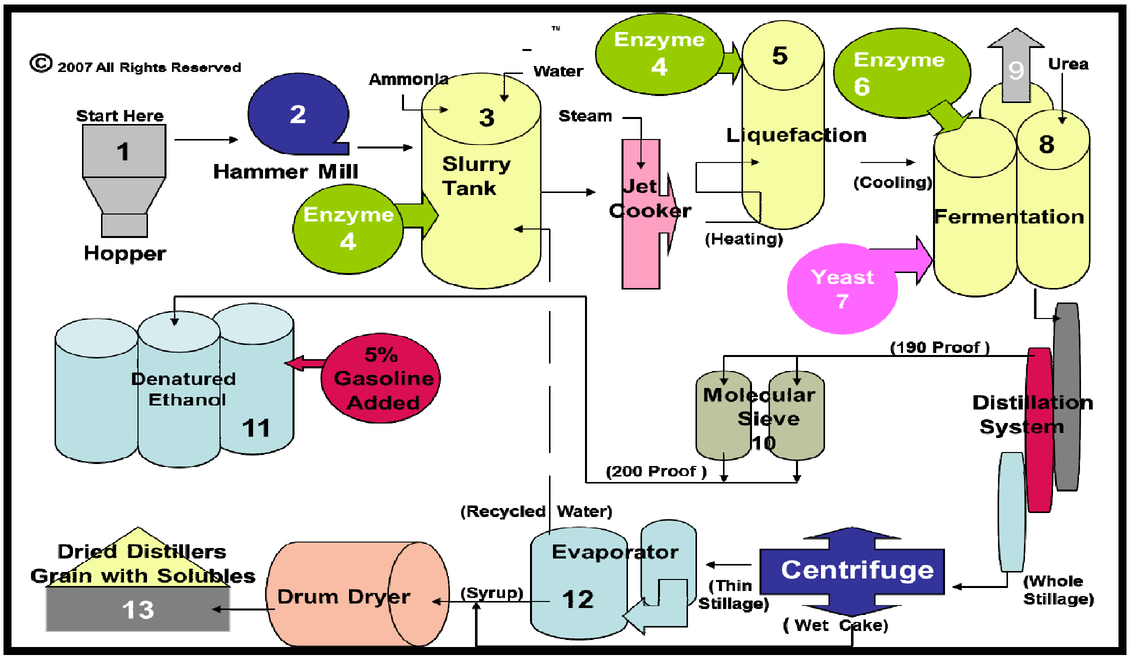
Appendix 1

Dry-Grind Ethanol Process



(Guardian Energy, LLC.)

Appendix 2

Medical Record:

Seven pigs were removed from the grow-finish trial due to health concerns including abdominal hernia (1), rectal prolapse (1), hind leg lameness (1), and miscellaneous injury (4).