THE EFFECTS OF LOW-, MEDIUM-, AND HIGH-OIL DRIED DISTILLERS GRAINS WITH SOLUBLES (DDGS) ON GROWTH PERFORMANCE, NUTRIENT DIGESTIBILITY, AND FAT QUALITY IN FINISHING PIGS

by

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B.S., The University of Tennessee, 2011

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2013

Approved by:

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Abstract

Three experiments used 1,756 pigs to evaluate the effects of corn dried distillers grains with solubles (DDGS) varying in oil content on growth performance, carcass characteristics, and fat quality in growing-finishing pigs. A fourth experiment used 12 pigs and determined the energy concentration and nutrient digestibility of the DDGS sources used in the previous 3 growth studies. Lastly, a fifth experiment used 576 pigs to determine the effects of DDGS and wheat middlings (midds) withdrawal 24 d before harvest in diets without or with ractopamine HCl (RAC) on growth performance, carcass characteristics, fat quality, and organ/intestine weights. Experiment 1 determined that increasing 7.4% oil DDGS decreased (linear, $P < 0.02$) ADG and G:F. Also, final BW, HCW, and carcass yield decreased (linear, $P < 0.03$), but jowl iodine value (IV) increased (linear, $P < 0.001$) as DDGS increased. Experiments 2 and 3 utilized DDGS sources that contained 5.2 vs. 9.3, and 9.2 vs. 11.8% oil, respectively. In brief, results suggested that while ADG was unaffected, feeding DDGS with 5.2% oil reduced G:F. In Exp. 4, stepwise regression was used to develop prediction equations based to determine that a 1% change in oil content of DDGS will change the DE by 71 kcal/kg and NE by 118 kcal/kg. Experiment 5 determined that pigs fed corn-soy (CS) diets throughout the finishing phase had greater ($P < 0.03$) ADG, G:F, and carcass yield and lower ($P < 0.01$) IV than those fed high fiber (HF; DDGS and wheat midds) diets throughout, with pigs fed the fiber withdrawal intermediately. Pigs fed RAC had greater ($P < 0.01$) ADG, G:F, and carcass yield than pigs not fed RAC. Iodine values were lowest ($P < 0.01$) for pigs fed the CS diets, highest ($P < 0.01$) for those fed HF diets throughout, and intermediate for pigs fed the withdrawal diet. Withdrawal of the HF diet to a CS diet partially mitigated negative effects on carcass yield and IV, and feeding RAC, regardless of dietary fiber regimen, improved growth performance and carcass yield.

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Acknowledgements

There are truly too many people to name that I sincerely thank for their role in helping me achieve this goal.

First, I'd like to thank my graduate advisor, Dr. Bob Goodband. I've told many people that I don't think I could have had the privilege to have worked for anyone better. I admire you for both your duties and accomplishments at KSU, but also as a person. I have come to care about you, Dani, and your greyhounds a great deal. I sincerely appreciate your willingness to "talk about life" when I needed someone to talk to. In the job search, when I was asked what I was looking for in a boss, every detail of my answer was modeled after you.

To the rest of my committee members: Dr. Mike Tokach, Dr. Joel DeRouchey, Dr. Steve Dritz, and Dr. Jim Nelssen, you have all been instrumental in my learning experience during my MS career. You are all extremely important to this program, and I want to thank each of you for allowing me the opportunity to work with the swine group here at KSU. In my opinion, you are all truly the very best at what you do.

I have had the pleasure of working alongside some of the brightest new minds in swine nutrition within the walls of Weber Hall 217. Dr. Sureemas Nitikanchana, Dr. Marcio Goncalves, Chad Paulk, Jeremiah Nemechek, Hyatt Frobose, Jon De Jong, Kelly Sotak, Matt Asmus, Amanda Reeg, Megan Morts, Devin Goehring, Josh Flohr, Kyle Coble, and Kari Beth Langbein, you are wonderful people and I've greatly enjoyed the privilege of working with you all.

To my husband, Garry, thank you for always standing beside me, through the ups and downs of graduate school. I am the luckiest woman in the world to be married to someone so devoted and caring. You and I both know that "life's too short to settle," and I can't tell you how excited I am to start our next adventure in our 4th home state together.

Dedication

I owe everything, including the person I am today, to my family.

Nothing seems impossible with family as great as you all. I love you all so very much,

Mom, I hope to be just like you.
Dad, you’ve been the absolute most encouraging Dad I could have ever asked for.
Ryan, I’ve looked up to you my whole life. I’m so proud of you.

Pa and Grandma Rhule, thank you both for your love and support since I was just a little kid.

Carolyn, thanks for always being such a great second mother to me.

Lisa, Logan, and Blake, I’m so happy to call you all part of my family.

Garry, you’re truly my better half.

HERE’S TO US!!

Chapter 1 - The effects of medium-oil dried distillers grains with solubles on growth performance, carcass traits, and nutrient digestibility in growing-finishing pigs

ABSTRACT

A total of 288 mixed sex pigs (PIC 327 × 1050; initially 68.9 kg BW) were used in a 67-d study to determine the effects of increasing medium-oil dried distillers grains with solubles (DDGS; 7.63% oil, 30.1% CP, 19.53% ADF, 36.47% NDF, and 4.53% ash; as-fed) on growth performance and carcass traits in finishing pigs. Treatments consisted of a corn-soybean meal control diet or the control diet with 15, 30, or 45% medium-oil DDGS. Diets were fed over 2 phases (69 to 100 and 100 to 126 kg) and not balanced for energy. Increasing medium-oil DDGS decreased (linear, $P < 0.02$) ADG and G:F. Average daily gain decreased approximately 2.3% for every 15% added medium-oil DDGS whereas G:F decreased 1.3% with every 15% added DDGS. In addition, final BW, HCW, carcass yield, and loin-eye depth decreased (linear, $P < 0.03$), and jowl iodine value (IV) increased (linear, $P < 0.001$) with increasing medium-oil DDGS. Nutrient digestibility of the DDGS source was determined using pigs that were fed either a corn-based basal diet (96.6 corn, and 3.4% vitamins and minerals) or a DDGS diet which was a 50:50 blend of basal diet and medium-oil DDGS. There were 12 replications for each diet that consisted of a 5 d adaptation period followed by 2 consecutive days of total fecal collection on a timed basis. Feces were analyzed for GE, DM, CP, crude fiber, NDF, ADF, and ether extract. On an as-fed basis, corn contained 3,871 and 3,515 kcal/kg GE and DE, respectively. Medium-oil DDGS contained 4,585 and 3,356 kcal/kg GE and DE, respectively (as-fed basis). Digestibility coefficients of the medium-oil DDGS were: DM, 70.3%; CP, 82.9%; ether extract, 61.4%; ADF, 77.4%; NDF, 67.5%; and crude fiber, 67.2%. Caloric efficiency (ADFI × dietary energy, kcal/kg gain) was not different when expressed on a DE, or a calculated ME or NE basis suggesting that the energy values derived from the nutrient balance study were accurate based on energy utilization for gain. In conclusion, increasing dietary inclusion of medium-oil DDGS decreased ADG and G:F such that it needs to be discounted in value relative to corn when adding to swine diets.

Key words: corn, DDGS, digestibility, finishing pigs, oil

INTRODUCTION

Dried distillers grains with solubles (**DDGS**) are a by-product of the ethanol industry that are now commonly used in swine diets to lower feed costs. Dried distillers grains with solubles historically contain greater than 10% oil, maintaining a relatively high feeding value similar to corn (Stein and Shurson, 2009). Stein and Shurson (2009) summarized that growth performance will remain unchanged with feeding DDGS up to 30% of the diet. However, carcass characteristics such as carcass yield and jowl iodine value (**IV**) are adversely affected with feeding DDGS.

Most ethanol plants utilize a “Step 1” oil extraction process that removes approximately 30% of the corn oil present in thin stillage via centrifugation to produce DDGS with approximately 10% oil (CEPA, 2011). Recently, ethanol plants are beginning to implement “Step 2” extraction processes to capture up to 30% more corn oil bound in whole stillage (CEPA, 2011). “Step 2” extraction involves extra washing and removal of oil from the wet cake, which traps more than 30% of the total corn oil. Variation in oil extraction procedures from plant to plant have led to DDGS products varying in oil content from 4 to 12%.

A concern is that the new, medium-oil DDGS (> 6 and < 9% oil: NRC, 2012) may negatively affect ADG and G:F because of its low oil (energy) content. Anderson et al. (2011) suggested that GE and TDF are the significant criteria in estimating energy values of corn coproducts. On the other hand, Pederson et al. (2007) observed that ash, oil, ADF, and GE were significant variables when predicting energy content of DDGS ranging in oil content from 8.6 to 12.4%. Little data is available on nutrient digestibility or feeding value of medium-oil DDGS.

Therefore, the objective of this study was to evaluate effects of medium-oil DDGS on finishing pig growth performance and carcass characteristics, as well as determine its DE and nutrient digestibility.

Materials and Methods

General

The protocols for these experiments were approved by the Kansas State University Institutional Animal Care and Use Committee. The experiments were conducted at the K-State Swine Teaching and Research Center in Manhattan, KS.

Experiment 1 was conducted in a totally enclosed, environmentally controlled, mechanically ventilated facility containing 36 pens. The pens (2.4 × 3.1 m) had adjustable gates facing the alleyway that allowed for 0.93 m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder with 2 eating spaces (Farmweld, Teutopolis, IL) located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility utilized a computerized feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) that both recorded and delivered diets to pens as specified. The equipment provided pigs with ad libitum access to feed and water.

In Exp. 2, pigs were housed in a totally enclosed, environmentally controlled, mechanically ventilated facility containing 12 stainless steel metabolism cages (1.5 × 0.6 m). Each cage was equipped with a feeder as well as a nipple waterer to allow ad libitum access to water. Each metabolism cage had metal mesh flooring that allowed for total collection of feces.

Animals and Diets

Experiment 1. A total of 288 mixed sex finishing pigs (327× 1050: PIC Hendersonville, TN; initially 68.9 kg BW) were used in a 67-d growth study. Pens of pigs were allotted to 1 of 4 dietary treatments with 8 pigs per pen and 8 replications per treatment. A single batch of corn and medium-oil DDGS were used in this study and analyzed for chemical composition (Table 1.1). The DDGS contained: 7.63% crude fat, 30.1% CP, 19.53% ADF, and 36.47% NDF (as-fed basis; AOAC, 2006; Ward labs, Kearney NE). Amino acid profile was analyzed at the University of Missouri-Columbia Agricultural Experiment Station Chemical Laboratory (Columbia, MO; AOAC, 2006). Fatty acid analysis (Sukhija and Palmquist, 1988) was conducted on the medium-oil DDGS at the K-State Analytical Lab (Manhattan, KS; Table 1.2). At the time of diet formulation, the 2012 NRC publication was not available; therefore, total AA in DDGS from Stein et al. (2007) were used. These total AA values were then multiplied by standardized ileal digestibility (**SID**) coefficients derived from Stein et al. (2007) and used in diet formulation.

Pigs were fed corn-soybean meal–based diets containing 0, 15, 30, or 45% medium-oil DDGS. Diets were fed in 2 phases from approximately 69 to 100 and 100 to 126 kg (Tables 1.3 and 1.4). All pigs and feeders were weighed on d 0, 33, and 67 to determine ADG, ADFI, and G:F.

On d 67, all pigs were weighed and transported approximately 2.5 h to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for harvest under USDA inspection. Before slaughter, pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weight was measured immediately after evisceration, and each carcass was evaluated for carcass yield, back fat depth, loin depth, and percentage lean. Carcass yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the plant. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Also, jowl fat samples were collected and analyzed by Near Infrared Spectroscopy (Bruker MPA; Multi-Purpose Analyzer) at the plant for IV using the equation of Cocciardi et al. (2009).

Experiment 2. A total of 12 barrows (initially 25.6 kg BW) were used in a 6 wk study to determine nutrient digestibility of corn, the medium-oil DDGS used in the growth study, and 4 other sources of DDGS. The other 4 sources of DDGS were used in a different growth study outlined by Graham et al. (2013). Pigs were randomly allotted to 1 of 2 Latin square designs with 6 pigs each to achieve 12 replications per diet. The medium-oil DDGS used in the digestibility study were from the same batch as the growth study and nutrient digestibility of the DDGS source was determined by feeding either a corn-based basal diet (96.6% corn, 3.4% vitamins and minerals) or a 50:50 blend of basal diet and DDGS (Table 1.5). Ingredients, complete diets and feces were analyzed for DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fiber (AOAC 978.10, 2006), NDF (ANKOM Technology, 1998), ADF (ANKOM Technology, 1998), and ether extract (AOAC 920.39 A, 2006) at acommercial laboratory (Ward Laboratories, Inc., Kearney, NE).

Pigs were fed the same amount of each diet (2.5× maintenance determined based on their BW on d 1 of each period) for the duration of each 7-d period. Each day's ration was equally divided between two meals fed at 0600 and 1800 h. Each period consisted of 5 d of diet adjustment (10 meals) followed by 2 consecutive days of total fecal collection. On the morning of d 6 (meal 11), just before the morning meal, pigs were allowed approximately 5 minutes to stand, drink, and defecate. After that time, feces were removed and the morning meal was fed. This meal on the morning of d 6 marked the beginning of the timed fecal collection period. On d 8 of period (d 1 of period 2 or meal 15), the same amount of time was given to pigs, allowing them to stand up, drink, and defecate. Prior to feeding, all feces were collected, and this marked the end of the timed collection period. On that same morning that collection ended, pigs were weighed and fed a new treatment diet in a random order. Feces were stored in a freezer (-20 °C) until further processing and analysis. At the conclusion of a collection period, all feces for each pig were combined, homogenized, and dried in a in a forced-air oven at 50°C. Samples were finely ground and then subsampled for further analysis (Jacela et al., 2009). Gross energy concentrations of the ingredients, diets, and fecal samples were measured via adiabatic bomb calorimetry (Parr Instruments, Moline, IL). Calculations outlined by Adeola (2001) were used to determine energy values.

Statistical Analysis

Data for the growth trial were analyzed as a completely randomized design with pen as the experimental unit. Analysis of variance was used with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Because HCW differed, it was used as a covariate for BF, loin depth, and percentage lean. Linear and quadratic contrasts were used to determine the effects of increasing medium-oil DDGS. Differences were considered significant at $P < 0.05$ and were considered a trend at $P < 0.10$. Single degree of freedom contrasts were used to separate means of pigs fed either the corn- or DDGS-based diet in the nutrient balance study.

RESULTS AND DISCUSSION

Chemical analysis

Dried distillers grains with solubles have historically contained approximately 10.5% oil or greater (Stein and Shurson, 2009). After the oil is removed from DDGS by the process of centrifugation, the remaining DDGS contains approximately 7% oil, similar to that of the medium-oil DDGS used in this study (Table 1.1). Ethanol plants have evolved methods and practices to capture more value fromcorn oil after fermentation and distillation. Most ethanol plants utilize “Step 1”oil extraction, which removes corn oil from thin stillage via centrifugation after it is separated from the whole stillage (CEPA, 2011). However, as the value of corn oil has risen, ethanol plants are increasingly implementing a “Step 2” oil extraction process that allows for a doubling of corn oil removed from the whole stillage prior to centrifugation (CEPA, 2011).

Dried distillers grains with solubles reviewed by Stein and Shurson (2009) are similar in NDF and lower in crude fiber and starch than the medium-oil DDGS used in this study. According to NRC (2012), the Lys concentration in medium-oil DDGS is greater (0.90% vs. 0.77%) than in traditional DDGS, but other amino acids remain relatively similar. This was indeed the case upon AA analysis of the medium-oil DDGS used in this study. The analyzed value of Lys from the medium-oil DDGS was 0.92%, which was similar to the reported Lys value for medium-oil DDGS in the NRC (2012). The analyzed Lys concentration of the medium-oil DDGS as a percentage of CP was 3.06%, suggesting that the medium oil DDGS was not subject to heat damage and would be predicted to have relatively high standardized ileal AA digestibility (Kim et al., 2012). The analyzed AA concentrations in the medium-oil DDGS were greater than those used in diet formulation, so diets containing DDGS contained slightly more lysine and other amino acids than calculated. Therefore, Lys should not have limited pig performance.

Growth performance and carcass traits

Experiment 1

Pigs fed increasing medium-oil DDGS had decreased (linear, $P < 0.02$) ADG and G:F (Table 1.6). There was a trend (linear, $P < 0.10$) for decreased ADFI with increasing medium-oil DDGS. Unlike observations in our study, in a review of over 20 papers, Stein and Shurson (2009) concluded that up to 30% DDGS could be added to the diet without negatively affecting growth performance. However, in the majority of the studies examined by Stein and Shurson (2009), the DDGS sources contained at least 10% oil. This is because Step 2 oil extraction had not widely been implemented until 2012 (CEPA, 2012). Average daily gain and G:F decreased approximately 2.2 and 1.3%, respectively, with every 15% added medium-oil DDGS.

Pigs fed increasing medium-oil DDGS had decreased (linear, $P < 0.03$) final BW, carcass yield, HCW, back fat, and loin-eye depth (Table 1.6). These findings are consistent with previous research that has observed similar changes in carcass characteristics with increasing DDGS (Cook et al., 2005; Whitney et al., 2006; Linneen et al., 2008). The decrease in carcass yield is consistent with other reports and has been verified to be related to increases in intestinal and organ weights that will vary based on the solubility of fiber used, the inclusion rate in the diet, and the duration of feeding (Agyekum et al., 2012; Asmus et al., 2013).

Increasing medium-oil DDGS also increased jowl IV (linear, $P < 0.001$).This is similar to previous observations (Jacela et al., 2009; Benz et al., 2010; Asmus et al., 2013), where increasing DDGS increased jowl IV. Bee et al. (2002) observed that fatty acid composition in the fat depots will be directly correlated to fatty acid composition of the diet. Farnworth and Kramer (1987) observed that dietary fat inhibits natural de novo synthesis allowing for direct deposition of fatty acids from the diet. De novo fat deposition typically is relatively saturated fat and includes the C16 and C18 saturated and monounsaturated fatty acids (Wood et al., 2008). Concentration of C18:2n-6 (linoleic acid) is considerably greaterin diets with DDGS and has been shown to linearly increase in concentration in tissues when dietary intake increases (Wood et al., 1984). Similarly, Benz et al. (2010) observed that concentrations of C18:2n-6, PUFA, and IV increased linearly in jowl, backfat, and belly fat as DDGS increased. It was their conclusion that feeding DDGS at 20% of the diet may result in unacceptable IV and fat quality. Some packing plants have listed a maximum jowl IV of 73 (Benz et al., 2009).

It was our original hypothesis that carcass fat quality traits such as C18:2n-6 concentrations and IV may not be as negatively affected by feeding medium-oil DDGS that have had a greater portion of corn oil removed during ethanol production than traditional DDGS. When feeding traditional DDGS (>10.5% oil), jowl IV increases approximately 2 mg/g for every 10% traditional DDGS added to the diet (Benz et al., 2010). In the present study, however, adding medium-oil DDGS to the diet increased jowl IV by only 1.4 mg/g for every 10% addition. Thus, the IV increase for medium-oil DDGS is approximately 70% of the increase with high-oil DDGS. This difference is consistent with the oil content in the medium-oil DDGS value (7.63%) which is approximately 70% of the oil content in high-oil DDGS (>10% oil).

Experiment 2

The GE and DE values observed for the corn used in this study, 3,871 and 3,515 kcal/kg (Table 1.7), respectively, were similar to published values of 3,933 and 3,451 kcal/kg, respectively (NRC, 2012). The GE in medium-oil DDGS in our study (4,585 kcal/kg) was 97%

of the listed value of medium-oil DDGS (4,710 kcal/kg; NRC, 2012), which was expected because the medium-oil DDGS used in this study contained approximately 1.5 percentage units less oil than that listed in the NRC (2012). Digestibility of GE was determined to be 73.2%, which is similar to GE digestibility values observed by Pederson et al. (2007). Multiplying GE by 73.2% resulted in DE of the medium-oil DDGS used in this study of 3,356 kcal/kg (as-fed). This value is lower (94%) than the DE of medium-oil DDGS listed in the NRC (2012) of 3,582 kcal/kg (as-fed). Using NRC (2012) equations (1-6 for ME and 1-7 for NE; Table 1.9), ME and NE of medium-oil DDGS is calculated to be 3,153 and 2,069 kcal/kg, respectively, or approximately 93 and 88% of ME and NE values listed for medium-oil DDGS in the NRC (2012) on an as-fed basis.

The DE, ME, and NE values determined or calculated in this study were assigned for the medium-oil DDGS and caloric efficiency from the growth trial (Exp. 1) was calculated based on ADFI × dietary energy, kcal/kg and divided by total gain (Table 1.8). Caloric efficiency for DE, ME, and NE did not change as medium-oil DDGS increased indicating that the values were accurate for the growth portion of this study. If the published NRC (2012) energy values are used, caloric efficiency on both a DE and an ME-basis increases (worsens) as medium-oil DDGS increase in the diet suggesting NRC (2012) values over-estimates the energy value of this particular medium-oil DDGS (Table 1.8). This would be logical because the oil content in the NRC (2012) medium-oil DDGS is slightly greater than the oil content in the medium-oil DDGS used in the present study. However, when calculated on a NE basis, there was no difference in caloric efficiency, suggesting that the NRC (2012) NE value (2,343 kcal/kg; 88% the value of corn; as fed-basis) was a better estimate of the energy content of medium-oil DDGS. This is supported by the ME and NE calculations derived in our study (3,153 and 2,069 kcal/kg, as fed, respectively), where ME was 93% of the NRC 2012 estimate, and NE was 88% of the NRC (2012) NE value.

Other prediction equations have been developed from studies comparing DDGS with varying nutrient composition to see if chemical analysis could predict energy content. Anderson et al. (2012) used 18 corn coproducts to generate prediction equations for DE and ME. Sources included DDGS, high protein distillers dried grains, corn bran, corn germ, corn germ meal, oil-extracted DDGS, corn gluten meal, corn gluten feed, and corn dried solubles. Using the equations of Anderson et al. (2011; Table 1.9), predicted values for DE and ME of medium oil DDGS were 3,291 and 3,124 kcal/kg (as-fed), respectively. The DE and ME valuesare similar to the 3,356 and 3,153 kcal/kg (as-fed), respectively, that was either observed in this study (DE) or calculated (ME) from NRC (2012) equations. Surprisingly, ether extract was not included in the prediction equation for ME but was for DE.

Using DE and ME equations from Pederson et al. (2007; Table 1.9), predicted values for DE and ME were 4,242 and 3,583 kcal/kg (as-fed), respectively. The predicted DE value was considerably greater than the value observed in the nutrient balance portion of this study. Predicted values of DE and ME using a simplerset of equations by Pederson (2007) were 5,341 and 4,783 kcal/kg (as-fed), respectively. These values are both considerably greater than all other calculated values. This would suggest that some degree of accuracy is lost as prediction equations use fewer components of the proximate analyses or the ingredient they are predicting contain nutrient values outside the range used to derive the prediction equations. This is especially true in the case of Pederson et al. (2007) where ether extract, ADF and NDF varied considerable compared with the values of the medium-oil DDGS used in the present study.

The digestibility of ether extract in this particular medium-oil DDGS source was lower than values of approximately 70% ether extract digestibility reported by Stein et al. (2009). However, the 4 DDGS sources used in the analysis by Stein et al, (2009) were, again, high-oil DDGS, ranging from 10 to 12.5% oil. Measurements in this study were taken on an apparent total tract digestibility basis; however, it has been suggested that to provide a more accurate measurement of lipid digestion, digestibility needs to be measured on a true ileal digestibility basis. This is largely due to the fact that microbes can synthesize fat from carbohydrates in the hindgut (Kil et al., 2011).

The CP digestibility of the corn and medium-oil DDGS used in this study was 85.5 and 83.1%, respectively, similar to the 82 and 83% for corn and DDGS observed by Pederson et al, (2007). Again the Lys concentration as a percentage of CP was greater than 3% suggesting there was little heat damage in the medium-oil DDGS hence the high CP digestibility (Kim et al., 2012). The medium-oil DDGS had similar crude fiber and ADF as the mean of 10 DDGS samples determined by Urriola et al. (2010). In addition, the medium-oil DDGS used in the present experiment was similar in NDF concentrations when compared to published values (36.5 vs. 36 to 38%; Urriola et al., 2010; NRC,2012). Urriola et al. (2010) estimated apparent total tract digestibility of ADF, NDF, and crude fiber at 58.5, 59.3 and 44.3%, respectively; compared to 77.5, 67.8, and 67.4% for ADF, NDF, and crude fiber of the medium-oil DDGS used in the present study.

Because energy content of DDGS appears to be one of the most important factors determining its value relative to corn, a reduction in energy content of the DDGS significantly reduces its feeding value. Results of this study indicate that increasing medium-oil DDGS in finishing pig diets reduced growth performance such that it needs to be discounted in value relative to corn when adding to swine diets.

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Figures and Tables

Table 1-1. Analyzed nutrient composition of medium-oil corn dried distillers grains with solubles (DDGS; as-fed basis)

Item	Medium-oil DDGS[1]
DM, %	93.70
CP, %	30.10
Crude fat, %	7.63
Crude fiber, %	10.58
Ash, %	4.53
ADF, %	19.53
NDF, %	36.47
Starch, %	7.6
P, %	0.92
Essential AA, %	
Arg	1.12
His	0.75
Ile	1.11 (1.01)
Leu	3.38 (3.17)
Lys	0.92 (0.78)
Met	0.53 (0.58)
Thr	1.03 (1.06)
Trp	0.23 (0.21)
Val	1.46 (1.35)

[1] Values represent the mean of 1 sample analyzed six times. Diets were prepared using values ( ) from NRC 1998.

Table 1-2. Fatty acid analysis of corn medium-oil dried distillers grains with solubles (DDGS)

Item	Medium-oil DDGS
Myristic acid (C14:0), %	0.08
Palmitic acid (C16:0), %	13.69
Palmitoleic acid (C16:1), %	0.15
Margaric acid (C17:0), %	0.11
Stearic acid (C18:0), %	1.86
Oleic acid (C18:1 *cis*-9), %	22.50
Vaccenic acid (C18:1n-7), %	1.25
Linoleic acid (C18:2n-6), %	56.75
α-Linoleic acid (C18:3n-3), %	1.80
Arachidic acid (C20:0), %	0.41
Gadoleic acid (C20:1), %	0.24
Eicosadienoic acid (C20:2), %	0.08
Arachidonic acid (C20:4n-6), %	0.05
Other fatty acids, %	1.00
Total SFA,[1] %	16.15
Total MUFA,[2] %	24.19
Total PUFA,[3] %	58.70
Total *trans* fatty acids,[4] %	0.15
UFA:SFA ratio [5]	5.13
PUFA:SFA ratio[6]	3.63
Iodine value,[7] g/100g	122.7

[1] Total saturated fatty acids= ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] +[C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[2] Total monounsaturated fatty acids= ([C14:1] + [C16:1] + [C18:1 cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[3] Total polyunsaturated fatty acids= ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[4] Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans]*); brackets indicate concentration.

[5] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[6] PUFA:SFA = total PUFA/total SFA.

[7] Calculated as iodinevalue = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 1-3. Diet composition, d 0 to 33 (Exp. 1 as-fed basis)[1]

	Medium-oil dried distillers grains with solubles, %			
Item	0	15	30	45
Ingredient, %				
Corn	79.00	66.83	54.80	42.45
Soybean meal (46.5% CP)	18.48	15.84	13.04	10.41
Medium-oil DDGS	---	15.00	30.00	45.00
Monocalcium P (21% P)	0.90	0.55	0.20	---
Limestone	0.89	1.03	1.17	1.32
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10
L-LysHCl	0.18	0.21	0.24	0.27
L-Thr	0.01	---	---	---
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible amino acids, %				
Lys	0.80	0.80	0.80	0.80
Ile:Lys	68	73	77	81
Leu:Lys	165	190	215	239
Met:Lys	29	34	38	43
Met &Cys: Lys	60	65	70	76
Thr: Lys	61	66	71	76
Trp: Lys	18	18	18	18
Valine: Lys	80	87	93	101
Total Lys , %	0.90	0.93	0.96	0.99
ME, kcal/kg	3,334	3,343	3,352	3,356
SID Lys : ME, g/Mkcal	2.40	2.39	2.39	2.38
CP, %	15.48	17.32	19.11	20.95
Ca, %	0.59	0.57	0.55	0.56
P, %	0.54	0.52	0.50	0.51
Available P, %	0.25	0.25	0.25	0.28

[1] Diets were fed in meal form from d 0 to 33 of the experiment.

[2] Amino acid values used in diet formulation for the medium-oil DDGS were derived from Stein et al. (2007) for values of DDGS (NRC, 1998).

[3] Provided per kg of premix: 4,409,249 IU vitamin A; 551,156 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

Table 1-4. Diet composition, d 33 to 67 (Exp. 1, as-fed basis)[1]

	Medium-oil dried distillers grains with solubles, %			
Item	0	15	30	45
Ingredient, %				
Corn	82.71	70.55	58.52	45.99
Soybean meal (46.5% CP)	14.96	12.31	9.52	6.90
Medium-oil DDGS	---	15.00	30.00	45.00
Monocalcium P (21% P)	0.75	0.40	0.05	---
Limestone	0.87	1.00	1.14	1.30
Salt	0.35	0.35	0.35	0.35
Vitamin premix	0.10	0.10	0.10	0.10
Trace mineral premix	0.10	0.10	0.10	0.10
L-lysine HCl	0.16	0.19	0.23	0.26
L-threonine	0.01	---	---	---
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible amino acids, %				
Lys	0.70	0.70	0.70	0.70
Ile:Lys	70	75	79	84
Leu:Lys	177	206	234	262
Met:Lys	31	36	41	47
Met &Cys: Lys	64	70	76	82
Thr: Lys	64	68	74	80
Trp: Lys	18	18	18	18
Valine: Lys	83	91	99	107
Total Lys, %	0.79	0.82	0.85	0.88
ME, kcal/kg	3,343	3,352	3,360	3,356
SID Lys: ME, g/Mkcal	2.09	2.09	2.09	2.09
CP, %	14.15	15.98	17.77	19.60
Ca, %	0.54	0.52	0.50	0.54
P, %	0.49	0.47	0.45	0.50
Available P, %	0.21	0.21	0.21	0.27

[1] Diets were fed in meal form from d 33 to 67 of the experiment.

[2] Amino acid values used in diet formulation for the medium-oil DDGS were derived from Stein et al. (2007) for values of traditional DDGS (NRC, 1998).

[3] Provided per kg of premix: 4,409,249 IU vitamin A; 551,156 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

Table 1-5. Diet composition, Exp. 2, as-fed basis[1]

Ingredient, %	Corn basal diet
Corn	96.90
Limestone	2.30
Salt	0.40
Vitamin premix[2]	0.25
Trace mineral premix[3,4]	0.15

[1] A total of 12 pigs (PIC 327 × 1050; initially 25.6 kg BW) were used in a 6 wk study to provide 12 observations per treatment. The basal diet was blended 50/50 with the medium-oil dried distillers grains with solubles to provide the other experimental diet.

[2] Provided per kg of premix: 4,409,249 IU vitamin A; 551,156 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[4] Vitamins and minerals are diluted by 50% in the test diets.

Table 1-6. Effect of medium-oil dried distillers grains with solubles on finishing pig growth performance and carcass characteristics (Exp. 1)[1]

	Medium-oil dried distillers grains with solubles, %					Probability, *P*<	
	0%	15%	30%	45%	SEM	Linear	Quadratic
Initial wt, kg	68.9	68.9	68.9	68.9	0.9	0.99	0.99
d 0 to 67							
ADG, kg	0.875	0.848	0.838	0.817	0.010	0.01	0.77
ADFI, kg	2.739	2.709	2.681	2.664	0.034	0.10	0.84
G:F	0.320	0.313	0.313	0.307	0.004	0.02	0.99
Final wt, kg	127.3	125.8	125.2	124.0	1.1	0.03	0.87
Carcass data							
HCW, kg	93.39	91.43	90.11	88.52	0.83	0.001	0.82
Carcass yield,[2]%	73.98	73.16	72.36	71.84	0.16	0.001	0.35
Backfat depth,[3] mm	19.4	19.8	19.4	18.7	0.40	0.17	0.15
Loin depth,[3] mm	61.0	60.0	59.7	57.9	0.81	0.01	0.58
Lean,[3]%	53.1	52.8	52.8	52.7	0.23	0.32	0.65
Jowl IV, mg/g	70.2	71.1	73.7	76.3	0.27	0.001	0.01

[1] A total of 288 mixed sex pigs (PIC 327 × 1050; initially 68.9 kg BW) were used in the 67-d trial with 8 pigs per pen and 9 replications (pens) per treatment.

[2] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[3] Adjusted by using HCW as a covariate.

Table 1-7. Apparent total tract digestibility of corn and medium-oil dried distillers grains with solubles (DDGS, as-fed basis)[1]

Item	Corn	Medium-oil DDGS
DM, %	88.0	93.7
Digestibility of DM, %	93.3^{a}	70.5^{b}
GE, kcal/kg	3,871	4,585
Digestibility of GE, %	91.1^{a}	73.2^{b}
CP, %	8.80	30.10
Digestibility of CP, %	85.5^{a}	83.1^{a}
Oil, %	2.17	7.63
Digestibility of Oil, %	21.8^{a}	61.7^{b}
ADF, %	5.83	19.53
Digestibility of ADF, %	59.4^{a}	77.5^{b}
NDF, %	16.22	36.47
Digestibility of NDF, %	59.9^{a}	67.8^{b}
CF, %	3.85	10.58
Digestibility of CF, %	47.4^{a}	67.4^{b}

[1] A total of 12 pigs (PIC 327 × 1050; initially 25.6 kg BW) were used in two, 6 wk Latin square design studies to provide 12 observations per treatment.

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

Table 1-8. Caloric efficiencies using published and observed energy values for medium-oil DDGS

	Medium-oil dried distillers grains with solubles, %					Probability, *P*<	
	0%	15%	30%	45%	SEM	Linear	Quadratic
Observed values[1]							
Caloric efficiency, mcal/kg							
DE	10.9	11.0	11.0	11.1	0.1	0.31	0.91
ME	10.5	10.6	10.5	10.6	0.1	0.66	0.90
NE	7.8	7.8	7.7	7.8	0.1	0.88	0.90
Published values[2]							
Caloric efficiency, mcal/kg							
DE	10.9	11.1	11.2	11.4	0.1	0.01	0.93
ME	10.5	10.7	10.7	10.9	0.1	0.02	0.93
NE	7.8	7.9	7.8	7.9	0.1	0.62	0.90

[1] Observed DE was determined in the digestibility portion of this study (Exp. 2), and ME and NE were calculated based on equations 1-6 and 1-7 from NRC, 2012.

[2] Calculations used the published DE, ME, and NE values for medium oil DDGS (>6, <9% oil) in the NRC, 2012.

Table 1-9. Energy prediction equations

Item	Equation	7.63% oil DDGS
NRC, 2012[1]		
ME[2]	(1.00 × DE) – (0.68 × CP)	3,153
NE[3]	(0.726 × ME) + (1.33 × EE) + (0.39 × Starch) – (0.62 × CP) – (0.83 × ADF)	2,069
Anderson et al. (2011)[4]		
DE	-2,161 + (1.39 × GE) – (20.70 × NDF) – (40.30 × EE)	3,291
ME	(0.94 × GE) – (23.45 × NDF) – (70.23 × Ash)	3,124
Pederson et al. (2007)[5]		
DE (1)	-12,637 – (128.27 × Ash) + (25.38 × CP) – (115.72 × EE) – (138.02 × ADF) + (3.569 × GE)	4,242
DE (2)	-9,929 – (180.38 × Ash) – (106.82 × EE) – (120.44 × ADF) + (3.202 × GE)	5,341
ME (1)	-11,128 – (124.99 × Ash) + (35.76 × CP) – (63.40 × EE) – (150.92 × ADF) + (14.85 × NDF) + (3.023 × GE)	3,583
ME (2)	-4,212 – (266.38 × ash) – (108.35 × ADF) + (1.911 × GE)	4,783

[1] NRC. 2012. Nutrient Requirements of Swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

[2] Refers to equation 1-6 to calculate ME.

[3] Refers to equation 1-7 to calculate NE.

[4] Anderson, P.V., B.J. Kerr, T.E. Weber, C.J. Ziemer, and G.C. Shurson. 2011. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242-1254.

[5] Pederson, C., M.G. Boersma, and H.H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

Chapter 2-The effects of low-, medium-, and high-oil dried distillers grains with solubles (DDGS) on growth performance, nutrient digestibility, and fat quality in finishing pigs

ABSTRACT

A total of 1,480 pigs were used in 3 experiments to determine the effects of dried distillers grains with solubles (DDGS) varying in oil content on growth performance, carcass characteristics, carcass fat quality,and nutrient digestibility in growing-finishing pigs. In Exp. 1, 1,198 pigs (PIC 337 × 1050, initially 46.1 kg) were used to evaluate the effects of corn DDGS with 5.4 or 9.6% oil (as-fed). Pigs were allotted to a corn-soybean meal–based control diet or diets with 20 or 40% of the 5.4% oil DDGS (29.5% CP, 8.9% ADF, and 21.8% NDF, as-fed) or 9.6% oil DDGS (29.6% CP, 15.3% ADF, and 28.6% NDF, as-fed). From d 0 to 82, ADG was unaffected by DDGS source or level. However, increasing 5.4% oil DDGS decreased (linear, $P < 0.01$) G:F whereas there was no change in pigs fed 9.6% oil DDGS(DDGS source × level interaction; $P < 0.01$). Regardless of DDGS source, carcass yield and HCW decreased (linear, $P<0.04$) with increasing DDGS. Increasing DDGS increased jowl iodine value (IV), but the magnitude was greater in those fed the 9.6% oil DDGS compared with those fed 5.4% oil DDGS (DDGS source × level interaction; $P < 0.01$). In Exp. 2, a total of 270 pigs (PIC 327 × 1050, initially 46.5 kg) were allotted to a corn-soybean meal–based control diet or diets with 20 or 40% of a 9.4% oil DDGS (29.4% CP, 19.6% ADF, and 34.5% NDF, as-fed) or a 12.1% oil DDGS (28.5% CP, 17.6% ADF, and 31.4% NDF, as-fed). From d 0 to 75, ADG increased then for pigs fed increasing 9.4% oil DDGS,but was not different among pigs fed 12.1% oil DDGS (quadratic interaction, $P < 0.02$). Increasing DDGS increased (linear, $P < 0.01$) jowl IV and tended (linear, $P < 0.07$) to increase G:F. Regardless of source, HCW and carcass yield decreased (linear, $P <$

0.05) as DDGS increased. In Exp. 3, nutrient digestibility of the 4 DDGS sources were determined using pigs that were fed either a corn-based basal diet (96.6 corn, and 3.4% vitamins and minerals) or a DDGS diet with 50% basal diet and 50% DDGS. On an as-fed basis, corn contained 3,871 and 3,515 kcal/kg GE and DE, respectively. The 5.4, 9.6, 9.4, and 12.1% oil DDGS contained 4,347, 4,648, 4,723, and 4,904 kcal/kg (as-fed) GE and 3,417, 3,690, 3,838, and 3,734 kcal/kg DE, respectively (as-fed). Stepwise regression indicated that the oil (ether extract) content was the only significant variable to explain differences in energy contentand a 1% change in oil content will change the DE by 62 kcal/kg (*Adjusted* R^2 = 0.41) and NE by 115 kcal/kg (*Adjusted* R^2 = 0.86; as-fed).

Key words: corn, DDGS, digestibility, growth, finishing pigs, iodine value

INTRODUCTION

Dried distillers grains with solubles (**DDGS**) are a by-product of the ethanol industry that iscommonly used to replace portions of corn and soybean meal in swine diets. Traditional dried distillers grains with solubles with approximately 10% oil have a relatively similar feeding value to that of corn (Stein, 2007). In a review of over 20 papers, Stein and Shurson (2009) concluded that growth performance will remain unchanged with feeding DDGS up to 30% of the diet. However, carcass characteristics such as carcass yield and jowl iodine value (**IV**) are adversely affected with feeding DDGS due to the high unsaturated fatty acid content of DDGS.

As the value of corn oil has risen, ethanol plants have begun implementing oil extraction procedures to remove a greater portion of the corn oil, resulting in DDGS that vary in oil content from approximately 4 to 12% (CEPA, 2011). Inherently, the feeding value of DDGS is largely based on its energy content and thus changing the oil content of DDGS may affect growth performance. As a result, NRC (2012) values for DDGS are based on oil content and are categorized as low (>4% oil), medium (between 6 and 9% oil), or high-oil (>10%; NRC, 2012).

Research suggests that variables such as GE, ash, oil (ether extract), ADF, and TDF are the significant criteria in estimating energy values of corn coproducts (Pederson et al., 2007; Anderson et al., 2011). However, relatively little data is available comparing the feeding value of DDGS containing less than 8% ether extract.

Therefore, the objective of this study was to evaluate effects of DDGS that vary in oil content on finishing pig growth performance, carcass characteristics, carcass fat quality, and to determine the DE content and nutrient digestibility relationships between DDGSsources.

MATERIALS AND METHODS

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in these experiments.

Three experiments were conducted to evaluate the effects of feeding DDGS sources that vary in oil content on growth performance, carcass characteristics, fat quality, and nutrient digestibility in growing-finishing pigs. Experiment 1 was conducted in a commercial research-finishing barn in southwestern Minnesota. The barn was naturally ventilated and double-curtain sided. Pens had completely slatted flooring and deep pits for manure storage. Each pen (5.5 × 3.0 m) was equipped with a 5-hole stainless steel dry self-feeder (Thorp Equipment, Thorp, WI) and a cup waterer for ad libitum access to feed and water.

Experiment 2 was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (2.4 × 3.1 m). The pens had adjustable gates facing the alleyway that allowed for 0.93m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. Both facilities in Exp. 1 and 2 were equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded daily feed additions and diets as specified. The equipment provided pigs with ad libitum access to food and water.

In Exp. 3, pigs were housed in a totally enclosed, environmentally controlled, mechanically ventilated facility containing 12 stainless steel metabolism cages (1.5 × 0.6 m). Each cage was equipped with a feeder as well as a nipple waterer to allow ad libitum access to water. Each metabolism cage had metal mesh flooring that allowed for total collection of feces.

Animals and diets

Samples of DDGS from Exp. 1 were taken upon delivery of every new batch, while DDGS from Exp. 2 were from a single batch of either 9.4 or 12.1% oil DDGS. Corn samples were obtained at the time of diet manufacture for Exp. 3. These DDGS and corn samples were combined, homogenized, and subsamples were taken and analyzed for DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fiber (AOAC 978.10, 2006), NDF (ANKOM Technology, 1998), ADF (ANKOM Technology, 1998), and ether extract (AOAC 920.39 A, 2006) at a commercial laboratory (Ward Laboratories, Inc., Kearney, NE; Table 2.1). Amino acid profile was analyzed at the University of Missouri-Columbia Agricultural Experiment Station Chemical Laboratory (Columbia, MO; AOAC, 2006). Samples of ingredients were taken from every DDGS delivery and a composite sample was used to measure bulk density

(SeedburoModel 8800, Seedburo Equipment, Chicago, IL; Table 2.3). Bulk density of a material represents the mass per unit of volume (g per L). Lastly, particle size was measured on all DDGS sources used (ASAE, 2008; Table 2.3).

Experiment 1. A total of 1,198 pigs (337× 1050: PIC Hendersonville, TN; initially 46.1 kg BW) were used in an 82-d growth study to determine the effects of 5.4 or 9.6% oil corn DDGS in finishing diets on growth performance, carcass characteristics, and carcass fat quality. There were 26 or 27 pigs per pen and pens of pigs were randomly allotted to 1 of 5 treatment groups with average pig BW balanced across treatments to provide 9 replications per treatment. All diets were fed in meal form and treatments were fed over 3 phases (46 to 71, 71 to 105, and 105 to 129 kg; Tables 2.4, 2.5, and 2.6). Pigs were allotted to a corn-soybean meal–based control diet or diets with 20 or 40% of the 5.4% oil DDGS or 9.6% oil DDGS. Diets were formulated to be balanced across treatments by phase for standardized ileal digestible (**SID**) Lys and available P, but diets were not balanced for energy. At the time of diet formulation, the 2012 NRC publication was not available; therefore, total AA in DDGS from Stein et al. (2007) were used. These total AA values were then multiplied by standardized ileal digestibility (**SID**) coefficients derived from Stein et al. (2007) and used in diet formulation. For DDGS sources, total AA values form the NRC (1998).

On d 61, the 3 heaviest pigs from each pen (determined visually) were weighed and sold in accordance with the farm’s normal marketing procedure. Near the conclusion of the trial, all remaining pigs were tattooed according to pen number and dietary treatment to allow for carcass data collection and data retrieval by pen. On d 82, 2 medium-weight barrows were selected from each pen and were transported approximately 1.5 h to a commercial packing plant (Sioux-Preme Packing Co., Sioux Center, IA) where they were harvested and jowl, backfat, and belly fat samples were collected and analyzed for their fatty acid content. Jowl samples were collected from the distal end of the carcass and belly fat samples were taken along the midline parallel to the diaphragm. Backfat samples were taken midline at the 10th rib, and care was taken to sample all 3 layers. Fatty acid analysis was conducted in the University of Nebraska Dept. of Nutrition and Health Sciences Analytical Lab (Lincoln, NE; Table 2.8; Supelco SP-2330). Also on d 82, the remainder of the pigs was transported approximately 1 h to a different commercial packing plant (JBS Swift and Company, Worthington, MN) for data collection. Standard carcass criteria of percentage carcass yield, HCW, backfat depth, loin depth, and percentage lean were calculated. Hot carcass weight was measured immediately after evisceration, and carcass yield was calculated as HCW divided by live weight at the plant. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index (FFLI) was calculated according to National Pork Producers Council (1991) procedures.

Experiment 2. A total of 270 pigs (327× 1050: PIC Hendersonville, TN; initially 46.5 kg BW) were used in a 75-d growth study to determine the effects of 9.4 or 12.1% oil corn DDGS in finishing diets on pig growth performance and carcass characteristics. There were 8 pigs per pen and 7 replications per treatment. All diets were fed in meal form and treatments were fed over 3 phases (47 to 73, 73 to 100, and 100 to 122 kg; Tables 3.4, 3.5, and 3.6). Pigs were allotted to a corn-soybean meal–based control diet or diets with 20 or 40% of a 9.4% oil DDGS source or a 12.1% oil DDGS. In this study, NRC (2012) nutrient values for DDGS with greater than 10% oil were used in formulation for both DDGS sources. Diets were formulated to be above the pig's requirement estimate for AA so that they would not limit growth performance.

All pigs and feeders were weighed on d 0, 14, 26, 38, 54 and 75 to determine ADG, ADFI, and G:F.

On d 75, all pigs were weighed and transported approximately 2.5 h to a commercial packing plant (Triumph Foods LLC, St. Joseph, MO) for harvest under USDA inspection. Before slaughter, pigs were individually tattooed according to pen number to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weight was measured immediately after evisceration, and each carcass was evaluated for carcass yield, back fat depth, loin depth, percentage lean, and jowl IV. Carcass yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the plant. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Also, jowl fat samples were collected and analyzed by Near Infrared Spectroscopy (Bruker MPA; Multi-Purpose Analyzer) at the plant for IV using the equation of Cocciardi et al. (2009).

Experiment 3. A total of 12 barrows (327 × 1050: PIC Hendersonville, TN; initially 25.6 kg BW) were used in a 6 wk study to determine nutrient digestibility of corn and the 4 DDGS sources used in Experiments 1 and 2, as well as a 5th source of medium-oil DDGS used in a different growth study outlined by Graham et al. (2013). The fifth source used contained 7.6% oil, 30.1% CP, 19.53% ADF, and 36.47% NDF (as-fed). The 5 DDGS sources plus control corn basal diets were evaluated using a replicated Latin square design with 6 pigs assigned to each square to achieve 12 replications per diet. The pigs within each replicate square were randomly allotted to treatment within each period using the Proc Plan procedure of SAS. The sources of DDGS used in the digestibility study were from the same batches as the corresponding growth trials.Nutrient digestibility of the DDGS source was determined by feeding either a 96.6% corn-based basal diet (corn, 3.4% vitamins and minerals) or 50% basal diet and 50% DDGS (Table 2.6). Thus, levels at which vitamins and minerals were fed in the test diets was half of the levels fed in the corn basal diet.

Pigs were fed the same amount of each diet for the duration of each 7-d period. Feeding level was 2.5× maintenance requirements, and was determined based on their BW on d 1 of each period. Each day's ration was equally divided between two meals fed at 0600 and 1800 h. Each period consisted of 5 d of diet adjustment (10 meals) followed by 2 consecutive days of total fecal collection. On the morning of day 6 (meal 11), just before the morning meal, pigs were allowed approximately 5 minutes to stand, drink, and defecate. After that time, feces were removed and the morning meal was fed. This meal on the morning of d 6 marked the beginning of the timed fecal collection period. On d 8 of period (d 1 of period 2 or meal 15), the same amount of time was given to pigs, allowing them to stand up, drink, and defecate. Before feeding, all feces were collected, and this marked the end of the timed collection period. On that same morning that collection ended, pigs were weighed and fed a new treatment diet in a random order. Feces were stored in a freezer (-20 °C) until further processing and analysis. At the conclusion of a collection period, all feces for each pig were combined, homogenized, and dried in a in a forced-air oven at 50°C. Samples were finely ground and then subsampled for further analysis following the procedures of Jacela et al. (2010). Gross energy concentrations of the ingredients, diets, and fecal samples were measured via adiabatic bomb calorimetry (Parr Instruments, Moline, IL). Calculations outlined by Adeola (2001) were used to determine energy values. Ingredients, diets, and feces were also analyzed for DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fiber (AOAC 978.10, 2006), NDF (ANKOM Technology, 1998), ADF (ANKOM Technology, 1998), and ether extract (AOAC 920.39 A, 2006) at a commercial laboratory (Ward Laboratories, Inc., Kearney, NE).

Statistical Analysis

Data for the growth trials was analyzed as a completely randomized design with pen as the experimental unit and treatment as a fixed effect. However, IV analysis in Exp. 1 was analyzed using a completely randomized design with the fixed effect of treatment and the random effect of pen. Analysis of variance was used with the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Because HCW differed, it was used as a covariate for backfat, loin depth, and percentage lean. For Exp. 1 and 2, contrasts were used to make comparisons between the 1) linear and quadratic interactions of DDGS source × level, 2) corn-soy and 20 and 40% DDGS- containing diets, and 3) linear and quadratic effects of increasing DDGS. In Exp. 3, period, pig, and Latin square were random effects and treatment was a fixed effect. Single degree of freedom contrasts were used to separate means of pigs fed either the corn- or DDGS-based diet in the nutrient balance study. Differences were considered significant at $P \leq 0.05$ and were considered a trend at $P > 0.05$ and $P \leq 0.10$. Stepwise regression was used to determine the effect of the feedstuff composition on DE and NE. Variables were retained in the model with *P*-values ≤ 0.15. The adjusted R^2, the SE of the estimate, the SE, and the Mallows statistic [C(p)] were used to define the best fit equation. If the intercept was determined to be nonsignificant in the final prediction model, it was excluded from the model and an adjusted R^2 value was calculated using the NOINT option of SAS.

RESULTS

Chemical analysis

Analyzed samples of DDGS were similar in CP concentrations, but varied considerably in fiber content (Table 2.1). Crude fiber ranged from 7.9 to 12% on an as-fed basis, with CF increasing as oil content increased. The same overall trend was observed in ADF and NDF concentrations. An abundance of research exists using DDGS with oil content over 10%, and the proximate analysis of the high oil (>10% oil) DDGS used in this study is comparable to DDGS used by Anderson et al. (2012).

According to NRC (2012), the Lys concentrations in low, medium-, and high-oil DDGS are 0.68, 0.90, and 0.77%, respectively. The analysis of AA on the 5.4, 9.6, 9.4, and 12.1% oil DDGS showed that Lys concentrations were 1.03, 1.12, 1.00, and 0.90%, respectively (Table 2.1). The analyzed values of Lys from the DDGS sources were greater than those used in diet formulation, so diets containing DDGS contained slightly more Lys and other amino acids than calculated. Therefore, Lys should not have limited pig performance. The remaining analyzed AA were similar in concentration to values listed in the NRC (2012).

Bulk density tests on the ingredients used in this study further demonstrated the variability in DDGS from different ethanol plants (Table 2.2). It is well established that as DDGS are added to corn-soybean meal based diets, diet bulk density will decrease (Asmus, 2012). Ethanol plants have begun to implement extra centrifugation processes to capture more corn oil during ethanol production (CEPA, 2011), and we would expect that oil removal would reduce bulk density; however, bulk density did not appear to be greatly influenced by oil content. Particle size variedfrom 371 to 744 microns in the DDGS used in these experiments.

Experiment 1

Overall (d 0 to 82), ADG was unaffected by DDGS source or level. There was a DDGS source by level interaction ($P < 0.02$) for ADFI and G:F. Increasing 5.4% oil DDGS increased ADFI and decreased G:F, while there was no significant change in ADFI or G:F when pigs were fed increasing 9.6% oil DDGS. There were no significant differences in final BW.

Regardless of DDGS source, carcass yield and HCW decreased (linear, $P < 0.04$) with increasing DDGS. As DDGS increased, there was a tendency for loin depth to increase (quadratic, $P = 0.05$), especially in pigs fed the 9.6% oil DDGS source. There were DDGS source by level interactions (linear, $P < 0.02$) observed for jowl, belly, and backfat IV. Increasing DDGS increased jowl, belly and backfat IV, but the magnitude of increase was greater in pigsfed the 9.6% oil DDGS compared with those fed 5.4% oil DDGS.

Experiment 2

Overall (d 0 to 75), ADG increased in pigs fed 20% of the 9.4% oil DDGS but then slightly decreased in those fed 40% DDGS relative to control fed pigs (quadratic interaction, $P < 0.02$). Average daily gain was not different among pigs fed 12.1% oil DDGS. Also, increasing DDGS, regardless of source, tended (linear, $P < 0.06$) to increase G:F. As DDGS increased, ADFI decreased (linear, $P < 0.04$), regardless of source. Final BW followed the same trend as ADG (quadratric interaction, $P < 0.10$) with those pigs fed 40% DDGS containing 9.4% oil having the lowest final BW among all treatments.

Regardless of source, increasing DDGS decreased (linear, $P < 0.04$) carcass yield and HCW. There were no significant differences in backfat depth, loin depth, or percentage lean. Increasing DDGS increased (linear, $P < 0.01$) jowl IV, but to a greater extent in pigs fed 12.1%

oil DDGS than 9.4% oil DDGS (DDGS source by level interaction, linear, $P < 0.001$) for jowl IV.

Energy concentration and nutrient digestibility

Experiment 3. Gross energy values observed for the corn, 5.4, 9.6, 9.4, and 12.1% oil DDGS used in the growth portion of this study were 3,871, 4,347, 4,648, 4,723, and 4,904 kcal/kg, respectively (as-fed; Table 2.11). Based on the corresponding GE digestibility coefficients calculated for each DDGS source (Table 2.11), DE values for the corn, 5.4, 9.6, 9.4, and 12.1% oil DDGS were 3,515, 3,417, 3,690, 3,838, and 3,734 kcal/kg, respectively (as-fed). Dry matter digestibility was relatively similar among the 4 DDGS sources. Crude protein digestibility was highest in the 9.4 and 9.6% oil DDGS. Digestibility of the ether extract in DDGS was considerably more variable, ranging from approximately 62 to 76%. In general, the digestibility of ether extract increases as the oil content of DDGS increased, with the exception of the 9.6% oil DDGS used in this study. Acid detergent fiber digestibility of the DDGS sources increased as the oil content increased, with the exception of the 9.4% oil DDGS source that was intermediate. Neutral detergent fiber and CF digestibility did not follow this pattern and were variable among sources.

DISCUSSION

It is well-established that corn DDGS can be fed at up to 30% of the diet without adversely affecting growth performance (Stein and Shurson, 2009). This is because > 10% oil DDGS have an energy value similar to that of corn (Stein, 2007). However, as new oil extraction capabilities are implemented in ethanol plants to harvest more corn oil, reduced-oil DDGS are becoming more abundant in the marketplace. A concern is that the new, reduced oil DDGS might negatively affect pig growth performance. This was the case in recent research by Graham et al. (2013) where pigs fed increasing medium-oil DDGS (7.6% oil) had linear decreases in ADG and G:F.

The 2012 NRC distinguishes between high- (>10% oil), medium-(>6, <9% oil), and low-oil (<4% oil) DDGS. However, recent research would suggest that NRC (2012)energy values tend to overestimate values of the low oil DDGS. Zamora et al. (2013) fed pigs diets containing 7.8% oil DDGS and estimated a NE value of the corn DDGS to be between 2,150 and 2,300 kcal/kg (as-fed), which is lower than the value of 2,343 kcal/kg (as-fed) listed for DDGS with 6 to 9% oil in the 2012 NRC. Graham et al. (2013) also observed DE and calculated NE values for DDGS containing 7.6% oil that were lower than those estimates by NRC (2012) for medium oil (>6, <9% oil) DDGS.

In both Exp. 1 and 2, increasing DDGS, regardless of source, decreased carcass yield. The decrease in carcass yield is consistent with other reports and has been verified to be related to increases in intestinal and organ weights that will vary based on the type of fiber used, the inclusion rate in the diet, and the duration of feeding (Agyekum et al., 2012; Asmus et al., 2013, Graham et al., 2013). The decrease in HCW and carcass yield agrees with findings by Cook et al.(2005), Whitney et al. (2006), and Linneen et al. (2008); however, they observed decreases in backfat and loin depth with increasing DDGS up to 30% inclusion. Based on their findings, we would have expected to see decreases in backfat and loin depth as well, because up to 40% DDGS were fed in the current study. However, this was not the case.

There were DDGS source × level interactions for jowl, backfat, and belly IV's measured in both experiments, with IV increasing as DDGS increased, but to a greater extent in DDGS with higher oil content. This is similar to previous observations (Jacela et al., 2009; Benz et al., 2010; Asmus et al., 2013) where increasing DDGS increased jowl IV. Based on the findings of

Bee et al. (2002), fatty acid composition in the fat depots will be directly correlated to fatty acid composition of the diet, which are inherently higher in unsaturated fatty acids. However, there are generally differences in the fatty acid composition among depots, which is tied to the rate of turnover of adipose tissue in that depot. For instance, the backfat is thought to have the faster turnover rate among depots, and thus, would be more amenable to changes in dietary fatty acid composition. The jowl fat depot, on the other hand, is generally the slowest of the depots to change once dietary fatty acid composition has been changed. The belly fat depot is somewhat intermediate in turnover rate compared to jowl and backfat (Bergstrom et al., 2010).

Anderson et al. (2012) and Pederson et al. (2007) created a series of DE and ME prediction equations based on digestibility trials and measured energy values of various corn coproducts. These studies were conducted before the widespread implementation of the oil extraction processes used in ethanol plants today, so most of DDGS sources used contain greater than 10% in oil. In fact, only Anderson et al. (2012) had an oil-extracted DDGS source that contained 2.8% ether extract (as-fed basis). While the work of Stein et al. (2005) had previously established that large amounts of variation exist in the energy content of various sources of DDGS, both studies determined that stepwise regression could be used to determine prediction equations for DE and ME values of DDGS from the proximate analysis of the sources. Typical variables found to be significant in their equations included GE, ash, ether extract, starch, and fiber components such as ADF or total dietary fiber. It was the hypothesis in the current study that oil content would be highly significant in the prediction of energy values of DDGS sources varying considerably in oil content.

Therefore, stepwise regression was used to determine DE and NE equations based on the 4 DDGS sources used in the growth portion of this study, and one other source of DDGS outlined by Graham et al. (2013). The DDGS source used in Graham et al. (2013) contained 7.6% oil (as-fed basis) and a DE of 3,356 kcal/kg.The DE content of the corn and 5 DDGS was determined by using the digestibility data collected from the 12 pigs housed in metabolism crates. The GE and DE values observed for the corn used in this study, 3,871 and 3,515 kcal/kg (as-fed), respectively, were similar to published values (3,993 and 3,451 kcal/kg, respectively; NRC, 2012). Initially, the GE of the diet, ingredients, and feces were determined via bomb calorimetry, and based on the total feed intake and feces output on a kcal/kg basis, apparent total tract digestibility of the energy in the diet was determined. Again, GE values observed for the 5.4, 9.6, 9.4, and 12.1% oil DDGS used in the growth portion of this study were 4,347, 4,648, 4,723, and 4,904 kcal/kg, respectively (as-fed; Table 2.11). These compare to values listed in the NRC(2012) for low-, medium-, and high-oil DDGS of 5,098, 4,710, and 4,849 kcal/kg (as-fed), respectively. In contrast to GE values from NRC(2012),those observed in the current study increased as oil content in DDGS increased.

Gross energy digestibility coefficients determined in the current study for 5.4, 9.6, 9.4, and 12.1% oil DDGS were 78.6, 79.4, 81.3, and 76.1%, respectively. The calculated GE digestibility coefficients from low-, medium-, and high-oil DDGS in NRC(2012) are 64.6, 76.1, and 74.7%, respectively. Digestibility of GE in the NRC(2012) is lowest for low-oil DDGS, which is not the case in the current study. However, GE digestibility of medium-oil DDGS in the NRC(2012) is greater than that of >10% oil DDGS. The same trend is evident in the current study, as the GE digestibility is decreased in the 12.1% oil DDGS source when compared to the 9.4 and 9.6% oil DDGS sources.

Based on the corresponding GE digestibility coefficients calculated for each DDGS source (Table 2.12), DE values for the 5.4, 9.6, 9.4, and 12.1% oil DDGS were 3,417, 3,690, 3,838, and 3,734 kcal/kg, respectively (as-fed). These DE values compare to values listed in the NRC(2012) for low-, medium-, and high-oil DDGS of 3,291, 3,582, and 3,620 kcal/kg (as-fed), respectively. In the current study, similar to NRC(2012) values, DE increases as the oil content of DDGS sources increases with the exception of the 12.1% oil DDGS source, which is intermediate. The NE of the DDGS sources was calculated based on the actual growth performance from Exp. 1 and 2 and data from the 7.6% oil DDGS from Graham et al. (2013). Net energy efficiency (**NEE**) was determined by calculating the calories of NE intake in kcal/kg per kg of gain on a phase basis (studies utilized either 2 or 3 phase-feeding strategies). This was accomplished by using solving functions to set the NEE of pigs fed each DDGS source equal to that of the corn-soybean meal control diet. This was done with the assumption that the NE content of corn and soybean meal are 2,672 and 2,087 kcal/kg, respectively (as-fed; NRC, 2012). Because growth performance was variable among phases of any particular study, best-fit equations on each phase NEE value, as well as averages of two or more phases, were fitted to the data for each study. The equation with the slope closest to zero, or with the most similar NEE's, was selected for each DDGS source, and that dietary NE content was then used to calculate the NE of DDGS according to the percentage of DDGS in that diet.

Stepwise regression was then used to establish DE and NE prediction equations. Variables included in the regression analysis were the linear and quadratic terms of oil (ether extract), CP, CF, ADF, NDF, particle size, and bulk density. Ether extractwas the only significant variable in the present model as compared to prediction equations from Pederson et al. (2007) and Anderson et al. (2011), which included GE, CP, EE, ADF, NDF, and starch in their models (Table 2.13).

Based on the DE values determined from the digestibility portion of this study, ME values were calculated using equation 1-6 from NRC (2012). Calculated ME values for the 5.4, 9.6, 9.4 and 12.1% oil DDGS were 3,216, 3,488, 3,638, and 3,540 kcal/kg (as-fed basis), respectively. Next, the DE and ME prediction equations of Pederson et al. (2007) and Anderson et al. (2012) were used to determine how energy values compared using the various equations (Table 2.13). Using the DE equation of Anderson et al. (2012), the predicted DE was relatively similar to the actual DE of the 5.4 and 12.1% oil DDGS sources, but the 9.4 and 9.6% oil DDGS sources were considerably underestimated in DE content. Using the ME equation of Anderson et al. (2012), the ME values predicted for the 5.4, 9.6, and 12.1% oil DDGS were relatively similar to values calculated based on the ME values observed in the current study, but values for the 9.4% oil DDGS were approximately 330 kcal/kg lower than the ME calculated based on data from the current study. While there is no explanation for these differences, it is important to note that 18 corn coproducts were used to generate the prediction equations of Anderson et al. (2012) for DE and ME. Sources included DDGS, high protein distillers dried grains, corn bran, corn germ, corn germ meal, oil-extracted DDGS, corn gluten meal, corn gluten feed, and corn dried solubles. Because of the inherent variation in the chemical composition of the ingredients used by Anderson et al. (2012) used to derive the prediction equations, conclusions can only be drawn that the variation among equations is a result of the variables either included or excluded by the model.

Using the two sets of prediction equations by Pederson et al. (2007), the DE and ME of 5.4, 9.6, 9.4, and 12.1% oil DDGS were calculated based on the proximate analysis of DDGS sources used in the current study (Table 2.13). These predicted values are considerably different than the measured DE and calculated ME values of DDGS sources from the current study. For instance, DE values calculated with equations of Pedersen et al. (2007) vary by as much as 800 kcal/kg. Several of the differences may be accounted for by the differences in chemical composition of DDGS sources used to derive the prediction equations. For instance, Pederson et al. (2007) used 10 samples of relatively high-oil DDGS, only ranging from 8.6 to 12.0% in oil content. While oil content was found to be significant in the prediction of energy values for DDGS and was used in the stepwise regression equation, analyzed ADF was considerably lower in concentration in the DDGS sources used by Pederson et al. (2007). Also, it is important to note that ash and NDF values of the medium-oil DDGS used in the current study were considerably lower in concentration than in the 10 DDGS sources used by Pederson et al. (2007).

Based on results from the growth portion of the current study as well as those of Graham et al. (2013), energy content of DDGS sources should be considered in determining a price relative to corn because of reduced feeding values from the extraction of larger quantities of corn oil from DDGS. This conclusion agrees with the research of Zamora et al. (2013), who also determined that the NE value of 7.8% oil DDGS is less than the stated value forDDGS with 6-9% oil in the NRC (2012), indicating a wide range of energy values that are dependent on the oil content of DDGS. The equations generated to predict DE and NE as a function of oil content on an as-fed basis were: DE (kcal/kg) = 62.347 * ether extract (%) + 3058.13 (n=5, *Adjusted* R^2 = 0.41); NE (kcal/kg) = 115.011* ether extract (%) + 1501.01 (n=5, *Adjusted* R^2 = 0.86). These equations indicate changing the oil content 1% in DDGS will change the DE by 62 kcal/kg and NE by 115 kcal/kg on an as-fed basis.

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TABLES AND FIGURES

Table 2-1. Analyzed nutrient composition of ingredients (as-fed basis)[1]

		Exp. 1		Exp. 2	
Item, %	Corn	5.4% oil DDGS[2]	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
DM	88.03	92.38	91.97	93.17	93.20
CP	8.80	29.53	29.63	29.40	28.53
Crude fiber	3.85	7.93	11.02	11.25	12.07
ADF	5.83	8.90	15.25	19.57	17.57
NDF	16.22	21.75	28.58	34.50	31.38
Ash	1.49	4.90	3.94	4.65	4.61

[1] Values represent the mean of 1 sample analyzed 6 times.

[2] Dried distillers grains with solubles.

Table 2-2. Bulk densities and particle size of dried distillers grains with solubles (DDGS) sources (as-fed basis)[1]

	Source and DDGS, %			
	Exp. 1		Exp. 2	
Item	5.4% oil DDGS	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
Bulk density, g/L[2]	588	549	564	517
Particle size, µ	371	562	744	687

[1] Ingredient samples were taken from every delivery (Exp. 1) and were combined so that a composite sample could be evaluated. In Exp. 2, all diets were made from single batches of both DDGS sources; therefore, a representative sample was analyzed.

[2] Bulk densities represent the mass per unit volume. Diet samples were taken from the tops of feeders during each phase.

Table 2-3. Phase 1 diet compositions (as-fed basis)[1]

	Exp. 1			Exp. 2		
	Control	DDGS source[2], % inclusion		Control	DDGS source[3], % inclusion	
Item	0	20	40	0	20	40
Ingredient, %						
Corn	76.2	59.4	41.9	74.2	58.1	41.8
Soybean meal (46.5% CP)	21.5	18.5	15.8	22.9	19.25	15.7
5.4 or 9.6% oil DDGS	-	20.0	40.0	-	-	-
9.4 or 12.1% oil DDGS	-	-	-	-	20.0	40.0
Monocalcium P (21% P)	0.43	0.03	-	0.90	0.45	-
Limestone	0.90	1.10	1.38	0.95	1.2	1.45
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vit./trace mineral premix[4]	0.10	0.10	0.10	0.30	0.30	0.30
L-LysHCl	0.48	0.53	0.58	0.23	0.27	0.31
DL-Met	0.04	-	-	0.02	-	-
L-Thr	0.07	0.01	-	0.03	-	-
Phytase	0.02	0.01	0.01	0.13	0.13	0.13
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.95	0.95	0.95	0.95	0.95	0.95
Ile:Lys	62	68	75	65	70	74
Leu:Lys	139	179	219	150	177	205
Met:Lys	29	30	34	29	32	37
Met &Cys: Lys	55	59	66	57	61	66
Thr: Lys	60	60	65	61	63	69
Trp: Lys	18	18	18	18	18	18
Valine: Lys	69	79	89	75	82	90
Total Lys, %	1.07	1.10	1.13	1.06	1.10	1.14
ME, kcal/kg	3,319	3,270	3,204	3,325	3,332	3,341
SID Lys: ME, g/Mkcal	2.86	2.91	2.96	2.86	2.85	2.84
CP, %	17.0	19.7	22.5	17.2	19.6	22.0
Ca, %	0.48	0.48	0.57	0.63	0.63	0.63
P, %	0.44	0.44	0.53	0.55	0.53	0.51
Available P, %	0.27	0.27	0.37	0.38	0.38	0.38

[1] Phase 1 diets were fed in meal form from d 0 to 27 (Exp. 1) and d 0 to 26 (Exp. 2).

[2] Diets included both 5.4 and 9.6% oil DDGS sources fed at 20 and 40% of the diet.

[3] Diets included both 9.4 and 12.1% oil DDGS sources fed at 20 and 40% of the diet.

[4] Provided per kg of premix: 4,409,249 IU vitamin A; 551,156 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}; 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

Table 2-4. Phase 2 diet compositions (as-fed basis)[1]

	Exp. 1			Exp. 2		
	Control	DDGS source[2], % inclusion		Control	DDGS source[3], % inclusion	
Item	0	20	40	0	20	40
Ingredient, %						
Corn	79.8	62.8	45.4	79.6	63.3	47.1
Soybean meal (46.5% CP)	18.2	15.3	12.4	17.7	14.2	10.5
5.4 or 9.6% oil DDGS	-	20.0	40.0	-	-	-
9.4 or 12.1% oil DDGS	-	-	-	-	20.0	40.0
Monocalcium P (21% P)	0.40	-	-	0.80	0.35	-
Limestone	0.90	1.10	1.35	0.98	1.25	1.43
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vit./trace mineral premix[4]	0.10	0.10	0.10	0.25	0.25	0.25
L-LysHCl	0.35	0.38	0.44	0.20	0.24	0.29
DL-Met	0.01	-	-	0.01	-	-
L-Thr	0.03	-	-	0.02	-	-
Phytase	0.02	0.01	0.01	0.13	0.13	0.13
Total	100	100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.80	0.80	0.80	0.80	0.80	0.80
Ile:Lys	66	74	82	67	72	77
Leu:Lys	156	203	250	163	196	228
Met:Lys	29	33	38	29	35	41
Met &Cys: Lys	58	66	75	60	66	73
Thr: Lys	61	65	71	62	66	73
Trp: Lys	18	18	18	18	18	18
Valine: Lys	75	87	98	78	87	96
Total Lys, %	0.91	0.94	0.98	0.90	0.94	0.98
ME, kcal/kg	3,321	3,272	3,208	3,330	3,338	3,345
SID Lys: ME, g/Mkcal	2.41	2.45	2.49	2.40	2.40	2.39
CP, %	15.5	18.3	21.1	15.2	17.6	20.0
Ca, %	0.47	0.47	0.55	0.60	0.61	0.60
P, %	0.42	0.42	0.51	0.51	0.49	0.49
Available P, %	0.26	0.26	0.36	0.35	0.35	0.38

[1] Phase 2 diets were fed in meal form from d 27 to 61 (Exp. 1) and d 26 to 54 (Exp. 2).

[2] Diets included both 5.4 and 9.6% oil DDGS sources fed at 20 and 40% of the diet.

[3] Diets included both 9.4 and 12.1% oil DDGS sources fed at 20 and 40% of the diet.

[4] Provided per kg of premix: 4,409,249 IU vitamin A; 551,156 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}; 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

Table 2-5. Phase 3 diet compositions (as-fed basis)[1]

	Exp. 1			Exp. 2		
	Control	DDGS source[2], % inclusion		Control	DDGS source[3], % inclusion	
Item	0	20	40	0	20	40
Ingredient, %						
Corn	76.6	59.4	42.0	83.1	66.9	50.6
Soybean meal (46.5% CP)	21.4	18.6	15.7	14.4	10.8	7.2
5.4 or 9.6% oil DDGS	-	20.0	40.0	-	-	-
9.4 or 12.1% oil DDGS	-	-	-	-	20.0	40.0
Monocalcium P (21% P)	0.15	-	-	0.80	0.30	-
Limestone	0.85	1.10	1.38	0.88	1.15	1.30
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vit./trace mineral premix[4]	0.10	0.10	0.10	0.20	0.20	0.20
L-LysHCl	0.38	0.43	0.48	0.18	0.22	0.27
DL-Met	0.05	-	-	-	-	-
L-Thr	0.08	0.04	-	0.03	-	-
Phytase	0.02	0.01	0.01	0.13	0.13	0.13
Paylean, 10 ppm[5]	0.03	0.03	0.03	-	-	-
Total	100	100	100	100	100	100
Standardized ileal digestible (SID) amino acids, %						
Lys	0.90	0.90	0.90	0.70	0.70	0.70
Ile:Lys	65	72	79	68	75	81
Leu:Lys	148	190	231	175	213	250
Met:Lys	32	31	36	31	38	44
Met &Cys: Lys	59	62	70	63	71	79
Thr: Lys	65	67	69	65	69	76
Trp: Lys	18	18	18	18	18	18
Valine: Lys	73	83	94	81	92	102
Total Lys, %	1.02	1.05	1.08	0.79	0.83	0.87
ME, kcal/kg	3,327	3,268	3,204	3,336	3,345	3,352
SID Lys: ME, g/Mkcal	2.70	2.75	2.80	2.10	2.09	2.09
CP, %	16.9	19.7	22.4	13.9	16.3	18.8
Ca, %	0.42	0.48	0.57	0.55	0.56	0.55
P, %	0.38	0.44	0.53	0.50	0.47	0.48
Available P, %	0.21	0.26	0.37	0.35	0.34	0.37

[1] Phase 3 diets were fed in meal form from d 61 to 82 (Exp. 1) and d 54 to 75 (Exp. 2).

[2] Diets included both 5.4 and 9.6% oil DDGS sources fed at 20 and 40% of the diet.

[3] Diets included both 9.4 and 12.1% oil DDGS sources fed at 20 and 40% of the diet.

[4] Provided per kg of premix: 4,409,249 IU vitamin A; 551,156 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}; 26.5 g Mn from manganese oxide; 110 g Fe from iron sulfate; 110 g Zn from zinc sulphate; 11 g Cu from copper sulfate; 198 mg I from calcium iodate; and 198 mg Se from sodium selenite.

[5] Paylean; Elanco Animal Health, Greenfield, IN.

Table 2-6. Diet composition, Exp. 3, as-fed basis[1]

Ingredient, %	Corn basal diet
Corn	96.90
Limestone	2.30
Salt	0.40
Vitamin premix[2]	0.25
Trace mineral premix[3]	0.15

[1] A total of 12 pigs (PIC 327 × 1050; initially 25.6 kg BW) were used in a 6 wk study to provide 12 observations per treatment. The basal diet was blended 50/50 with the 4 dried distillers grains with solubles sources to provide the other experimental diets.

[2] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

Table 2-7. Effects of low vs high-oil dried distillers grains with solubles (DDGS) on growth performance of finishing pigs (Exp.1)[1]

	Control	5.4% oil DDGS		9.6% oil DDGS			5.4% oil DDGS		9.6% oil DDGS		5.4 vs 9.6%	DDGS Level		Source × Level	
	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.	Oil	Linear	Quad.	Linear	Quad.
d 0 to 82															
ADG, kg	1.03	1.04	1.02	1.03	1.03	0.01	0.29	0.33	0.73	0.84	0.96	0.42	0.62	0.47	0.36
ADFI, kg	2.60	2.69	2.75	2.58	2.64	0.03	0.002	0.69	0.40	0.36	0.002	0.02	0.73	0.02	0.30
G:F	0.398	0.386	0.370	0.398	0.390	0.004	0.001	0.62	0.21	0.37	0.0003	0.001	0.36	0.001	0.76
BW, kg															
d 0	46.18	46.15	46.14	46.18	46.15	0.63	0.96	0.99	0.98	0.98	0.97	0.97	0.99	0.99	0.98
d 27	72.00	70.92	70.31	71.33	71.58	0.79	0.14	0.80	0.70	0.64	0.29	0.28	0.64	0.26	0.86
d 61	106.64	105.71	104.01	105.68	105.90	0.93	0.05	0.74	0.57	0.61	0.32	0.15	0.90	0.16	0.52
Final BW, kg	129.60	129.84	128.54	129.40	129.86	1.09	0.50	0.57	0.87	0.80	0.69	0.77	0.83	0.40	0.52

[1] A total of 1198 pigs (PIC 337 × 1050, initially 46.1 kg) were used in this 82-d study.

Table 2-8. Effects of low vs high-oil dried distillers grains with solubles (DDGS) on carcass characteristics of finishing pigs (Exp.1)[1]

	CS[2]	5.4% oil DDGS		9.6% oil DDGS			5.4% oil DDGS		9.6% oil DDGS		5.4 vs 9.6% Oil	DDGS Level		Source × Level	
	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.		Linear	Quad.	Linear	Quad.
HCW, kg	95.44	94.03	92.92	93.27	93.83	0.81	0.03	0.88	0.16	0.18	0.93	0.04	0.32	0.43	0.35
Carcass yield, %[3]	76.23	75.99	74.92	75.43	75.21	0.46	0.05	0.47	0.13	0.62	0.78	0.05	0.89	0.66	0.34
Backfat depth, mm[4]	15.58	15.65	15.51	15.33	15.67	0.36	0.89	0.81	0.86	0.50	0.82	0.99	0.77	0.75	0.48
Loin depth, mm[4]	71.62	70.18	70.77	70.05	71.14	0.64	0.36	0.18	0.59	0.09	0.84	0.40	0.05	0.67	0.75
Lean, %[4]	57.92	57.74	57.91	57.92	57.84	0.22	0.97	0.49	0.80	0.89	0.78	0.87	0.72	0.83	0.53
FFLI[4]	51.26	51.21	51.29	51.38	51.22	0.17	0.88	0.74	0.89	0.49	0.75	0.99	0.81	0.77	0.43
Jowl IV[5]	67.36	70.92	76.68	72.02	78.73	0.96	<0.001	0.32	<0.001	0.27	0.06	<0.001	0.17	0.06	0.96
Belly IV[5]	62.10	67.84	73.52	70.88	76.18	0.96	<0.001	0.98	<0.001	0.11	0.002	<0.001	0.29	0.03	0.24
Backfat IV[5]	66.48	70.30	75.79	71.74	78.83	0.74	<0.001	0.34	<0.001	0.25	0.001	<0.001	0.94	0.001	0.94

[1] A total of 1198 pigs (PIC 337 × 1050, initially 46.1 kg) were used in this 82-d study.

[2] Refers to the control, corn-soybean meal diet.

[3] Percentage yield was calculated by dividing HCW by live weight obtained at the packing plant.

[4] Adjusted by using HCW as a covariate.

[5] Calculated as iodine value = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Table 2-9. Effects of low-vs high-oil dried distillers grains with solubles (DDGS) on growth performance of finishing pigs (Exp.2)[1]

	DDGS Source and % of Diet														
	Control	9.4% oil DDGS		12.1% oil DDGS			9.4% oil DDGS		12.1% oil DDGS		9.4 vs 12.1%	DDGS Level		Source × Level	
Item	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.	Oil	Linear	Quad.	Linear	Quad.
d 0 to 90															
ADG, kg	1.01	1.05	0.98	1.00	1.00	0.02	0.23	0.01	0.79	0.70	0.34	0.40	0.11	0.34	0.02
ADFI, kg	2.85	2.81	2.68	2.75	2.73	0.05	0.04	0.51	0.14	0.63	0.96	0.04	0.90	0.54	0.38
G:F	0.355	0.375	0.366	0.363	0.368	0.005	0.12	0.03	0.08	0.82	0.31	0.06	0.11	0.85	0.13
BW, kg															
d 0	46.4	46.3	46.4	46.3	46.3	1.3	0.99	0.95	0.93	0.97	0.96	0.95	0.95	0.95	0.99
d 26	72.8	73.8	71.4	72.7	71.8	1.4	0.50	0.35	0.62	0.81	0.80	0.50	0.44	0.86	0.58
d 54	100.6	102.1	97.9	99.7	98.9	1.6	0.22	0.15	0.43	0.99	0.66	0.25	0.35	0.66	0.26
Final BW, kg	122.0	125.1	119.9	121.6	121.9	1.7	0.38	0.06	0.96	0.85	0.66	0.59	0.25	0.41	0.10

[1] A total of 270 pigs (PIC 327 × 1050, initially 102.6 lb BW) were used in this 75-d study. There were 8 pigs per pen and 7 pens per treatment.

Table 2-10. Effects of low-vs high-oil dried distillers grains with solubles (DDGS) on carcass characteristics of finishing pigs (Exp.2)[1]

	DDGS Source and % of Diet													
	CS[2]	9.4% oil DDGS		12.1% oil DDGS			9.4% oil DDGS		12.1% oil DDGS		9.4 vs 12.1%	DDGS Level		Source × Level	
	0	20	40	20	40	SEM	Linear	Quad.	Linear	Quad.	Oil	Linear	Quad.	Linear	Quad.
HCW, kg	88.60	89.20	84.66	87.63	86.77	1.11	0.02	0.06	0.24	0.97	0.81	0.04	0.23	0.18	0.14
Carcass yield, %[3]	72.59	71.94	71.02	72.30	71.16	0.18	0.001	0.54	0.001	0.06	0.17	0.001	0.10	0.59	0.31
Backfat depth[4]	18.59	18.27	18.25	19.06	18.09	0.48	0.62	0.79	0.46	0.23	0.52	0.47	0.53	0.81	0.25
Loin depth[4]	61.28	60.05	59.90	60.17	60.38	0.85	0.26	0.60	0.46	0.54	0.73	0.28	0.45	0.70	0.93
Lean, %	53.72	53.55	53.51	53.29	53.65	0.30	0.63	0.86	0.88	0.29	0.84	0.72	0.41	0.74	0.49
Jowl fat IV[5]	66.80	73.08	77.47	73.38	80.01	0.42	0.001	0.07	0.001	0.96	0.002	0.001	0.25	0.0001	0.15

[1] A total of 270 pigs (PIC 327 × 1050, initially 102.6 lb BW) were used in this 75-d study. There were 8 pigs per pen and 7 pens per treatment.

[2] Refers to the control, corn-soybean meal treatment.

[3] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[4] Adjusted by using HCW as a covariate.

[5] Analyzed by Near Infrared Spectroscopy (Bruker MPA; Multi-Purpose Analyzer) at the plant for IV using the equation of Cocciardi et al. (2009).

Table 2-11. Energy values of corn and dried distillers grains with solubles (DDGS) sources and a 7.6% oil DDGS (Graham et al., 2013; as-fed basis)

		Exp. 1		Exp. 2		Graham et al. (2013)
Item, kcal/kg	Corn	5.4% oil DDGS	9.6% oil DDGS	7.6% oil DDGS	12.1% oil DDGS	7.6% oil DDGS
GE	3,871	4,347	4,648	4,585	4,904	4,585
DE	3,515	3,417	3,690	3,356	3,734	3,356
ME[1]	3,455	3,216	3,488	3,153	3,540	3,153

[1] Eqn 1-6 from NRC(2012).

Table 2-12. Comparison of corn and DDGS source digestibilities[1]

		Exp. 1		Exp. 2	
Item, %	Corn	5.4% oil DDGS	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
DM	93.3^{a}	70.0^{b}	73.6^{b}	73.3^{b}	71.9^{b}
GE	91.1^{a}	78.6^{bc}	79.4^{bc}	81.3^{b}	76.1^{c}
CP	85.5^{a}	78.6^{b}	86.3^{a}	88.4^{a}	76.0^{b}
Ether extract	21.8^{c}	67.0^{ab}	61.8^{b}	71.2^{ab}	75.6^{a}
ADF	59.4^{c}	62.8^{c}	79.3^{ab}	74.9^{b}	82.2^{a}
NDF	59.9^{b}	54.8^{bc}	72.0^{a}	61.5^{b}	51.4^{c}
CF	47.4^{d}	45.3^{d}	53.5^{c}	72.1^{a}	63.4^{b}

[1] A total of 12 pigs were used to achieve 12 replications per treatment.

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

Table 2-13. Energy prediction equations for dried distillers grains with solubles (DDGS; as-fed basis)

Item	Equation	5.4% oil DDGS	9.6% oil DDGS	9.4% oil DDGS	12.1% oil DDGS
Graham (2013)					
DE[1]	(62.347 × EE) + 3058.13	3,392	3,655	3,643	3,813
NE[2]	(115.011 × EE) + 1501.01	2,116	2,602	2,580	2,893
Anderson et al. (2011)[4]					
DE	-2,161 + (1.39 × GE) – (20.70 × NDF) – (40.30 × EE)	3,380	3,497	3,458	3,667
ME	(0.94 × GE) – (23.45 × NDF) – (70.23 × Ash)	3,232	3,423	3,304	3,550
Pederson et al. (2007)[5]					
DE (1)	-12,637 – (128.27 × Ash) + (25.38 × CP) – (115.72 × EE) – (138.02 × ADF) + (3.569 × GE)	3,824	4,938	5,045	5,689
DE (2)	-9,929 – (180.38 × Ash) – (106.82 × EE) – (120.44 × ADF) + (3.202 × GE)	4,722	5,716	5,830	6,407
ME (1)	-11,128 – (124.99 × Ash) + (35.76 × CP) – (63.40 × EE) – (150.92 × ADF) + (14.85 × NDF) + (3.023 × GE)	2,853	3,798	3,883	4,429
ME (2)	-4,212 – (266.38 × ash) – (108.35 × ADF) + (1.911 × GE)	4,394	4,982	5,067	5,415

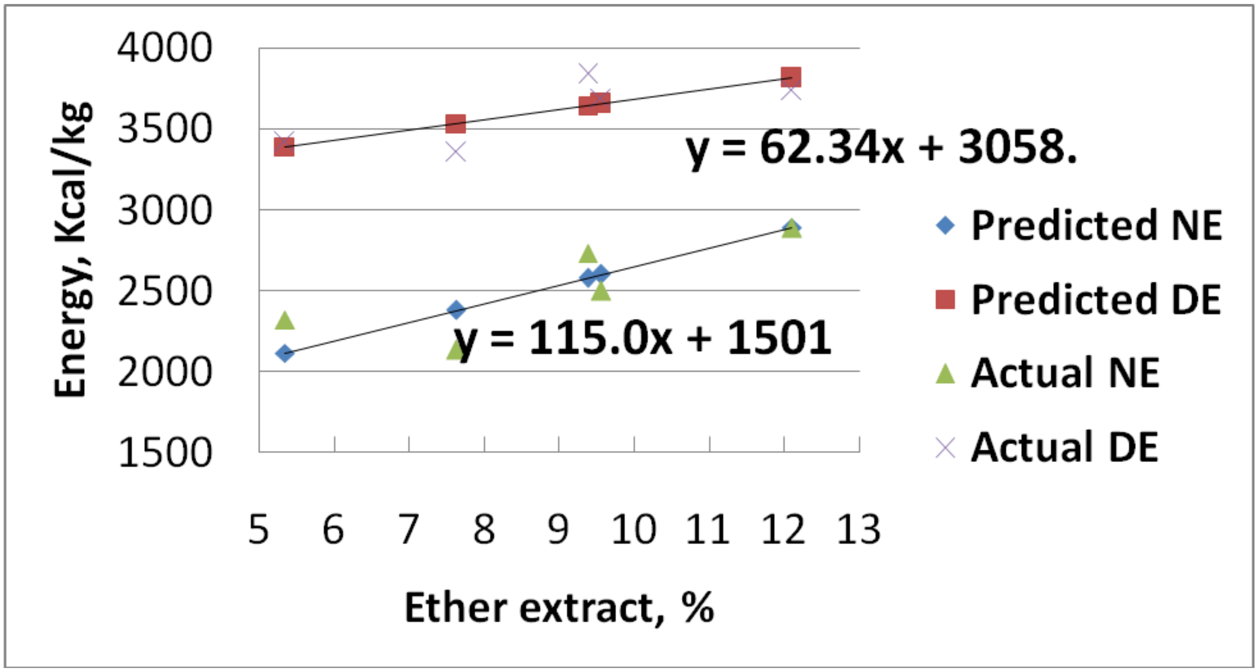
[1] *Adjusted* R^2 = 0.41.

[2] *Adjusted* R^2 = 0.86.

[4] Anderson, P.V., B.J. Kerr, T.E. Weber, C.J. Ziemer, and G.C. Shurson. 2011. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242-1254.

[5] Pederson, C., M.G. Boersma, and H.H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168-1176.

Figure 2-1. Predicted and measured DE and NE values of DDGS sources varying in oil content (as-fed basis) using equations created in stepwise regression.



Chapter 3- The interactive effects of high-fiber diets and ractopamine HCl on finishing pig growth performance, carcass characteristics, and carcass fat quality

ABSTRACT

A total of 576 mixed sex pigs (327 × 1050: PIC; initially 55.8 ± 5.5kg) were used to determine the effects of dried distillers grains with solubles (DDGS) and wheat middlings (midds) withdrawal 24 d before harvest in diets without or with ractopamine HCl (RAC) on growth performance, carcass characteristics, carcass fat quality, and digestive tract weights. From d 0 to 49, pigs were fed a corn-soybean meal–based diet (CS) or diets with 30% DDGS and 19% wheat midds (HF). During this period, pigs fed CS diets had increased ($P < 0.01$) ADG and G:F compared with pigs fed HF diets. On d 49, pens of pigs were re-allotted to 1 of 6 dietary treatments; pigs remained on the CS diet, switched from HF to CS (withdrawal diet), or were maintained on the HF diet. These 3 regimens were fed without or with 10 ppm RAC. There were 12 pens per treatment with 8 pigs per pen. There were no significant diet regimen × RAC interactions observed. Overall (d 0 to 73), pigs fed the CS diet throughout had greater ($P < 0.03$) ADG and G:F than those fed HF diets throughout. Pigs fed the withdrawal diet had greater ($P < 0.03$) ADG, but similar G:F to those fed HF diets throughout. Pigs fed the CS diet throughout had greater ($P < 0.01$) carcass yield compared with pigs fed the HF diet throughout, with those fed the withdrawal diets intermediate. Pigs fed RAC had greater ($P < 0.01$) ADG, G:F, and carcass yield than pigs not fed RAC. Jowl, backfat, belly, and leaf fat iodine value (IV) were lowest ($P < 0.01$) for pigs fed the CS diets, highest ($P < 0.01$) for those fed HF diets throughout, and intermediate for pigs fed the withdrawal diet. Feeding RAC increased ($P < 0.04$) IV of backfat, but did not influence IV of other fat depots. There were no differences in intestine and organ weights between pigs that were fed CS diets throughout and pigs fed the withdrawal diet; however, pigs fed the HF diets throughout the study had increased ($P < 0.05$) full cecum and large intestine weights compared with the pigs that were switched from high-fiber diets to the corn-soybean meal diets at d 49. Withdrawing the HF diet and switching to a CS diet for the last 24 d before harvest partially mitigated negative effects on carcass yield and IV often associated with unsaturated fat-containing high-fiber products such as DDGS and wheat midds. Feeding RAC for the last 24 d before market, regardless of dietary fiber regimen, improved growth performance and carcass yield.

Key words: dried distillers grains with solubles, fiber, growth, iodine value, pigs, withdrawal

INTRODUCTION

By-product ingredients such as dried distillers grains with solubles (**DDGS**) and wheat middlings (**midds**) are common feed ingredients used in diet formulation. An abundance of research has been conducted to determine levels at which DDGS can be included in the diet without negatively affecting growth performance. Research has demonstrated that growth performance would not be changed relative to a corn-based diet when DDGS were added at up to 20% (Drescher et al., 2008; Widmer et al., 2008) or 30% (Cook et al., 2005; DeDecker et al., 2005) of the diet. A review by Stein and Shurson (2009) also concluded that feeding up to 30% DDGS in the diet will not have detrimental effects on growth performance.

A major concern with feeding a high amount of DDGS is increased iodine value (**IV**) and decreased carcass yield (Whitney et al., 2006; Xu et al., 2007; Linneen et al., 2008). However, complete dietary withdrawal of DDGS and wheat midds before marketing has been successful in lowering IV and improving carcass yield (Hill et al., 2008; Xu et al., 2008; Asmus et al., 2012).

Ractopamine HCl (**RAC**; Paylean, Elanco Animal Health, Greenfield, IN) is added to finishing swine diets before marketing to increase weight gain, G:F, and carcass yield (Apple et al., 2007). Therefore, in addition to using a withdrawal diet before marketing, feeding RAC may also mitigate the negative effects of high-fiber diets on carcass yield. Thus, the objective of this study was to determine the possible interactive effects of RAC on growth performance, carcass characteristics, carcass fat quality, and intestinal weights of pigs withdrawn from the high-fiber diets before market versus pigs fed corn-soybean meal based diets or high-fiber diets containing DDGS and midds.

MATERIALS AND METHODS

General

The protocols for this experiment were approved by the Kansas State University Institutional Animal Care and Use Committee.

This experiment was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (2.4× 3.1m). The pens had adjustable gates facing the alleyway that allowed for 0.93m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

Animals and diets

A total of 575 pigs (PIC 327 × 1050: PIC Hendersonville, TN; initially 55.8 kg BW) were used in two consecutive studies (73 and 72d, respectively). Initially, pens of pigs (4 barrows and 4 gilts per pen) were randomly allotted to 1 of 2 dietary treatments with initial pen weight balanced across treatments. The dietary treatments included a corn-soybean meal–based control diet or diets with 30% DDGS and 19% midds. Diets were not balanced for energy. In each replicate trial, 12 pens of pigs were fed the corn-soybean meal control diet, and 24 pens were fed the high-fiber diet. On d 49, pigs were re-allotted to 1 of 6 treatments (diets A-F). Pens of pigs previously fed the corn-soybean meal–based diets remained on corn-soybean meal diets without or with the addition of RAC. Half of the high fiber–fed pigs were switched to corn-soybean meal–based diets, which served as the high-fiber withdrawal treatment, again without or with RAC. Finally, half of the high-fiber diet–fed pigs remained on a high-fiber diet without or with RAC. Thus, there were 72 total pens with 12 replications of the 6 final dietary treatments. Dietary treatments were corn-soybean meal-based and were fed in 3 phases (Tables 3.1 and 3.2). All diets were prepared at the K-State Animal Sciences and Industry feed mill and fed in meal form.

Composite samples of the DDGS and wheat midds from each feed delivery were analyzed in a commercial laboratory (Ward Laboratories, Inc., Kearney, NE; Table 3.3) for DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006.), P (AOAC 965.17/985.01, 2006) ADF (ANKOM Technology, 1998), NDF (ANKOM Technology, 1998). Composite samples of complete diets sampled at the feeder during each phase were used to measure bulk density (Seedburo Model 8800, Seedburo Equipment, Chicago, IL; Table 3.4). Bulk density of a material represents the mass per unit of volume (g per Liter).

Pigs and feeders were weighed on d 0, 28, 49, and 73 to calculate ADG, ADFI, and G:F. In the first trial, before marketing, all pigs were weighed individually to allow for calculation of carcass yield. The second heaviest barrow in each pen (1 pig per pen, 6 pigs per treatment) was identified to be harvested for carcass data collection at the K-State Meats Lab, all other pigs were transported to a commercial packing facility.No other carcass measurements were collected. Of the pigs slaughtered at K-State, HCW was measured immediately after evisceration. Following evisceration, the entire pluck (heart, lungs, liver, kidneys, spleen, stomach, cecum, large intestine and small intestine) was weighed and then the individual organs were weighed (heart, liver, kidneys as well as the stomach, small and large intestine and cecum). After organ weights were recorded, the large intestine, stomach, and cecum were physically stripped, flushed with water, and weighed again. Belly, jowl, back fat, and leaf fat samples were taken from all 36 pigs and were analyzed for their fatty acid content according to the procedure by Metcalfe and Schmitz (1961). Belly fat samples were taken along the proximal end of the teat line. Jowl fat samples were collected from the distal end of the carcass. Backfat samples were taken midline at the 10th rib, with care taken to sample all three layers of adipose tissue. Leaf fat was collected in its entirety and subsampled before fatty acid analysis. After carcasses had chilled for 24 h at 0°C, 10th-rib backfat and loin eye area measurements were taken.

In the second trial, all pigs were transported approximately 2 h to a commercial packing plant (Farmland Foods, Crete, NE). Prior to transport, pigs were individually weighed and tattooed to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weights were measured immediately after evisceration to allow for calculation of carcass yield. Belly and jowl fat samples were collected from each carcass and analyzed for their fatty acid content. Belly fat samples were taken along the midline parallel to the diaphragm. Jowl fat was collected from the distal end of the carcass. All fatty acid analysis on fat samples for this experiment was conducted in the University of Nebraska Dept. of Nutrition and Health Sciences Analytical Lab (Lincoln, NE; Tables 3.8-3.13; Supelco SP-2330; Metcalfe and Schmitz, 1961). Percentage carcass yield was calculated by dividing HCW at the plant by live weight at the farm before transport to the KSU Meats Lab or commercial packing plant (studies 1 and 2, respectively).

Statistical Analysis

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. Contrasts were used to evaluate differences in performance of pigs that were maintained on corn-soybean meal diets or high fiber diets, or were removed from high fiber diets to corn-soybean meal diets at d 49. Also, contrasts were used to determine the effects of using RAC. Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P > 0.05$ and $P \leq 0.10$.

RESULTS

Chemical Analysis

The DDGS used in this study were slightly higher in CP than the published value for DDGS (>10% oil) in the NRC (2012), at 29.2 and 27.3% CP, respectively. The same was true for the wheat midds, with those used in the study analyzed to contain 17.5% CP and the published value for CP in the wheat midds in the NRC (2012) being 15.8%.The oil content of DDGS and wheat midds used in this study were approximately 1% less than those listed in the NRC (2012). Crude fiber for DDGS was similar to published values, but crude fiber in wheat midds was higher than published values (8.4 vs. 5.2%, respectively). The NDF and ADF components of DDGS and wheat midds only varied slightly from published NRC (2012) values. Bulk density test showed that as high fiber ingredients such as wheat midds and DDGS were included in the diets, bulk density decreased. Although DDGS contains more oil, fatty acid analysis of the ingredients showed that the wheat midds contain a slightly higher level of linoleic acid (C18:2n-6), resulting in a higher IV for wheat midds than DDGS (Table 3.5). Similarly, PUFA concentrations were higher in the wheat midds than DDGS.

Growth Performance

From d 0 to 49, pigs fed the corn-soybean meal–based diet had increased ($P < 0.001$) ADG and G:F compared to pigs fed the high-fiber diet (Table 3.6). From d 49 to 73, no significant interactions were observed between fiber withdrawal regimen and RAC for any response criteria. Pigs maintained on the corn-soybean meal diet or those switched to the corn-soybean meal diet on d 49 (fiber withdrawal) had similar ADG and G:F, and both were greater ($P < 0.03$) than pigs maintained on the high fiber diet throughout. Regardless of dietary treatment, pigs fed RAC had improved ($P < 0.001$) ADG and G:F. Overall (d 0 to 73), pigs fed the corn-soybean meal diet throughout had greater ($P < 0.03$) ADG and G:F than those fed the high-fiber withdrawal regimen or those fed the high-fiber diets for the duration of the study. Pigs fed the withdrawal diet had greater ($P < 0.03$) ADG and ADFI but similar G:F to that of pigs fed high-fiber diets throughout. Pigs fed RAC had increased ($P < 0.001$) ADG and G:F compared with those not fed RAC.

Carcass Characteristics

Pigs that remained on high fiber diets throughout, either those slaughtered at K-State or the commercial packing plant, had decreased ($P < 0.03$) final BW compared with those maintained on the corn-soybean meal diets throughout or switched from high fiber to the corn-soybean meal diet. Of the pigs slaughtered at the commercial packing plant, those fed high-fiber diets throughout had decreased ($P < 0.001$) carcass yield and HCW compared with pigs fed corn-soybean meal diets for the entire study, whereas pigs that were switched from high-fiber diets to corn-soybean meal diets on d 49 were intermediate ($P < 0.01$) for carcass yield. However, HCW was not different among pigs fed either maintained on the corn-soybean meal diets throughout the study or switched at d 49 from the high fiber diet to the corn-soybean meal diet.

Of the pigs slaughtered at K-State, those fed corn-soybean meal-based diets for the duration of the study or withdrawal diets had greater ($P < 0.01$ and 0.06, respectively) HCW than pigs fed high fiber diets throughout. Also, pigs fed either the corn-soybean meal-based diet throughout or those withdrawn from the HF diets had increased ($P < 0.03$) carcass yield than those that remained on high fiber diets for the entire study. Pigs fed RAC had increased ($P <$ 0.001) carcass yield and HCW compared with pigs that were not fed RAC. In the first trial, no differences were observed in 10th-rib fat depth or loin eye area among the different dietary fiber regimens; however, RAC tended to decrease ($P < 0.10$) back fat.

Intestine and Organ Weights

No differences were observed in intestine and organ weights between pigs that were fed corn-soybean meal diets for the duration of the study and pigs switched to the corn-soybean meal from high fiber at d 49 (Table 3.7); however, pigs that remained on the high-fiber diets throughout the study had increased ($P < 0.05$) full cecum and large intestine weights compared with the pigs switched from high-fiber diets to the corn-soybean meal diets at d 49 and increased large intestine weights compared to pigs fed corn-soybean meal diets. Pigs fed RAC had decreased ($P = 0.01$) rinsed stomach weight and tended to have decreased ($P = 0.07$) full stomach weight compared with pigs that were not fed RAC. Leaf fat was decreased ($P = 0.02$) in pigs fed the high-fiber diets throughout compared with those fed either the corn-soybean meal diet, or those switched from high fiber to the corn-soybean meal diet.

Carcass Fatty Acid Composition

In both trials, pigs fed high fiber diets throughout had increased ($P = 0.02$) linoleic (C18:2n-6), palmitic (C16:0), stearic (C18:0), and oleic (C18:1 *cis*-9) acid concentrations in backfat, belly, leaf, and jowl fat when compared to those fed corn-soybean meal diets (Tables 3.8 to 3.13). Therefore, IV was lowest ($P < 0.001$) in all 4 fat depots for pigs fed the corn-soybean meal diet throughout, highest ($P < 0.01$) for those fed high fiber throughout, with those on the fiber withdrawal regimen intermediate.

In jowl fat samples, regardless of where they were harvested, palmitic and linoleic acid concentrations were decreased ($P < 0.02$) in pigs fed corn-soybean meal based diets compared to those fed high fiber diets until marketing, with those fed withdrawal diets being intermediate in concentration. Oleic acid concentrations showed this response in pigs harvested at K-State, however, in pigs that were harvested at the commercial packing facility, oleic acid concentrations were decreased ($P < 0.001$) in pigs fed corn-soybean meal based diets compared to those fed withdrawal or high fiber diets, but those fed withdrawal diets were not different than those maintained on high fiber diets until marketing.

In belly fat samples from pigs that were harvested at the commercial packing plant, palmitic, stearic, and oleic acid concentrations were decreased ($P < 0.02$) in pigs fed corn-soybean meal diets for the duration of the study compared to those that were fed high fiber diets for the duration of the study, with withdrawal pigs having intermediate fatty acid concentrations. Linoleic acid concentrations had the same response, regardless of where pigs were harvested. However, in belly fat samples from pigs that were harvested at K-State, palmitic and stearic acid concentrations were increased (*P* < 0.05) in pigs fed high fiber diets compared to those fed either the corn-soybean meal or withdrawal diets, although pigs fed corn-soybean meal-based diets were not different than those fed withdrawal diets. Oleic acid concentrations, however, were decreased (*P* < 0.02) in pigs fed corn-soybean meal based diets compared to those fed withdrawal diets and high fiber diets, although pigs fed withdrawal diets were not different than those fed high fiber diets.

In leaf fat, concentrations of palmitic and stearic acid were decreased (*P* < 0.003) in pigs fed corn-soybean meal diets throughout and those fed withdrawal diets compared to those that were fed high fiber diets throughout. Also in leaf fat samples, linoleic acid concentrations were decreased (*P* < 0.001) in pigs fed corn-soybean meal based diets throughout compared to those fed high fiber diets, with withdrawal pigs intermediate.

In backfat, concentrations of oleic and linoleic acids were decreased (*P* < 0.003) in pigs fed corn-soybean meal diets throughout compared to those fed high fiber diets throughout, with withdrawal pigs having intermediate concentrations.

Added RAC had no effect on leaf fat IV, but increased (*P* < 0.04) IV in back fat, likely due to increased (*P* < 0.05) linoleic acid concentrations in backfat with the addition of RAC. Linoleic acid concentrations in the belly fat depot increased (*P* < 0.002) with the addition of RAC; however, only pigs killed at the commercial packing plant had increased (*P* < 0.002) belly fat IV when RAC was used. In the jowl fat depot, the use of RAC had no effect on either linoleic acid concentrations or IV in pigs harvested at the K-State Meats Lab, but increased (*P* < 0.02) linoleic acid concentrations and thus, increased (*P* < 0.01) jowl fat IV when RAC was included in the diet.

DISCUSSION

The proximate analysis and fatty acid values of DDGS and wheat midds used in this trial were similar to values reported in the NRC (2012). Bulk densities of high-fiber test diets were similar to values reported by Asmus et al. (2012), who fed DDGS and wheat midds at the same inclusion levels as the current study. The high-fiber regimen used by Asmus et al. (2012) has been used as a model to test the effects of fiber and fiber withdrawal before harvest on HCW and carcass yield. Similar to the results of Asmus et al. (2012), the feeding strategy employed herein was successful in creating these differences in HCW and yield.

Stein and Shurson (2009) reviewed several studies and determined that feeding of DDGS in swine finisher diets at levels of up to 30% will not result in decreased growth performance. In support of this finding, Jacela et al. (2009) fed 30% DDGS and observed no decreases in growth performance, but saw a substantial increase in IV of pigs fed DDGS compared to those fed a control corn-soybean meal diet. Also, Xu et al. (2010) determined that while feeding DDGS at levels of up to 30% will not have detrimental effects on growth performance, feeding DDGS at levels of greater than 20% will likely result in poorer carcass and fat quality. Barnes (2011) conducted a study to determine if the fat provided in the diet from DDGS or midds was additive in increasing IV; it was observed, again, that feeding 30% DDGS had no effect on growth criteria, but as 10 or 20% midds were included in diets containing 30% DDGS, growth performance and carcass characteristics reduced linearly. However, based on the conclusions from that study, the negative effects on fat IV of adding wheat midds to diets containing DDGS is not additive. In another trial reported by Barnes (2011), it was determined that pigs fed DDGS at a constant rate of 15% had increased IV compared to pigs fed 20% midds. Furthermore, Asmus (2012), and Nemechek et al., (2012) fed diets containing 30% DDGS and approximately

19 to 20% midds. In all cases, IV was substantially increased and carcass yield decreased with the use of thehigh fiber ingredients. Therefore, these diets were used as a model in the current study to investigate ways to mitigate the decreased yield and often unacceptable IV by some packers.

Contrary to findings by Asmus (2012), carcass yield in the present study was not fully recovered by feeding a withdrawal diet for the last 3 wk before marketing. These results would agree with research by Gaines et al. (2008) who did not fully recover carcass yield from pigs withdrawn from high fiber diets for the last 3 wk, but did see fully recovered carcass yield when pigs were withdrawn from high fiber diets 6 wk. Still yet, Xu et al. (2010) reported that regardless of fiber level or when they were withdrawn to corn-soybean meal control diets, there were no differences in carcass yield. The results of Xu et al. (2010) agree with the findings of Jacela et al. (2009), who observed that feeding and withdrawal strategies had no effects on HCW or carcass yield. However, the large amount of variation in quality and digestibility of fiber content in DDGS sources may account for the differences reported among researchers (Urriola et al., 2010).

No differences in organ weights (heart, liver, kidneys) among treatments were observed in the current study, agreeing with research by Agyekum et al. (2012), but contradicting results by Asmus (2012), who reported minor differences in kidney weights. Anugwa et al. (1989) reported increased liver and kidney weights in pigs fed high fiber diets with excess CP, which was identified as a possible confounding factor. Of the intestinal weights measured (whole intestine, full and rinsed stomach, full and rinsed cecum, full and rinsed large intestine, and full small intestine), the increased cecum and large intestine weights in the present study agree with the findings of Anugwa et al. (1989) and Asmus (2012). In agreement with our results, Asmus

(2012) observed that as fiber reduction strategies are implemented, cecum and large intestine weights will regress back to that of control fed pigs.

It has been determined that the rate of change in the fatty acid profile of adipose tissue in pigs changes as the dietary intake of particular fatty acids increases (Wood, 1984; Teye et al., 2006; Wood et al., 2008). Research by Jacela et al. (2009) and Asmus (2012) evaluated various fiber withdrawal durations and the rate of change in fatty acid profile. Jacela et al. (2009) used diets containing 15 and 30% DDGS that were withdrawn at varying intervals to determine if improvements in backfat, belly, or jowl fat IV could be achieved before marketing relative to pigs fed either none or 30% DDGS for the entirety of the study. Asmus (2012) again maintained control groups of pigs on control corn-soybean meal diets or with 30% DDGS and 19% midds for the duration of the study. Other pigs were initially fed the high fiber diets and then were reduced to a medium fiber (15% DDGS, 9.5% midds) or the low fiber control diet (0% DDGS, 0% midds). Jacela et al (2009) was able to determine that as DDGS withdrawal duration increases, IV for all fat depots will decrease. Asmus (2012) reported that jowl IV decreased as lower fiber diets were fed for longer periods of time. Jacela et al (2009) was able to determine that as DDGS withdrawal duration increases, IV for all fat depots will decrease. Jacela et al. (2009) indicated that jowl IV can be improved approximately 0.35 g/100 g per wk for every 10% DDGS withdrawn from the diet before marketing. In the current study, a similar decrease in IV of jowl fat was observed for pigs fed RAC (0.32 g/100 g per wk), but slightly slower change in pigs not fed RAC (0.30 g/100 g per wk), which agrees with the findings of Asmus (2012) and Bergstrom et al. (2010). In the present study, it was observed that with a 24-d withdrawal, IV for all fat depots decreased, but complete mitigation of negative effects on fat quality was not achieved. These results agree with the findings of Jacela et al (2009), who reported IV that was still higher than that of pigs fed a control, corn-soybean meal based diet when high fiber was removed from the diet for up to 6 wk before marketing.

The current study also agrees with research by Benz et al. (2010) who also saw linearly increased IV in backfat, jowl, and belly fat depots with increasing DDGS. Interestingly, they found that concentrations of C18:2n-6 and PUFA were linearly increased in all 3 fat depots, and C18:1 *cis*- 9 and MUFA concentrations linearly decreased as DDGS increased (Benz et al., 2010). Also, it has been determined that the rate of change in IV of different fat depots will vary due to differences in turnover rates (Benz et al., 2010; Xu et al., 2010). Research by Jacela et al. (2009), Benz et al. (2010), and Bergstrom et al. (2010) support the rate of change varies among fat depots, with backfat IV increasing most rapidly and jowl IV increasing at the slowest rate. The same trend was evident in the current study, with backfat IV increasing substantially more than jowl and belly IV's as DDGS were fed in the diet; however, the increase in IV in the leaf fat depot was very similar to that of the backfat depot.

Withdrawal of pigs from high fiber diets for before harvest is often implemented to decreased its negative effects on IV. Therefore, the rate of IV decrease after the removal of high fiber dietary components is a much more practical measurement when considering the benefits of withdrawal programs. Again, however, there are differences in the rate of decrease in IV based on turnover rates as high fiber products such as DDGS and midds are removed from the diet prior to marketing. In the current trial, as pigs were removed from high fiber diets 24 d before market, belly and leaf fat IV's were reduced considerably more than jowl and backfat IV's. These results would suggest that belly and leaf fat IV's may be more amenable to change than the backfat depot: however, since backfat IV increases rapidly as DDGS are included in the diet, the depot is less susceptible to IV decreases with the removal of DDGS from the diet. Jacela et al. (2009), however, implemented a 20 d withdrawal period and observed that backfat and belly fat IV's were reduced to a greater extent than jowl IV's. Agreeing with the research of Bergstrom et al. (2010), the results of the current study and Jacela et al. (2009) identify that jowl fat IV appears to be the most difficult to modify using withdrawal strategies.

Ractopamine HCl is a phenethanolamine ß-adrenergic agonist that is used in swine finishing diets prior to marketing because it is known to repartition nutrients from fat deposition to increased protein synthesis and muscle gain (Apple et al., 2007). While the response to RAC is well-established, it was the initial hypothesis of the current study that RAC might have an interactive effect when used with high fiber diets in the finisher phase because RAC is known to increase carcass yield and high fiber diets have been shown to decrease carcass yield. However, an interactive response was not observed. Feeding RAC increased carcass yield regardless of fiber withdrawal regimen.

Overall conclusions drawn in a review by Apple et al. (2007) were that RAC usage alters the fatty acid composition of subcutaneous fat; however, no indication was reported that RAC usage would have an interactive effect when fed in conjunction with high fiber diets. Xi et al. (2005) reported that the PUFA content of pigs fed 10 ppm RAC was increased 8.2 percentage units compared to those not fed RAC. Also, because of the increased rate of change in IV in the backfat depot (Bergstrom et al., 2010), we suspected that RAC may have interactive effects with the fatty acid profile of the backfat depot because of its effects on reducing backfat depth. In the current study, however, IV was increased in the backfat depot of pigs harvested at K-State and in the belly and jowl fat depots of pigs harvested at the commercial packing facility with the use of RAC, but there were no interactive effects observed between RAC and high fiber diets.

In summary, pigs fed RAC had increased ADG and G:F as well as carcass yield, regardless of fiber withdrawal regimen. Feeding high-fiber diets containing DDGS and midds until marketing generally decreases growth performance, increases full intestine weight, decreases carcass yield, and increases carcass fat IV (depending on fat depot) compared to pigs fed a corn-soybean meal diet. Withdrawal of high-fiber diets containing DDGS and midds to corn-soybean meal diets in the weeks immediately before harvest will restore carcass yield to values similar to pigs fed corn-soybean meal–based diets but will only partially mitigate negative effects on carcass fat IV.

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Figures and Tables

Table 3-1. Phase 1 and 2 diet composition (as-fed basis)[1]

	Phase 1		Phase 2	
Item	Corn-soy	High fiber	Corn-soy	High fiber
Ingredient, %				
Corn	79.0	40.0	82.7	43.6
Soybean meal (46.5% CP)	18.9	8.7	15.3	5.2
DDGS[2]	-	30.0	-	30.0
Wheat middlings	-	19.0	-	19.0
Monocalcium P (21% P)	0.35	-	0.25	
Limestone	1.00	1.28	0.98	1.29
Salt	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.13	0.13	0.10	0.10
Trace mineral premix[4]	0.13	0.13	0.10	0.10
L-Lys HCl	0.15	0.29	0.14	0.28
DL-Met	-	-	-	-
L-Thr	0.01	-	-	-
Phytase[5]	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lys	0.79	0.79	0.69	0.69
Ile:Lys	70	74	72	76
Met:Lys	30	37	32	41
Met &Cys:Lys	62	77	66	83
Thr:Lys	63	69	64	72
Trp:Lys	19	19	19	19
Val:Lys	81	94	85	99
Total Lys, %	0.89	0.94	0.78	0.83
ME, kcal/kg	3,343	3,277	3,352	3,279
SID Lys: ME, g/Mkcal	2.36	2.41	2.06	2.10
CP, %	15.6	18.9	14.3	17.6
Crude fiber, %	2.5	4.9	2.4	4.8
NDF, %	9.3	19.0	9.3	19.0
ADF, %	3.2	6.6	3.1	6.5
Ca, %	0.53	0.56	0.49	0.55
P, %	0.42	0.56	0.39	0.55
Available P, %	0.16	0.27	0.13	0.27

[1] Diets were fed in meal form from d 0 to28 (Phase 1) and d 28 to 49 (Phase 2).

[2] Dried distillers grains with solubles.

[3] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5] Phytase was added to all diets at a rate of 0.125% to provide 778.4 FTU/kg of complete diet and a 0.12% P release.

Table 3-2. Phase 3 diet composition (as-fed basis)[1]

	Phase 3			
	Corn-soy		High fiber	
Item RAC:	-	+	-	+
Ingredient, %				
Corn	85.0	75.3	45.7	35.9
Soybean meal (46.5% CP)	13.2	22.7	3.1	12.7
DDGS[2]	-	-	30.0	30.0
Wheat middlings	-	-	19.0	19.0
Monocalcium P (21% P)	0.20	0.15	-	-
Limestone	0.93	0.90	1.40	1.40
Salt	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.08	0.08	0.08	0.08
Trace mineral premix[4]	0.08	0.08	0.08	0.08
L-Lys HCl	0.13	0.17	0.27	0.31
DL-Met	-	0.02	-	-
L-Thr	0.01	0.06	-	-
RactopamineHCl, 10 ppm[5]	-	0.05	-	0.05
Phytase[6]	0.125	0.125	0.125	0.125
Total	100	100	100	100
Calculated analysis				
Standardized ileal digestible (SID) amino acids, %				
Lys	0.63	0.90	0.63	0.90
Ile:Lys	73	69	78	72
Met:Lys	33	30	43	35
Met &Cys:Lys	69	60	88	72
Thr:Lys	67	67	74	67
Trp:Lys	19	19	19	19
Val:Lys	87	79	91	89
Total Lys, %	0.72	1.01	0.77	1.06
ME, kcal/kg	3,356	3,354	3,277	3,272
SID Lys: ME, g/Mkcal	1.88	2.68	1.92	2.75
CP, %	13.5	17.2	16.7	20.4
Crude fiber, %	2.4	2.5	4.8	4.9
NDF, %	9.3	9.3	19.0	18.9
ADF, %	3.1	3.3	6.4	6.7
Ca, %	0.46	0.47	0.59	0.62
P, %	0.37	0.40	0.54	0.58
Available P, %	0.10	0.10	0.26	0.27

[1] Diets were fed in meal form from d 49 to 73 of the experiment.

[2] Dried distillers grains with solubles.

[3] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5] Paylean; Elanco Animal Health, Greenfield, IN.

[6] Phytase was added to all diets at a rate of 0.125% to provide 778.4 FTU/kg of complete diet and a 0.12% P release.

Table 3-3. Chemical analysis of dried distillers grains with solubles (DDGS) and wheat middlings (as-fed basis)[1]

	Exp. 1		Exp. 2	
Item	DDGS	Wheat midds	DDGS	Wheat midds
Nutrient, %				
DM, %	92.0	90.7	90.2	89.7
CP, %	29.0	17.0	29.2	14.3
Fat/oil, %	9.7	4.1	8.4	3.3
Crude fiber, %	7.7	7.8	8.5	7.9
ADF, %	12.1	12.9	13.5	10.2
NDF, %	27.4	33.5	27.6	31.4
Ash, %	5.9	5.6	4.3	5.3

[1] Values represent the mean composite samples of ingredients taken from every feed delivery within experiment.

Table 3-4. Bulk densities of experimental diets (as-fed basis)[1]

		Treatment	
	DDGS[3]:	0	30
	Wheat midds:	0	19
Bulk density,[2] g/L	RAC[4]:	None	None
Phase 1		723	554
Phase 2		687	526
Phase 3		744	552

[1] Diet samples were taken from the feeders during each phase. Values represent composite samples from both experiments.

[2] Phase 1 was d 0 to 28; Phase 2 was d 28 to 49; Phase 3 was d 49 to 73.

[3] Dried distillers grains with solubles.

[4] RactopamineHCl (Paylean;Elanco Animal Health, Greenfield, IN).

Table 3-5. Fatty acid analysis of dried distillers grains with solubles (DDGS) and wheat middlings (as-fed basis)

	Exp. 1		Exp. 2	
Item	DDGS	Wheat midds	DDGS	Wheat midds
Myristic acid (C14:0), %	0.05	0.11	0.06	0.10
Palmitic acid (C16:0), %	13.71	15.62	13.64	15.42
Palmitoleic acid (C16:1), %	0.17	0.21	0.16	0.19
Margaric acid (C17:0), %	0.15	0.28	0.14	0.29
Stearic acid (C18:0), %	2.16	1.02	2.08	1.14
Oleic acid (C18:1 *cis*-9), %	25.22	16.62	24.75	16.33
Vaccenic acid (C18:1n-7), %	1.23	1.53	1.22	1.40
Linoleic acid (C18:2n-6), %	54.06	56.74	54.59	56.87
α-Linolenic acid (C18:3n-3), %	1.53	4.20	1.58	4.26
Arachidic acid (C20:0), %	0.43	0.26	0.42	0.24
Gadoleic acid (C20:1), %	0.25	0.70	0.24	0.71
Eicosadienoic acid (C20:2), %	0.08	0.14	0.09	0.174
Arachidonic acid (C20:4n-6), %	0.04	0.06	0.04	0.06
Other fatty acids, %	0.87	2.58	1.00	2.79
Total SFA,[1] %	16.50	17.29	16.33	17.19
Total MUFA[2], %	27.11	19.25	26.55	18.83
Total PUFA[3], %	55.71	61.13	56.30	61.33
Total *trans* fatty acids,[4] %	0.08	ND	0.10	0.06
UFA:SFA ratio[5]	5.02	4.65	5.07	4.66
PUFA:SFA ratio[6]	3.38	3.54	3.45	3.57
Iodine value,[7] g/100g	120	124	120	124

[1] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), brackets indicate concentration.

[2] Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), brackets indicate concentration.

[3] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), brackets indicate concentration.

[4] Total *trans* fatty acids = ([C18:1 *trans*] + [C18:2 *trans*] + [C18:3 *trans*]), brackets indicate concentration.

[5] UFA: SFA = (total MUFA + total PUFA)/total SFA.

[6] PUFA: SFA = total PUFA/total SFA.

[7] Calculated as IV value (IV) = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Table 3-6. Effects of fiber level with or without ractopamine HCl (RAC[1]) on growth performance and carcass characteristics[2]

	Treatment											
	A	B	C	D	E	F						
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber		Probability, *P*<				
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		d 0 to 49	d 49 to 73			
RAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
d 0 to 49												
ADG, kg	1.02	1.01	0.96	0.96	0.95	0.96	0.04	<0.001	-	-	-	-
ADFI, kg	2.79	2.75	2.72	2.77	2.69	2.68	0.05	0.13	-	-	-	-
G:F	0.365	0.366	0.352	0.347	0.354	0.358	0.009	0.001	-	-	-	-
d 49 to 73												
ADG, kg	0.91	1.09	0.92	1.12	0.86	0.99	0.09	0.32	0.46	0.02	0.002	<0.001
ADFI, kg	3.15	3.04	3.31	3.25	3.17	3.11	0.14	0.02	0.002	0.44	0.02	
G:F	0.286	0.358	0.278	0.343	0.271	0.317	0.016	0.01	0.22	0.001	0.01	<0.001
d 0 to 73												
ADG, kg	0.98	1.03	0.95	1.01	0.92	0.97	0.05	0.001	0.03	<0.001	0.01	<0.001
ADFI, kg	2.91	2.84	2.91	2.92	2.84	2.82	0.07	0.951	0.23	0.279	0.03	0.42
G:F	0.337	0.364	0.325	0.346	0.324	0.343	0.011	<0.001	<0.001	<0.001	0.64	<0.001
BW, kg												
d 0	55.7	55.7	55.8	55.8	56.0	56.0	2.8	0.73	0.84	0.70	0.85	0.99
d 49	105.4	105.1	103.0	102.9	102.7	102.9	1.5	0.03	0.03	0.02	0.89	0.91
d 73	126.8	130.5	125.2	129.3	122.9	126.3	1.8	0.23	0.23	0.001	0.03	0.001
Carcass traits												
HCW, kg[8]	92.2	97.8	91.4	95.6	88.5	91.4	1.25	0.001	0.22	<0.001	0.01	<0.001
Carcass yield, %[8]	74.22	75.13	73.73	74.58	72.77	73.61	0.19	<0.001	0.01	<0.001	<0.001	<0.001
Average BF, mm[9]	25.51	19.67	19.86	17.94	19.99	17.72	1.89	0.15	0.19	0.23	0.98	0.10
LEA, mm[9]	195.10	204.38	202.93	218.64	202.21	200.61	8.61	0.36	0.84	0.84	0.24	0.23

[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] A total of 575 pigs (PIC 327 ×1050, initially 123 lb BW) were used in a 73-d growth trial. There were 8 pigs per pen and 12 replications per treatment.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal X RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

[8] Values represent 283 pigs that were shipped approximately 2 hr to Farmland Foods, Crete, NE.

[9] Values represent 36 barrows (6 per treatment) selected for harvest at Kansas State University's Meats Lab, Manhattan, KS.

Table 3-7. Effects of fiber withdrawal without or with ractopamineHCl (RAC[1]) on intestine and organ weights (Exp. 1)[2]

	Treatment											
	A	B	C	D	E	F		Probability, *P*<				
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber		d 0 to 49	d 49 to 73			
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber						
Item RAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
Whole intestine	8.17	8.69	8.26	8.68	9.26	8.92	0.45	0.38	0.92	0.16	0.18	0.59
Stomach												
Full	1.04	1.14	1.29	0.90	1.21	1.00	0.11	0.92	0.97	0.89	0.92	0.07
Rinsed	0.72	0.70	0.75	0.67	0.78	0.70	0.02	0.34	0.80	0.16	0.25	0.01
Cecum												
Full	0.63	0.69	0.79	0.73	0.78	0.92	0.09	0.08	0.30	0.05	0.33	0.56
Rinsed	0.33	0.34	0.36	0.34	0.30	0.31	0.02	0.58	0.45	0.09	0.02	0.72
Large intestine												
Full	4.38	4.30	4.24	4.64	5.41	5.36	0.29	0.03	0.74	0.001	0.003	0.70
Rinsed	2.01	1.90	1.96	2.00	1.89	1.99	0.09	0.93	0.76	0.87	0.64	0.89
Small intestine												
Full	3.37	3.59	3.47	3.37	3.64	3.09	0.22	0.63	0.77	0.58	0.80	0.42
Heart	0.46	0.43	0.45	0.42	0.42	0.45	0.02	0.66	0.70	0.70	1.00	0.59
Liver	2.05	1.96	2.08	2.13	2.12	2.11	0.07	0.09	0.15	0.14	0.96	0.77
Kidneys	0.47	0.47	0.47	0.45	0.46	0.51	0.02	0.77	0.74	0.41	0.25	0.38
Leaf fat	1.80	1.74	1.61	1.46	1.40	1.29	0.17	0.03	0.17	0.02	0.25	0.43

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[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] Values represent 36 barrows (6 pigs per treatment) selected for harvest at Kansas State University's Meats Lab, Manhattan, KS.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal × RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

Table 3-8. Effects of fiber withdrawal without or with ractopamineHCl (RAC[1]) on fatty acid analysis of jowl fat samples (Exp. 1)[2]

	Treatment							Probability, *P*<				
	A	B	C	D	E	F						
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		d 0 to 49	d 49 to 73			
ItemRAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
Myristic acid (C14:0), %	1.37	1.34	1.40	1.31	1.30	1.33	0.04	0.53	0.98	0.29	0.32	0.32
Palmitic acid (C16:0), %	23.10	23.24	22.21	21.81	21.31	21.23	0.32	0.001	0.001	0.001	0.02	0.64
Palmitoleic acid (C16:1), %	3.55	3.70	3.48	3.17	3.26	3.10	0.13	0.001	0.02	0.001	0.23	0.28
Stearic acid (C18:0), %	9.20	9.28	8.87	8.97	8.49	8.63	0.25	0.02	0.19	0.01	0.14	0.59
Oleic acid (C18:1 *cis*-9), %	48.50	48.59	45.24	45.67	44.02	42.74	0.79	0.001	0.001	0.001	0.01	0.67
Vaccenic acid (C18:1n-7), %	0.23	0.18	0.20	0.24	0.20	0.20	0.04	0.88	0.65	0.84	0.52	0.93
Linoleic acid (C18:2n-6), %	10.31	9.64	14.24	14.54	16.56	17.63	0.67	0.001	0.001	0.001	0.001	0.65
α-Linolenic acid (C18:3n-3), %	0.46	0.52	0.61	0.60	0.70	0.76	0.03	0.001	0.001	0.001	0.001	0.11
Arachidic acid (C20:0), %	0.21	0.21	0.17	0.20	.021	0.24	0.02	0.92	0.32	0.39	0.07	0.16
Gadoleic acid (C20:1), %	1.03	0.97	0.87	1.02	0.91	0.97	0.06	0.24	0.34	0.29	0.93	0.30
Eicosadienoic acid (C20:2), %	0.53	0.49	0.66	0.77	0.77	0.84	0.04	0.001	0.001	0.001	0.02	0.13
Arachidonic acid (C20:4n-6), %	0.20	0.22	0.25	0.26	0.26	0.29	0.02	0.004	0.14	0.001	0.03	0.59
Other fatty acids, %	1.33	1.64	1.81	2.01	2.01	2.05	0.23	0.07	0.47	0.02	0.09	0.97
Iodine value,[8] g/100g	65.76	64.97	70.09	70.74	73.18	74.06	0.82	0.001	0.001	0.001	0.001	0.72

[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] Values represent 36 barrows (6 per treatment) selected for harvest at Kansas State University's Meats Lab, Manhattan, KS.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal × RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

[8] Calculated as IV value (IV) = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Table 3-9. Effects of fiber withdrawal without or with ractopamine HCl (RAC[1]) on fatty acid analysis of jowl fat samples (Exp. 2)[2]

	Treatment											
	A	B	C	D	E	F						
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber		Probability, *P*<				
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		d 0 to 49	d 49 to 73			
ItemRAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
Myristic acid (C14:0), %	1.35	1.31	1.30	1.29	1.28	1.28	0.02	0.01	0.07	0.01	0.43	0.37
Palmitic acid (C16:0), %	23.35	22.83	22.09	21.90	21.48	21.57	0.15	0.001	0.001	0.001	0.001	0.07
Palmitoleic acid (C16:1), %	3.67	3.58	3.51	3.44	3.30	3.40	0.08	0.001	0.05	0.0003	0.10	0.75
Stearic acid (C18:0), %	9.72	9.57	9.05	8.79	8.82	8.56	0.13	0.001	0.001	0.001	0.07	0.03
Oleic acid (C18:1 *cis*-9), %	48.27	48.20	46.30	45.79	45.85	45.56	0.25	0.001	0.001	0.001	0.14	0.13
Vaccenic acid (C18:1n-7), %	0.59	0.56	0.52	0.56	0.51	0.47	0.02	0.003	0.14	0.0002	0.03	0.68
Linoleic acid (C18:2n-6), %	9.25	9.78	12.84	13.58	14.25	14.38	0.26	0.001	0.001	0.001	0.001	0.02
α-Linolenic acid (C18:3n-3), %	0.49	0.53	0.59	0.65	0.63	0.66	0.02	0.001	0.001	0.001	0.07	0.001
Arachidic acid (C20:0), %	0.22	0.22	0.21	0.22	0.20	0.21	0.01	0.40	0.66	0.31	0.58	0.27
Gadoleic acid (C20:1), %	0.93	0.97	0.93	0.95	0.95	0.99	0.02	0.65	0.46	0.12	0.02	0.01
Eicosadienoic acid (C20:2), %	0.47	0.52	0.64	0.70	0.73	0.76	0.02	0.001	0.001	0.001	0.001	0.0002
Arachidonic acid (C20:4n-6), %	0.30	0.32	0.35	0.38	0.36	0.36	0.01	0.001	0.001	0.001	0.89	0.08
Other fatty acids, %	1.41	1.59	1.68	1.76	1.64	1.80	0.06	0.001	0.001	0.001	0.99	0.002
Iodine value,[8] g/100g	63.52	64.44	68.10	69.08	70.08	70.23	0.35	0.001	0.001	0.001	0.001	0.01

[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] Values represent 283 pigs that were shipped approximately 2 h to Farmland Foods, Crete, NE.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal × RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

[8] Calculated as IV value (IV) = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Table 3-10. Effects of fiber withdrawal without or with ractopamine HCl (RAC[1]) on fatty acid analysis of backfat samples (Exp. 1)[2]

	Treatment							Probability, *P*<				
	A	B	C	D	E	F						
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		d 0 to 49	d 49 to 73			
Item RAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
Myristic acid (C14:0), %	1.37	1.35	1.39	1.27	1.34	1.22	0.06	0.27	0.57	0.18	0.43	0.10
Palmitic acid (C16:0), %	23.87	23.28	22.62	21.99	22.07	20.93	0.59	0.003	0.04	0.001	0.18	0.11
Palmitoleic acid (C16:1), %	2.87	3.03	2.68	2.49	2.45	2.34	0.12	0.001	0.005	0.001	0.13	0.65
Stearic acid (C18:0), %	10.86	9.92	10.15	9.64	10.10	9.04	0.60	0.21	0.41	0.17	0.59	0.09
Oleic acid (C18:1 *cis*-9), %	45.84	45.64	41.10	42.36	39.02	39.31	0.79	0.001	0.001	0.001	0.003	0.49
Vaccenic acid (C18:1n-7), %	0.21	0.21	0.28	0.04	0.13	0.14	0.06	0.20	0.35	0.19	0.72	0.09
Linoleic acid (C18:2n-6), %	11.23	12.56	17.11	17.92	20.25	22.07	0.82	0.001	0.001	0.001	0.001	0.05
α-Linolenic acid (C18:3n-3), %	0.53	0.63	0.72	0.76	0.77	0.85	0.04	0.001	0.001	0.001	0.09	0.02
Arachidic acid (C20:0), %	0.25	0.23	0.27	0.15	0.25	0.24	0.05	0.83	0.55	0.82	0.40	0.20
Gadoleic acid (C20:1), %	0.92	0.87	0.79	0.91	0.79	0.80	0.05	0.07	0.29	0.04	0.28	0.46
Eicosadienoic acid (C20:2), %	0.50	0.56	0.69	0.75	0.79	0.86	0.04	0.001	0.001	0.001	0.02	0.09
Arachidonic acid (C20:4n-6), %	0.21	0.34	0.36	0.28	0.34	0.37	0.05	0.14	0.35	0.10	0.46	0.48
Other fatty acids, %	1.34	1.38	1.86	1.45	1.70	1.84	0.18	0.04	0.12	0.03	0.54	0.61
Iodine value,[8] g/100g	64.54	67.47	71.39	73.45	74.77	78.37	1.65	0.001	0.001	0.001	0.02	0.04

[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] Values represent 36 barrows (6 per treatment) selected for harvest at Kansas State University's Meats Lab, Manhattan, KS.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal × RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

[8] Calculated as IV value (IV) = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Table 3-11. Effects of fiber withdrawal without or with ractopamine HCl (RAC[1]) on fatty acid analysis of belly fat samples (Exp. 1)[2]

	Treatment							Probability, $P<$				
	A	B	C	D	E	F						
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		d 0 to 49	d 49 to 73			
Item RAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
Myristic acid (C14:0), %	1.52	1.46	1.51	1.41	1.41	1.39	0.06	0.24	0.64	0.12	0.27	0.18
Palmitic acid (C16:0), %	25.60	25.21	24.71	24.25	22.63	22.09	0.62	0.001	0.15	0.001	0.002	0.37
Palmitoleic acid (C16:1), %	3.34	3.34	3.03	2.67	3.12	2.91	0.22	0.04	0.03	0.15	0.47	0.30
Stearic acid (C18:0), %	12.36	11.80	11.75	12.59	9.67	9.75	1.17	0.27	0.94	0.05	0.04	0.90
Oleic acid (C18:1 *cis*-9), %	45.08	44.11	41.55	40.08	41.54	39.75	1.58	0.01	0.02	0.02	0.91	0.28
Vaccenic acid (C18:1n-7), %	0.26	0.24	0.20	0.19	0.20	0.19	0.03	0.03	0.06	0.06	0.95	0.57
Linoleic acid (C18:2n-6), %	8.41	10.27	13.54	14.42	16.96	19.30	0.64	0.001	0.001	0.001	0.001	0.003
α-Linolenic acid (C18:3n-3), %	0.43	0.53	0.58	0.67	0.71	0.77	0.03	0.001	0.001	0.001	0.001	0.001
Arachidic acid (C20:0), %	0.25	0.23	0.23	0.32	0.25	0.22	0.02	0.40	0.12	0.89	0.09	0.39
Gadoleic acid (C20:1), %	0.81	0.79	0.73	0.84	0.78	0.76	0.06	0.59	0.76	0.54	0.76	0.66
Eicosadienoic acid (C20:2), %	0.38	0.44	0.51	0.62	0.68	0.75	0.04	0.001	0.001	0.001	0.001	0.01
Arachidonic acid (C20:4n-6), %	0.18	0.22	0.23	0.24	0.27	0.31	0.01	0.001	0.03	0.001	0.001	0.01
Other fatty acids, %	1.40	1.37	1.43	1.71	1.78	1.84	0.12	0.01	0.13	0.001	0.06	0.32
Iodine value,[8] g/100g	59.06	61.80	65.02	65.31	71.56	74.12	1.68	0.001	0.01	0.001	0.001	0.19

[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] Values represent 36 barrows (6 per treatment) selected for harvest at Kansas State University's Meats Lab, Manhattan, KS.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal × RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

[8] Calculated as IV value (IV) = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Table 3-12. Effects of fiber withdrawal without or with ractopamine HCl (RAC[1]) on fatty acid analysis of belly fat samples (Exp. 2)[2]

	Treatment							Probability, $P<$				
	A	B	C	D	E	F						
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		d 0 to 49	d 49 to 73			
Item RAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
Myristic acid (C14:0), %	1.43	1.39	1.38	1.38	1.35	1.37	0.02	0.01	0.12	0.003	0.17	0.86
Palmitic acid (C16:0), %	24.35	23.93	23.32	22.95	22.34	22.40	0.16	0.001	0.001	0.001	0.001	0.05
Palmitoleic acid (C16:1), %	3.60	3.57	3.46	3.45	3.15	3.24	0.07	0.001	0.04	0.001	0.001	0.77
Stearic acid (C18:0), %	10.74	10.64	10.16	9.75	9.76	9.55	0.14	0.001	0.001	0.001	0.02	0.03
Oleic acid (C18:1 *cis*-9), %	47.42	47.34	45.48	44.66	44.14	43.80	0.26	0.001	0.001	0.001	0.001	0.04
Vaccenic acid (C18:1n-7), %	0.60	0.59	0.55	0.55	0.52	0.53	0.02	0.001	0.003	0.001	0.07	0.99
Linoleic acid (C18:2n-6), %	8.61	9.07	12.01	13.21	14.74	14.98	0.27	0.001	0.001	0.001	0.001	0.002
α-Linolenic acid (C18:3n-3), %	0.43	0.49	0.53	0.62	0.62	0.64	0.01	0.001	0.001	0.001	0.001	0.001
Arachidic acid (C20:0), %	0.22	0.22	0.21	0.22	0.22	0.22	0.01	0.59	0.57	0.72	0.83	0.58
Gadoleic acid (C20:1), %	0.82	0.85	0.82	0.84	0.85	0.87	0.01	0.14	0.81	0.02	0.04	0.03
Eicosadienoic acid (C20:2), %	0.38	0.41	0.52	0.58	0.64	0.66	0.01	0.001	0.001	0.001	0.001	0.0004
Arachidonic acid (C20:4n-6), %	0.29	0.30	0.32	0.36	0.36	0.38	0.01	0.001	0.001	0.001	0.001	0.01
Other fatty acids, %	1.12	1.20	1.22	1.42	1.31	1.38	0.05	0.001	0.002	0.0003	0.66	0.004
Iodine value,[8] g/100g	61.39	62.27	65.72	67.32	69.22	69.48	0.38	0.001	0.001	0.001	0.001	0.002

[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] Values represent 283 pigsthat were shipped approximately 2 h to Farmland Foods, Crete, NE.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal × RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

[8] Calculated as IV value (IV) = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Table 3-13. Effects of fiber withdrawal without or with ractopamine HCl (RAC[1]) on fatty acid analysis of leaf fat samples (Exp. 1)[2]

	Treatment							Probability, P<				
	A	B	C	D	E	F						
d 0 to 49 diet:	Corn-soy	Corn-soy	High fiber	High fiber	High fiber	High fiber						
d 49 to 73 diet:	Corn-soy	Corn-soy	Corn-soy	Corn-soy	High fiber	High fiber		d 0 to 49	d 49 to 73			
Item RAC:	-	+	-	+	-	+	SEM	Corn-soy vs high fiber[3]	Corn-soy vs high fiber withdrawal[4]	Corn-soy vs high fiber[5]	High fiber withdrawal vs high fiber[6]	RAC vs no RAC[7]
Myristic acid (C14:0), %	1.45	1.41	1.60	1.45	1.39	1.45	0.07	0.45	0.14	0.85	0.11	0.43
Palmitic acid (C16:0), %	27.96	27.83	27.96	26.70	25.25	24.62	0.51	0.001	0.23	0.001	0.001	0.09
Palmitoleic acid (C16:1), %	2.32	2.25	2.12	2.07	2.00	1.90	0.13	0.02	0.13	0.01	0.24	0.48
Stearic acid (C18:0), %	18.01	18.18	17.37	16.90	15.72	14.29	0.69	0.001	0.13	0.001	0.003	0.27
Oleic acid (C18:1 *cis*-9), %	38.77	38.66	34.95	36.41	33.51	33.59	1.00	0.001	0.003	0.001	0.03	0.52
Vaccenic acid (C18:1n-7), %	0.18	0.17	0.16	0.18	0.16	1.15	0.01	0.31	0.74	0.17	0.28	0.86
Linoleic acid (C18:2n-6), %	8.46	8.53	12.57	12.83	18.02	19.80	0.79	0.001	0.001	0.001	0.001	0.24
α-Linolenic acid (C18:3n-3), %	0.35	0.40	0.49	0.48	0.64	0.73	0.03	0.001	0.002	0.001	0.001	0.11
Arachidic acid (C20:0), %	0.26	0.29	0.27	0.28	0.35	0.26	0.04	0.68	0.93	0.44	0.39	0.50
Gadoleic acid (C20:1), %	0.67	0.69	0.63	0.72	0.60	0.64	0.05	0.42	0.89	0.22	0.28	0.24
Eicosadienoic acid (C20:2), %	0.37	0.36	0.42	0.50	0.54	0.65	0.02	0.001	0.001	0.001	0.001	0.002
Arachidonic acid (C20:4n-6), %	0.11	0.15	0.16	0.14	0.24	0.27	0.02	0.001	0.30	0.001	0.001	0.41
Other fatty acids, %	1.09	1.07	1.30	1.34	1.59	1.66	0.13	0.001	0.06	0.001	0.02	0.75
Iodine value,[8] g/100g	52.14	52.35	56.23	57.90	64.96	68.35	1.48	0.001	0.001	0.001	0.001	0.13

[1] Paylean; Elanco Animal Health, Greenfield, IN.

[2] Values represent 36 barrows (6 per treatment) selected for harvest at Kansas State University's Meats Lab, Manhattan, KS.

[3] Treatments A, B vs C, D, E, F. There were no fiber withdrawal × RAC interactions.

[4] Treatments A, B vs C, D.

[5] Treatments A, B vs E, F.

[6] Treatments C, D vs E, F.

[7] Treatments A, C, E vs B, D, F.

[8] Calculated as IV value (IV) = [C16:1] × 0.9502 + [C18:1] × 0.8598 + [C18:2] × 1.7315 + [C18:3] × 2.6152 + [C20:1] × 0.7852 + [C20:4] × 3.2008, brackets indicate concentration.

Chapter 4- Amino acid digestibility and energy concentration of fermented soybean meal and camelina meal for swine

ABSTRACT

A nutrient balance study was conducted to determine the AA and GE digestibility of fermented soybean meal (FSBM) and camelina meal (CLM). For the AA digestibility portion of the study, five growing gilts (BW= 27.4 kg) were surgically fitted with T-cannulas at the terminal ileum and randomly allotted to 1 of 3 dietary treatments in a crossover design with 3 periods.The treatment diets were 1) 30% FSBM and 2) 39.25% CLM as the sole protein sources, and 3) a N-free diet for determining basal endogenous AA losses. For the determination of energy content, 6 growing barrows (BW= 29.4 kg) were randomly allotted to 1 of 3 dietary treatments in a crossover design with 3 periods. The corn-based treatment diets were 1) 25% FSBM; 2) 30% CLM, and 3) a corn basal diet to allow for energy calculations by the difference method. All diets contained 0.25% titanium oxide as in indigestible marker. Digesta samples were collected and analyzed for AA concentrations, and fecal samples were collected and analyzed for energy concentrations. After chemical analysis, standardized and apparent ileal digestible (SID and AID, respectively) AA, as well as the DE, ME, and NE were determined for each ingredient. The FSBM source contained 4,350, 3,035, 2,715, and 1,940 kcal/kg GE, DE, ME, and NE, respectively (DM-basis). The CLM contained 4,574, 2,536, 2,296, and 1,576 kcal/kg GE, DE, ME, and NE, respectively (DM-basis). In FSBM, the AID for Lys, Met, Thr, and Trp were 63.5 ± 7.5, 84.6 ± 1.0, 74.0 ± 3.5, and 81.8 ± 1.4%, respectively, and SID values were 71.1 ± 6.2, 89.2 ± 2.1, 88.0 ± 3.1, and 93.7 ± 2.0%, respectively. For CLM, the AID for Lys, Met, Thr, an Trp were 47.3 ± 7.7, 74.6 ± 3.3, 39.7 ± 6.8, and 67.3 ± 8.3%, respectively, and SID values were 53.9 ± 6.4, 77.7 ± 3.5, 51.6 ± 6.7, and 79.7 ± 6.8%, respectively. While SID

availability for AA in FSBM were relatively high and similar to that of soybean meal with the exception of lysine, SID AA availability for CLM were low indicating that itmay have contained high glucosinolate concentrations generally observed in CLM.

INTRODUCTION

Soybean meal is traditionally included in most swine diets because it provides a good balance of indispensable AA. However, the presence of certain antinutritional factors such as trypsin inhibitors, pectins, and lectins have been shown to reduce the growth performance of weanling pigs, because their gastro-intestinal tract is not fully developed (Li et al., 1991). Thus, highly digestible animal proteins such as spray-dried animal plasma, poultry by-product meal and fish meal are often included in early swine diets (Pierce et al., 2005). Recent research, however, has concluded that fermented soybean meal (**FSBM**) may be used to replace conventional soybean meal in diets fed to young pigs without reducing growth performance because the antinutritional factors are virtually eliminated during the fermentation process (Cervantes-Pahm and Stein, 2010; Jones et al., 2010; Kim et al., 2010). Feeding FSBM in lieu of conventional soybean meal may decrease nursery diet costs because it may be possible to reduce levels of specialty animal products and increase levels of FSBM, reducing diet cost.

Similar to canola, camelina is traditionally produced for oil production because of its relatively high concentration of omega-3 fatty acids. It is distantly related to Rapeseed and is classified in the mustard family. Its major limitation in animal diets is high glucosinolate concentration (Tripathi and Mishra, 2007). While camelina meal (**CLM**) is a relatively unused product in current swine diets, an increasing amount may be available in the future as a potential source of oil for biofuel production. Camelina meal is extruded from the cold extraction of camelina oil. It still contains a high level of oil (10 to 15%), as well as at least 30% protein.

Currently, FDA has granted approval for CLM to be fed in swine diets at up to 2% of the diet, but companies must obtain a commercial feed license before manufacturing feed with CLM as an ingredient. Thus, very limited research had been done to determine the AA digestibility and energy content to determine its feeding value in swine diets.

Thus, the objective of this study was to determine the AA digestibility and energy values of FSBM and CLM for swine.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved protocols used in this study.

Experiment 1.Five growing gilts (initially 27.4 kg of BW; PIC, Hendersonville, TN) were surgically fitted with a T-cannula on their right flank approximately 15 cm anterior to the ileocecal valve using the procedures described by Knabe et al. (1989). The pigs were allowed to recover from surgery and were then placed in individual stainless-steel metabolism cages (1.5 × 0.6 m) in an environmentally controlled building. Each cage was equipped with a feeder and a nipple drinker to allow for ad libitum access to water. During the first 9 d after surgery (recovery period), the pigs were fed a common diet ad libitum. On d 10 after surgery, the pigs were randomly allotted to 1 of 3 dietary treatments in a single Latin square design. The treatments were 1) 30% FSBM, 2) 39.25% CLM, and 3) a N-free diet formulated to determine basal AA endogenous losses (Table 4.1). The FSBM and CLM were analyzed for their AA content (Table 4.4). Titanium oxide was added in all diets at 0.35% as an indigestible marker. There were 3 periods in the experiment; each period consisted of 7 d. The first 5 d of each period were used to allow pigs to adapt to the dietary treatment. On d 6 and 7, ilealdigesta was collected over a 10-h period (between 0700 and 1700 each day). Pig BW was determined at the start of each period before new diets were fed to allow for determination of the daily feed allocation, which was given at 3 times the estimated daily maintenance requirements for energy. The daily feed allocation was equally divided between two equal amounts and given twice daily at 0600 and 1800 h.

On collection days, the cannula of each pig was opened to allow the digesta to flow out of the ileum, and ilealdigesta was collected by attaching a latex balloon to the cannula. Balloons were checked for fill and were removed every 30 min or as they were full. Contents of the balloons were then transferred into 500-mL plastic containers and were stored in a freezer (-20°C) until further chemical analyses were conducted. After the collection phase of the experiment, digesta samples from each period from each animal were thawed and homogenized. A subsample from each homogenized ilealdigesta collection was then transferred to a new 500-mL plastic container, freeze-dried, and ground for AA analysis.

Titanium oxide was an indigestible marker used to calculate AA digestibility values. The concentration of titanium oxide in the diets and digesta was determined by using the procedure of Short et al. (1996). Amino acid analysis for the diets, FSBM, CLM, and ilealdigesta samples was conducted at the University of Missouri-Columbia Agricultural Experiment Station Chemical Laboratories [Official Method 982.30 E (a,b,c), chapter 45.3.05; AOAC International, 2006]. The test diets, FSBM, and CLM were submitted to a commercial laboratory (Ward Laboratories, Inc., Kearney, NE) for DM (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006.), P (AOAC 965.17/985.01, 2006) ADF (ANKOM Technology, 1998), NDF (ANKOM Technology, 1998).

The apparent ileal digestibility for AA in the experimental protein sources were calculated using the following equation (Fan et al., 1995):

$$AID = \{100 - [(AAd/AAf) \times (Tif/Tid)]\} \times 100$$

where AID is the apparent ileal digestibility of an AA (%), AAd is the AA concentration in the ilealdigesta DM, AAf is the AA concentration in the feed DM, Tif is the titanium concentration in the feed DM, and Tid is the titanium concentration in the ilealdigesta DM.

The basal endogenous AA loss (EAAL) to the ileum of each AA was determined based on the digesta obtained after feeding the nitrogen-free diet using the following equation (Stein et al., 2001):

$$EAAL = [AAd \times (Tif/Tid)]$$

where EAAL is the basal endogenous AA loss (g/kg of DMI), AAd is the AA concentration in the ilealdigesta DM, Tif is the titanium concentration in the feed DM, and Tid is the titanium concentration in the ilealdigesta DM.

Standardized ilealdigestibilities of each AA were then calculated by correcting the AID for the EAL for each AA using the following equation (Stein et al., 2001):

$$SID = [AID + (EAL/AAf) \times 100]$$

where SID is the standardized ileal digestibility of an AA (%).

Experiment 2. Six growing barrows (initially 29.4 kg of BW; PIC, Hendersonville, TN) were housed in individual stainless-steel metabolism cages (1.5 × 0.6 m) in an environmentally controlled building. Each cage was equipped with a feeder and a nipple drinker for ad libitum access to water. Pigs were randomly allotted to 1 of 3 dietary treatments in a single Latin square design in which pigs were fed all 3 diets in a random order. The treatments were 1) 25% FSBM; 2) 30% CLM, and 3) a corn basal diet to allow for calculation of energy concentration by the difference method (Table 4.2). Titanium oxide was added in all diets at 0.35% as an indigestible marker. There were 3 periods in the experiment; each period consisted of 8 d. The first 5 d of each period were used to allow pigs to adapt to the dietary treatment followed by 3 days of total fecal collection. On the morning of d 5, a marker (ferric oxide) was added to the first 100 g of the feed allocation, and after the 100 g was consumed, the remainder of the allocation was given. Fecal collection began when the marker first appeared in the feces. On the morning of day 9, a marker was added to the feed again, and the pig began its next diet. Collection, however, continued until the marker appeared again in the feces.

On collection days, fecal collections were collected twice daily at the time of feeding. Collections were stored in a freezer (-20°C) until further chemical analyses were conducted. After the collection period for the experiment, fecal collections were thawed and homogenized within each pig and diet. Homogenized collections were dried in a forced-air over at 50°C and were weighed, ground, and subsampled for chemical analysis.

Adiabatic bomb calorimetry (Parr Instruments, Moline, IL) was used to determine the GE energy content in the diets, FSBM, CLM, and fecal samples. The concentration of titanium oxide in the diets and fecal samples was determined by using the procedure by Short et al. (1996).

The Digestible Energy (**DE**) values of both the FSBM and CLM diets were calculated using the method described by Stein et al. (2006) where we used the same equation for AID to determine the total tract digestibility (**ATTD**) of energy. This value was then multiplied by the analyzed concentration of GE in the diets to obtain the DE of the diet. The following metabolizableenergy (**ME**) and netenergy (**NE**) values were determined using equations: $ME = 1 \times DE - 0.68 \times CP$ ($R^2 = 0.99$; Noblet and Perez, 1993) and $NE = (0.87 \times ME) - 442$ ($R^2 = 0.94$; Noblet et al., 1994).

RESULTS AND DISCUSSION

Chemical composition

Nutrient compositions of FSBM and CLM are reported in Table 4.4. The CP content of FSBM was 42.5% on an as-fed basis, which was considerably lower than DM values of CP reported for FSBM by Jones et al., (2010; 65.3% CP), Cervantes-Pahm and Stein (2010; 53.7% CP), as well as the NRC (2012; 54.1% CP). As a result, the amounts of most AA in FSBM were less than those reported for other FSBM sources. Thus, there appears to be considerable CP and AA variability between sources of FSBM.Also, the crude fat content of FSBM was 1.8%, which is approximately double the crude fat content of FSBM reported by Cervantes-Pahm and Stein (2010), but is considerably less than the value reported in NRC (2012) of 2.5% crude fat when converted to a DM basis. This would suggest variation in the fermentation process among plants manufacturing FSBM.

The CP content of CLM in the present study was 35.3% (DM basis), which is similar to the 35.15% reported by NRC (2012); however, the NRC value is on an as fed basis and DMwas not reported. The CLM source used by Pekel et al., (2009) was similar in CP content, at 38% CP (DM basis). In general, the AA levels were very similar between the current trial and the reports of Pekel et al., (2009), although they did not report values for Trp. The AA profile provided in the NRC (2012) for CLM was similar to the values in the current study, and Trp content was similar to that of the current study.

In general, research is lacking on CLM, but it is noted for being a high CP, high oil content product, which is supported by the crude fat level of 13.0% (DM basis), reported in the current study. This is similar to the reported value for crude fat by Pekel et al. (2009), at 14.7% (DM basis). However, the crude fat reported by the NRC (2012) for CLM is higher, at 18.5% on an as-fed basis. Again, we were unable to compare the nutrient values from the CLM source listed in the NRC (2012) on a DM basis because theDM content was not listed. We would expect some variation in the crude fat content of CLM sources, as camelina is used in the biofuels production industry, and oil extraction methods vary considerably.

AA digestibility

It is a common practice to balance swine diets based on the digestibility of nutrients for ingredients used (Stein et al., 2007). This study was conducted to determine digestibility coefficients for AA values for new FSBM and CLM products.

For FSBM, the AID for Lys, Met, Thr, and Trp were 63.5, 84.6, 74.0, and 81.8%, respectively (Table 4.5). The FSBM source used in this study had less AID for Lys, similar AID for Met, and higher AID for Thr and Trp than the product evaluated by Cervantes-Pahm and Stein (2010) and the values listed for FSBM in the NRC (2012). However, with the exception of AID Lys, AID values for Met, Thr, and Trp were similar to AID values reported by Rojas Martinez (2012). After AID values were corrected for basal ileal endogenous losses, SID values for Lys, Met, Thr, and Trp were calculated to be 71.1, 89.2, 88.0, and 89.9%, respectively. Again, the SID values followed the same trend compared to the SID values calculated by Cervantes-Pahm and Stein (2010) and the values listed for FSBM in the NRC (2012); the FSBM source used in this study had less SID for Lys, similar SID for Met, and higher SID for Thr and Trp. Again, with the exception of SID Lys being lower in the current study, values for SID Met, Thr, and Trp were similar to those reported by Rojas Martinez (2012).

Soybean meal is traditionally included in most swine diets because it provides a good balance of indispensable AA, but due to the presence of certain anti-nutritional factors such as trypsin inhibitors, pectins, and lectins, growth performance of weanling pigs is often reduced because their gastro-intestinal tract is not fully developed (Li et al., 1991). Research, however, has concluded that fermented soybean meal (**FSBM**) may be used to replace conventional soybean meal in diets fed to young pigs without reducing growth performance because the antinutritional factors are virtually eliminated during the fermentation process (Cervantes-Pahm and Stein, 2010; Jones et al., 2010; Kim et al., 2010). Also, FSBM is expected to have decreased levels of trypsin inhibitors, other anti-nutritional factors, and some oligosaccharides compared to SBM due to the fermentation process. Research by Kim et al. (2007) has demonstrated that FSBM will results in improved AA digestibility and feed efficiency. For growth data, Jones et al. (2010) found that pigs fed diets with increasing amounts of FSBM (up to 6%) had improved G:F. Also, Kim et al., (2010) fed up to 6% FSBM in place of SBM in nursery pigs diets, and reported that G:F was improved.

For CLM, the AID for Lys, Met, Thr, and Trp were 47.3, 74.6, 39.7, and 67.3%, respectively (Table 4.5). There is no other published research determining digestibility of AA in CLM in swine diets. Again, AA levels in the current study were similar to those reported for CLM in the NRC (2012). After AID values were corrected for basal ileal endogenous losses, SID values for Lys, Met, Thr, and Trp were calculated to be 53.9, 77.7, 51.6, and 79.7%, respectively. Camelina*sativa* is an oilseed crop of the mustard family that has gained popularity in the biofuel industry because of its high oil content (>40%), but also because it contains large proportions of n-3 fatty acids (Aziza et al., 2010). Camelina meal, however, may contain plant metabolites such as glucosinolates that are common to rapeseed and other members of the *Brassica* family (Tripathi and Mishra, 2007). The metabolites, such as glucosinolates, are known to reduce diet palatability, growth, and subsequent production. Camelina meal has been more extensively researched for use in poultry diets and Ryhanen et al. (2007) reported that inclusion of 5 or 10% CLM in broiler diets reduced ADFI and growth. Important to note in the current study, feed refusals were recorded for the CLM diet, as it appeared to have decreased palatability. This response is similar to what we would expect of a rapeseed variety, which is also a high glucosinolate variety of canola.

Energy concentration

Analyzed and calculated energy values for FSBM and CLM are reported in Table 4.6. The GE and calculated DE, ME, and NE for FSBM were 4,350, 3,035, 2,715, and 1,940 kcal/kg of DM, respectively. These values are all considerably lower than values reported by Rojas Martinez (2012) of 4,533, 4,296, 3,781, 2,951 kcal/kg of DM or GE, DE, ME, and NE, respectively. Oil content in the current study and that reported by Rojas Martinez (2012) were similar. The NRC (2012) values reported for FSBM are 4,880, 4,280, and 3,884 kcal/kg for GE, DE and ME, respectively, when converted to a DM basis. The reason for the difference in energy content is not fully known.

The GE and calculated DE, ME, and NE for CLM were 4,574, 2,536, 2,296, and 1,576 kcal/kg of DM, respectively. This compares to the GE reported in the NRC (2012) of 4,931 kcal/kg as-fed basis. Again, a DM was not reported in the NRC (2012) for CLM. However, the GE observed in the current study converted to an as-fed basis is 4,178 kcal/kg, which is considerably lower than that reported by the NRC (2012). However, the oil content of the source listed in the NRC (2012) was 18.5%, while the source in the current study was only 11.9% when converted to an as-fed basis. This is likely responsible for the large difference in energy content between the two sources.

In conclusion, FSBM is a plant protein source that, when used in nursery pigs diets, has the potential to improve AA digestibility compared to traditional SBM. Camelina meal however had lower SID AA availability and combined with the feed intake challenges, it may have contained high glucosinolate concentrations generally observed in CLM.

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TABLES AND FIGURES

Table 4-1. Diet composition, Exp. 1, as-fed basis[1]

Ingredient, %	Fermented soybean meal	Camelina meal	N-free
Corn starch	53.77	44.79	68.89
Fermented soybean meal	30.00	-	-
Camelina meal	-	39.25	-
Soybean oil	3.00	3.00	3.00
Monocalcium phosphate, 21% P	1.20	1.00	1.50
Limestone	0.63	0.79	0.86
Salt	0.40	0.40	0.40
Vitamin premix[2]	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15
Sow add pack[4]	0.25	0.25	0.25
Potassium chloride	-	-	0.50
Magnesium oxide	-	-	0.10
Titanium oxide	0.35	0.35	0.35
Solka floc[5]	-	-	4.00
Sucrose	10.00	10.00	20.00

[1] A total of 5 pigs (PIC 327 × 1050; initially 27.4 kg BW) were used in a crossover design with 3 periods to provide 5 observations per treatment.

[2] Provided per kg of premix: 4,409,200 IU vitamin A, 551,150 IU vitamin $D_{3,}$ 17,637 IU vitamin E, 1,764 mg vitamin K, 3,307 mg riboflavin, 11,023 mg pantothenic acid, 19,841 mg niacin, and 15.4 mg vitamin B_{12}.

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[4] Provided per kg of premix: 8,818 IU vitamin E (dl-α-tocopherol acetate), 88 mg biotin, 661 mg folic acid, 1,984 mg pyridoxine HCl, 220,462 mg choline chloride, 19,842 mg L-carnitine, and 79 mg chromium piconlinate.

[5] Fiber Sales and Development Corp., Urbana, OH.

Table 4-2. Diet composition, Exp. 2, as-fed basis[1]

Ingredient, %	Fermented soybean meal	Camelina meal	Corn
Corn	71.40	66.40	96.00
Fermented soybean meal	25.00	-	-
Camelina meal	-	30.00	-
Monocalcium phosphate, 21% P	1.60	1.60	1.80
Limestone	0.85	0.85	1.05
Salt	0.40	0.40	0.40
Vitamin premix[2]	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15
Titanium oxide	0.35	0.35	0.35

[1] A total of 5 pigs (PIC 327 × 1050; initially 27.4 kg BW) were used in a crossover design with 3 periods to provide 5 observations per treatment.

[2] Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[3] Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

Table 4-3. Analyzed nutrient composition of experimental diets, Exp. 1 (% as-fed basis)

Item	Fermented soybean meal	Camelina meal	N-free
DM	90.29	90.75	91.70
CP	11.31	13.36	0.33
Indispensable AA			
Arg	0.70	1.08	0.01
His	0.26	0.28	0.00
Ile	0.49	0.49	0.02
Leu	0.82	0.83	0.03
Lys	0.52	0.61	0.01
Met	0.14	0.22	0.00
Phe	0.55	0.55	0.02
Thr	0.41	0.51	0.01
Trp	0.13	0.12	<0.04
Val	0.56	0.70	0.02
Dispensable AA			
Ala	0.49	0.62	0.02
Asp	1.17	1.04	0.02
Cys	0.14	0.28	0.00
Glu	1.84	2.13	0.03
Ser	0.46	0.53	0.01
Tyr	0.36	0.36	0.00

Table 4-4. Analyzed DM content and nutrient composition of fermented soybean meal (FSBM) and camelina meal (CLM, %; nutrients on a DM-basis)

Item	Fermented soybean meal	Camelina meal
DM	89.43	91.34
CP	47.5	35.3
Crude fat	1.8	13.0
ADF	6.5	26.6
NDF	13.6	48.8
Ca	0.50	0.57
P	0.93	0.95
Ash	7.13	6.33
Indispensable AA		
Arg	2.89	2.78
His	1.07	0.72
Ile	1.98	1.16
Leu	3.30	2.07
Lys	2.20	1.55
Met	0.59	0.63
Phe	2.21	1.35
Thr	1.63	1.31
Trp	0.56	0.32
Val	2.14	1.70
Dispensable AA		
Ala	1.91	1.54
Asp	4.71	2.62
Cys	0.57	0.72
Glu	7.06	5.13
Ser	1.76	1.36
Tyr	1.56	0.92

Table 4-5. Apparent (AID) and standardized ileal digestibility (SID) coefficients (%) of fermented soybean meal (FSBM) and camelina meal (CLM)[1]

	AID, %		SID,[2] %	
AA, %	Fermented soybean meal	Camelina meal	Fermented soybean meal	Camelina meal
Indispensable AA				
Arg	81.6(7.6)	77.4 (5.8)	93.4 (4.6)	84.5 (3.4)
His	80.3(1.6)	67.2 (4.8)	88.2 (2.7)	74.7 (3.2)
Ile	82.4(1.3)	60.8 (4.1)	89.1 (2.1)	67.5 (3.5)
Leu	83.0(0.8)	65.6 (4.4)	89.9 (1.5)	72.7 (3.8)
Lys	63.5(7.5)	47.3 (7.7)	71.1 (6.2)	53.9 (6.4)
Met	84.6(1.0)	74.6 (3.3)	89.2 (2.1)	77.7 (3.5)
Phe	84.3(0.3)	64.6 (4.2)	90.4 (2.0)	70.9 (3.5)
Thr	74.0(3.5)	39.7 (6.8)	88.0 (3.1)	51.6 (6.7)
Trp	81.8(1.4)	67.3 (8.3)	93.7 (2.0)	79.7 (6.8)
Val	82.1(2.0)	63.3 (4.1)	89.9 (2.2)	69.6 (4.4)
Dispensable AA				
Ala	73.8(4.7)	52.2 (6.4)	86.8 (4.0)	62.2 (3.7)
Asp	77.4(3.4)	56.9 (4.6)	84.4 (3.6)	64.9 (4.1)
Cys	67.7(3.9)	51.3 (5.3)	80.6 (3.4)	58.0 (4.8)
Glu	82.6(1.4)	73.3 (3.5)	87.8 (1.6)	77.8 (3.0)
Ser	77.4(3.2)	44.7 (7.0)	89.2 (2.8)	55.1 (6.1)
Tyr	79.7(2.5)	52.2 (4.6)	86.6 (1.1)	59.1 (3.7)

[1] Values are the mean of 5 observations per treatment. Standard deviation for each digestibility value is shown in parentheses.

[2] The SID represents the corrected AID for basal endogenous loss of an AA. Calculated basal endogenous losses after feeding the N-free diet were (g/kg of DMI) Arg, 0.08; His, 0.02; Ile, 0.04; Leu, 0.06; Lys, 0.04; Met, 0.01; Phe, 0.04; Thr, 0.07; Trp, 0.02; Val, 0.05; Ala, 0.07; Asp, 0.09, Cys, 0.02; Glu, 0.11; Ser, 0.06; Tyr, 0.03.

Table 4-6. Energy values (g/kg of DM) of fermented soybean meal (FSBM) and camelina meal (CLM)[1]

Ingredient, %	Fermented soybean meal	Camelina meal
GE	4,350	4,574
DE[2]	3,035 (198)	2,536 (400)
ME[3]	2,715 (198)	2,296 (400)
NE[4]	1,940 (172)	1,576 (348)

[1] A total of 5 pigs (PIC 327 × 1050; initially 27.4 kg BW) were used in a crossover design with 3 periods to provide 5 observations per treatment.

[2] TheDE values were determined using the difference procedure (Adeola, 2001).

[3] ME was calculated using the equation: ME = 1 × DE – 0.68 × CP ($R^2 = 0.99$; Noblet and Perez, 1993).

[4] NE was calculated by using the equation: NE = (0.87 × ME) - 442 ($R^2 = 0.94$; Noblet et al., 1994).