THE EFFECTS OF CRUDE GLYCEROL, DRIED DISTILLERS GRAINS WITH SOLUBLES, RACTOPAMINE HCL, NUTRIDENSE CORN, AND FEEDER ADJUSTMENT ON GROWING AND FINISHING PIG PERFORMANCE

by

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Abstract

A total of 6,858 pigs were used in 6 experiments to evaluate the effects of crude glycerol, dried distillers grains with solubles (DDGS), Ractopamine HCl (RAC), NutriDense corn, and feeder adjustment on growing and finishing pig performance. In Exp. 1, pigs were fed diets with 0, 2.5, or 5% crude glycerol with 0 or 20% DDGS. Adding DDGS increased ADFI and decreased G:F with no differences for pigs fed glycerol. Neither glycerol nor DDGS affected any carcass characteristics. Pigs fed DDGS had increased iodine value in carcass fat. In Exp. 2, pigs were fed diets with 0 or 5% glycerol with 0 or 7.5 ppm RAC. Feeding RAC increased ADG and G:F and decreased ADFI while glycerol tended to improve G:F. Ractopamine HCl improved carcass traits. Loin chop drip loss worsened when glycerol and RAC were added separately, however, drip loss decreased when the combination of both were fed. Glycerol did not affect loin characteristics. Neither RAC nor glycerol influenced iodine value of carcass fat. Exp. 3 and 4 were conducted to determine the 4th limiting amino acid in diets containing NutriDense corn. In Exp. 3, pigs fed the positive control and the diet with added Ile, Trp, and Val (in combination) had greater ADG. Pigs fed added Ile or Trp had greater ADG than pigs fed the negative control indicates these amino acids were co-4th limiting for 37 to 59 kg pigs. In Exp. 4, pigs fed the positive control, added Trp, or the combination of added Ile, Trp and Val had greater ADG then pigs fed the negative control or pigs fed either Ile or Val indicates these amino acids were co-4th limiting for 77 to 100 kg pigs. Exp. 5 and 6 evaluated feeder adjustment on growth performance of finishing pigs. In Exp. 5, reducing feeder opening decreased ADFI. In Exp. 6, pigs were fed at three feeder opening and either a corn-soybean meal or byproduct-based diet. Diet type did not affect pig performance. Widening feeder openings increased ADG and ADFI. Feeder setting tended to influence G:F with the best G:F at the intermediate opening.

Table of Contents

List of Figures

List of Tables

Chapter 1 - Effects of increasing crude glycerol and dried distillers grains with solubles on growth performance, carcass characteristics, and carcass fat quality of finishing pigs

Abstract

This study was conducted to determine the effects of dietary crude glycerol and dried distillers grains with solubles (DDGS) on growing-finishing pig performance, carcass characteristics, and carcass fat quality. We hypothesized that because dietary crude glycerol has been observed to increase carcass saturated fatty acids, it might ameliorate the negative effects of DDGS on fat quality. The 97-d study was conducted at a commercial swine research facility in southwestern Minnesota with 1,160 barrows (initial BW = 31.0 ± 1.1 kg). Pigs were blocked by initial BW, and pens were randomly allotted to 1 of 6 dietary treatments with 7 replications per treatment. Treatments were arranged in a 2 × 3 factorial with main effects of crude glycerol (0, 2.5, or 5%) and DDGS (0 or 20%). All corn-soybean meal-based diets contained 3% added fat (choice white grease). There were no glycerol × DDGS interactions for any response criteria evaluated. Increasing dietary glycerol did not affect finishing pig growth performance. Adding 20% DDGS to the diet did not affect ADG; however, finishing pigs fed diets with added DDGS had greater (2.47 vs. 2.41 kg/d; $P = 0.02$) ADFI and poorer (0.39 vs. 0.40; $P = 0.01$) G:F than pigs not fed DDGS. Feeding increasing dietary glycerol or 20% DDGS did not affect carcass characteristics. For carcass fat quality, feeding 20% DDGS resulted in decreased ($P < 0.01$) palmitic and oleic acids, total saturated fatty acids, and total monounsaturated fatty acids (MUFA) and increased ($P < 0.01$) linoleic, total polyunsaturated fatty acids (PUFA), total unsaturated fatty acids and iodine value (IV) in jowl fat, belly fat, and backfat. Increasing dietary crude glycerol increased myristic acid (linear, $P < 0.03$) and MUFA (quadratic, $P < 0.04$) in jowl fat and increased (quadratic, $P < 0.05$) oleic acid and MUFA in backfat. In conclusion, feeding 20% DDGS to finishing pigs increased ADFI, reduced G:F, and increased carcass fat IV, whereas feeding crude glycerol did not influence growth performance, carcass characteristics, and had a minor influence on fatty acids of carcass fat. Both of these biofuel coproducts can be used in

combination without affecting finishing pig performance or carcass traits; however, feeding crude glycerol did not fully mitigate the increased unsaturation of carcass fat observed when feeding DDGS.

Key Words: dried distiller grains with solubles, glycerol, growth, iodine value, swine

Introduction

The Energy Independence and Security Act of 2007 spurred the rapid expansion of biofuel production in the United States (Renewable Fuels Association, 2009). This growth in production and the demand for alternative fuels led to increased availability of coproducts such as dried distiller grains with solubles (**DDGS**) from ethanol production (Belyea et al., 2004) and crude glycerol from biodiesel production (Thompson and He, 2006). These coproducts provide alternative ingredients for livestock feed, but a better understanding of their feeding value is needed.

Stein and Shurson (2009) reviewed research on the use of DDGS in swine diets and reported that up to 20% DDGS can be fed to growing-finishing pigs without negatively affecting growth performance. Past research studies demonstrated that feeding glycerol in swine diets had no impact on performance (Lammers et al., 2008; Schieck et al., 2010a) while other data has shown benefits for both nursery (Groesbeck et al., 2008; Shields et al., 2011) and finishing pigs (Schieck et al., 2010b). Feeding biofuel coproducts to pigs may also affect carcass quality. For carcass fat quality, research has consistently documented carcass quality changes when pigs are fed DDGS such as reduced percentage carcass yield, increased carcass fat softness, and reduced belly firmness (Stein and Shurson, 2009). In contrast, Mourot et al. (1994) showed that carcass fat was more saturated when pigs were fed dietary glycerol while Schieck et al. (2010b) reported that carcasses firmness was improved when fed the last 8-wks prior to slaughter. However, the mechanism for this effect is not fully understood. Thus the use of glycerol in diets containing higher level of unsaturated fats, such as from DDGS, may provide a dietary means to ameliorate some of the negative carcass quality characteristics associated with feeding DDGS.

Therefore, the objective of this study was to evaluate the effects of dietary crude glycerol and DDGS on growing-finishing pig performance, carcass characteristics, and carcass fat quality.

Materials and Methods

All animal procedures were reviewed and approved by the Kansas State University Institutional Animal Care and Use Committee.

General

The trial was conducted at a commercial research facility in southwestern Minnesota. The facility has 4 individual barns (12.5 m × 76.2 m), each with 48 pens (3.05 m × 5.49 m) that provide approximately 0.69 m^2 per pig. All pens contain one 4-hole dry self-feeder and a cup waterer to allow for ad libitum access to feed and water. Each barn has a deep pit for manure storage and completely slatted floors. The barns operate on natural ventilation during the summer and mechanically assisted ventilation during the winter. All barns are curtain sided.

Multiple lots of crude glycerol from the same soybean biodiesel production facility (Minnesota Soybean Processors, Brewster, MN) and multiple lots of DDGS from two ethanol production facilities (Agri-Energy, LLC, Luverne, MN fed from d 0 to 70 and VeraSun Energy, Aurora, SD fed from d 70 to 97) were used in the trial (Tables 1.1 and 1.2).

Animals and Diets

A total of 1,160 barrows (Line 337 × 1050, PIC, Hendersonville, TN) with an initial BW of 31.0 ± 1.1 kg were used in a 97-d growth assay. Pigs were randomly allotted to pens, and pens of pigs were allotted to 1 of 6 dietary treatments with 7 pens per treatment. Pens were blocked on the basis of average initial pen weight. Each pen contained 27 or 28 barrows.

Pigs were fed corn-soybean meal-based diets in 4 phases (Tables 1.3, 1.4, 1.5, and 1.6) in meal form. The treatments were arranged in a 2 × 3 factorial with main effects of crude glycerol (0, 2.5, or 5%) and DDGS (0 or 20%). All experimental diets were

balanced to maintain a constant standardized ileal digestible (SID) Lys:ME ratio within each phase. For both DDGS and crude glycerol, the NRC (1998) ME value of corn (3,420 kcal/kg) was used in diet formulation. Pedersen et al. (2007) reported that DDGS has the same energy value as corn and the DDGS nutrient composition and digestibility values used in diet formulation were determined by Stein et al. (2006) and Pedersen et al. (2007). Pigs and feeders were weighed approximately every 14 d to determine the response criteria of ADG, ADFI, and G:F. Pigs were marketed on d 97 of the study.

At the end of the 97-d experiment, pigs from each pen were individually tattooed with pen number and shipped approximately 96 km to the JBS Swift & Company processing plant (Worthington, MN). Pigs were slaughtered under commercial conditions with carbon dioxide stunning. Standard carcass criteria of loin and backfat depth, HCW, fat-free lean index, and yield were collected. Yield was calculated as HCW divided by BW obtained at the plant immediately prior to slaughter. Fat depth and loin depth were measured with an optical probe (Fat-O-Meater, SFK Technology A/S, Herlev, Denmark) inserted between the third and fourth rib from the last rib (counting from the posterior of the carcass) and 7 cm from the dorsal midline of the hot carcass. Fat-free lean index was calculated according to the National Pork Producers Council (2000b) procedures.

Fatty Acid Analysis

After exiting the kill floor, carcasses were sent through deep-chill chambers (approximately -40°C) for approximately 90 min. After deep chill, carcasses were segregated on an outside rail in a holding cooler. Approximately 2 h after exiting deep chill, the right side jowl was removed with a perpendicular cut flush with the carcass shoulder from 2 randomly selected barrows from each pen. Backfat and belly fat samples were collected from the same barrows. A sample (approximately 200 g total) of backfat was removed from the 10th rib area off the carcass midline. An attempt was made to remove all layers of backfat. The jowl fat and backfat samples were placed in a vacuum bag, vacuum sealed, and stored at approximately 4^{o}C. Then carcasses were allowed to chill overnight. At approximately 18 h after slaughter, the bellies were removed and collected from the right side of the carcass (IMPS 408). A belly strip (approximately 5 cm wide and 70 cm long) was removed from the dorsal edge of each belly. Belly strips were vacuum packaged, stored at 4^{o}C, and then transported to Kansas State University

under refrigerated conditions. Samples were frozen at -18°C until sample preparation and fatty acid analysis. Samples were thawed and dissected to separate adipose tissue from skin and lean tissue. Adipose tissue was subsampled and ground. Grinding was performed by cutting fat samples into approximately 1 cm^3 pieces, freezing the pieces in liquid N, and grinding them in a stainless steel grinding tub powered by a Waring Commercial Blender (Dynamics Corporation of America, New Hartford, CT). Ground fat (50 µg) was then weighed into screw-cap tubes with Teflon-lined caps. Fat was combined with 3 mL of methanolic-HCl and 2 mL of internal standard (2 mg/mL of methyl tridecanoic acid (C13:0) in benzene) and subsequently heated in a water bath for 135 min at 70°C for transmethylation. Tubes were vortexed at 45 and 90 min. during this heating period. Upon cooling, addition of 2 mL of benzene and 3 mL of K_2CO_3 allowed the methyl esters to be extracted and transferred to a vial for subsequent quantification of methylated fatty acids by GC for fatty acid analysis. Injection port and detector temperatures were 250°C with a flow rate of 1 mL/min helium and a split ratio of 100:1. Oven temperature began at 140°C, increased at 2°C/min to 200°C, increased at 4°C/min to 245°C, and was held for 17 min. From the fatty acid analysis, IV was calculated from the following equation (AOCS, 1998): IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785+ [C22:1] × 0.723, where the brackets indicate concentration (percentage) of the fatty acid.

Statistical Analysis

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC), with pen as the experimental unit. Main effects of crude glycerol level and DDGS and their interactions were tested. Linear and quadratic polynomial contrasts were used to determine the effects of increasing dietary glycerol. Statistical significance and tendencies were set at $P \leq 0.05$ and $P \leq 0.10$, respectively, for all statistical tests. When treatment effect was a significant ($P \leq 0.05$) source of variation, differences were determined by using the PDIFF option of SAS. Least squares means were calculated for each independent variable.

Results

In general, analyzed composition values for crude glycerol (Table 1.1) were higher than those reported in Lammers et al. (2008). Analyzed composition values for the 2 DDGS sources used in this study were similar to those used in diet formulation (Table 1.2).

Overall (d 0 to 97), there were no glycerol × DDGS interactions for growth performance, carcass characteristics, or carcass fat quality; therefore, only main effects are discussed. Increasing dietary glycerol did not affect growth performance (Table 1.7). Adding 20% DDGS to the diet did not affect ADG; however, finishing pigs fed diets with added DDGS had greater ($P = 0.02$) ADFI and poorer ($P = 0.01$) G:F than pigs not fed DDGS. Increasing dietary glycerol did not affect HCW, HCW variation, carcass yield, backfat depth, loin depth, or fat-free lean index (Table 1.8). Likewise, adding 20% DDGS to the diet did not affect any carcass characteristics measured.

For carcass fat quality, as expected, feeding 20% DDGS to finishing pigs resulted in decreased ($P < 0.01$) palmitic and oleic acids, total saturated fatty acids (SFA), and total monounsaturated fatty acids (MUFA) and increased ($P < 0.01$) linoleic, total polyunsaturated fatty acids (PUFA), total unsaturated fatty acids (UFA; MUFA + PUFA):SFA, PUFA:SFA, and IV in jowl fat, belly fat, and backfat compared with feeding no DDGS (Tables 1.9, 1.10, and 1.11). Feeding DDGS did not affect total *trans* fatty acids concentration in any of the three fat depots.

Increasing dietary crude glycerol increased myristic acid (linear, $P < 0.03$) and MUFA (quadratic, $P < 0.04$) while tending to increase (quadratic, $P < 0.10$) the vaccenic acid level in jowl fat. Also, margaric acid tended (quadratic, $P < 0.10$) to be reduced in jowl fat when 2.5% dietary glycerol was fed. Also in jowl fat, pigs fed increasing glycerol tended to have decreased (quadratic, $P < 0.09$) linoleic acid and PUFA. For belly fat, pigs fed increasing glycerol tended to have increased myristic (linear, $P < 0.09$) while margaric acid tended (quadratic, $P < 0.06$) to be reduced in jowl fat when 2.5% dietary glycerol was fed compared to 0 or 5.0%.. Finally for backfat, pigs fed increasing dietary glycerol had increased (quadratic, $P < 0.05$) oleic acid and MUFA, while having a tendency for increased (linear, $P < 0.09$) myristic and palmitic acids. However, there was a tendency for increased (linear, $P < 0.08$) linoliec acid and decreased (linear, $P < 0.10$)

PUFA:SFA ratio. Although differences were found in all depots for dietary glycerol altering fatty acid composition to be more saturated, no significant differences were found for carcass fat iodine value in any of the three fat depot locations tested.

Discussion

Growth Performance

For pork producers, the importance of identifying alternatives to traditional ingredients in swine diets has dramatically increased in recent years because of significant increases in grain and supplement costs. In the past decade, much research has been devoted to determining the feeding value of DDGS, and this led to a rapid increase in DDGS usage in commercial pig production. Optimal inclusion levels of DDGS in swine diets have been determined on the basis of growth performance and economics (Fu et al., 2004; Hastad, 2005; Whitney et al., 2006); however, the main issue with using higher levels of DDGS is the negative effect on carcass fat quality (Whitney et al., 2006; Benz et al., 2010; Xu et al., 2010).

Biodiesel is produced through transesterification of triglycerides in oils or fats with an alcohol, usually methanol (Van Gerpen, 2005). Through this reaction, fatty acids are methylated to form methyl alkyl esters (i.e., biodiesel) and the principal coproduct, crude glycerol (Ma and Hanna, 1999; Thompson and He, 2006). Early studies assessing the effects of feeding pure or crude glycerol to broiler chickens (Simon et al., 1996) and pigs (Kijora et al., 1997) provided initial evidence that glycerol can be used as a source of dietary energy for livestock. This was expected because glycerol plays an important role in energy metabolism. Glycerol is an important structural component of triglycerides and phospholipids (Min et al., 2010). Glycerol is a precursor to glyceraldehyde 3-phosphate, an intermediate in the lipogenesis and gluconeogenesis pathways, and yields energy through glycolysis and the citric acid cycle (Lin, 1997; Brisson et al., 2001). As an energy source, glycerol can be oxidized, which yields 22 moles of ATP/mol (Min et al., 2010). In a study with growing pigs, Lammers et al. (2008) demonstrated that dietary crude glycerol provides 3.21 Mcal of ME/kg and is well digested, with apparent total tract energy digestibility ranging from 89 to 92%. Thus, the ability to feed pigs both

crude glycerol and DDGS may provide a means to reduce feed costs by replacing corn and soybean meal.

Stein and Shurson (2009) reported that feeding 20% DDGS to finishing pigs does not negatively affect growth performance. However, in the present study, we observed increased ADFI and reduced G:F. Gaines et al. (2007a,b) also observed poorer G:F, whereas Xu et al. (2010) reported improved G:F in finishing pigs fed diets containing DDGS. These differences in G:F may be due to the innate variability in energy concentration among the DDGS sources used in these experiments (Stein and Shurson, 2009). In the present study, the NRC (1998) ME value of corn (3,420 kcal/kg) was assigned to DDGS in formulation of diets containing DDGS. Unfortunately, the ME value used by Gaines et al. (2007a,b) and Xu et al. (2010) was not reported. The reduction in G:F in the present study may suggest that the energy concentration of DDGS was lower than what was used in diet formulation.

Compared with the analyzed values of crude glycerol reported by Lammers et al. (2008), our values were slightly greater for CP and ether extract and slightly lower for total glycerol. However, these differences did not result in any significant effects on growth performance compared with pigs not fed glycerol. Our results agree with most previous research, in which including crude glycerol at 2.5 to 5% of the diet did not affect growth performance of growing and finishing pigs fed corn-soybean meal diets (Lammers et al., 2008; Huang et al., 2010), barley-soybean meal diets (Kijora et al., 1997; Kijora and Kupsch, 2006), corn-barley-soybean meal diets (Della Casa et al., 2009), or wheat-soybean meal diets (Mourot et al., 1994).

Some studies have shown improved ADG (Stevens et al., 2008; Schieck et al., 2010b), increased ADFI, and lower G:F (Stevens et al., 2008) in finishing pigs fed glycerol. The difference in responses between Stevens et al. (2008) and the current study may be due to glycerol quality. Stevens et al. (2008) fed crude glycerol (84% glycerol, <100 mg/kg methanol) in the first 3 phases (d 0 to 84) and then used food-grade glycerol (99.7% glycerol) in the fourth and final phase (d 84 to d 105). In contrast, crude glycerol (82.2% glycerol, 136 mg/kg methanol) was fed in all 4 phases of our study. Additional research is needed to determine the effect of purity of glycerol source on pig growth performance.

Carcass Characteristics

Whitney et al. (2006) reported a linear increase in the CV for final BW as DDGS was added to the diet. However, Drescher et al. (2009) observed no differences in the CV for final BW and HCW, which was similar to our results. The majority of the studies included in Stein and Shurson's (2009) review article showed no effects of feeding DDGS on carcass characteristics of growing-finishing pigs. Results of the current study are consistent with those findings for pigs fed DDGS.

Kijora and Kupsch (1996) observed that pigs fed 10% crude glycerol had leaner carcasses than control pigs, but the authors attributed this to differences in growth rates during the finishing phase rather than to glycerol intake. In contrast, Stevens et al. (2008) reported a linear increase in 10th rib backfat and a linear decrease in percentage fat free lean when dietary crude glycerol was fed. However, the present study data is consistent with other research (Kijora et al., 1995; Lammers et al., 2008; Schieck et al., 2010b) that showed that feeding dietary glycerol to finishing pigs did not alter carcass characteristics. A reason for the inconstancy among research reports is unknown. However, Stevens et al. (2008) used food-grade glycerol, which contains a higher percentage of glycerol than the glycerol used in other research; therefore, their glycerol-supplemented diets might have had higher energy concentrations that may have resulted in the fatter carcasses.

Carcass Fat Quality

It is widely accepted that fatty acid composition of the fat depots closely mimics fatty acid composition of the diet (Wiseman and Agunbiade, 1998; Averette Gatlin et al., 2002). This is mainly the result of dietary fats inhibiting de novo fatty acid synthesis in favor of direct deposition of dietary fatty acids in adipose tissue (Farnworth and Kramer, 1987; Chilliard, 1993). Thus, carcass fat composition can be manipulated by selecting dietary fat sources and feed ingredients on the basis of certain quality criteria. Carcass fat quality is important for meat processors mainly because of its effects on several processing and quality issues, especially for bacon production, retail packaging, product shelf life, and susceptibility to oxidative damage (Wood and Enser, 1997; NPPC, 2000a). Therefore, standards for pork carcasses based on different measures such as fat IV,

PUFA:SFA ratio, and belly firmness have been established to determine acceptable levels of fat quality.

One of the major issues in using high levels of DDGS in finishing diets is the effect on carcass fat quality. Soft carcass fat is indicative of high dietary C18:2n6 and PUFA concentrations, but this effect is mainly a result of a proportional decrease in SFA and changes in the distribution of fatty acids in fat tissues (Enser et al., 1984). This was observed in the current study, in which adding 20% DDGS to the diet increased linoleic acid (C18:2n6), PUFA, and PUFA:SFA ratio and reduced oleic acid (C18:1c9), palmitic acid (C16:0), and SFA concentrations in all fat depots. These results also conform to those of Benz et al. (2010) and Xu et al. (2010). Thus, feeding ingredients high in unsaturated fats, such as DDGS, changes the proportion of fatty acids in adipose tissues.

Carcass fat IV provides an overall estimate of fatty acid unsaturation, which can serve as an indicator of the percentage of unsaturated fatty acids, softness of fat, or potential rancidity (Hugo and Roodt, 2007). As expected, pigs fed DDGS had greater carcass fat IV than those fed diets without DDGS, which is consistent with numerous studies (White et al., 2007; Hill et al., 2008; Stender and Honeyman, 2008). The current study showed an increase of approximately 3.4, 2.3, and 3.2 g/100 g in backfat, jowl fat, and belly fat IV, respectively, when 20% DDGS was included in the diet. Benz et al. (2010) showed an increase of approximately 2.3, 1.6, and 2.2 g/100 g in backfat, jowl fat, and belly fat IV, respectively, for every 10% increase in DDGS in the diet. Both studies indicate that jowl fat IV increased at a slower rate relative to belly fat and backfat IV as DDGS increased in the diet. In the present study all diets contained 3% choice white grease. It has been shown that feeding 5.0% choice white grease for 83 d prior to slaughter increased IV values by 3.0 and 4.4 g/100g in jowl and backfat, respectively (Benz et al., 2011). However, no previous data is available to suggest the response to carcass fat quality would be altered depending if added fat was or was not included in diets containing glycerol.

While present, we observed limited differences for fat to be more saturated in pigs fed crude glycerol in jowl fat, backfat, or belly fat. Mourot et al. (1994) observed that finishing pigs fed glycerol had increased oleic acid and decreased linoleic and linolenic acid in backfat, which resulted in a greater degree of saturation. Schieck et al. (2010b)

also reported that pigs fed 8% glycerol tended to have a greater degree of belly firmness compared with pigs that were not fed glycerol. We hypothesized adding crude glycerol to finishing diets with DDGS may ameliorate the negative effects of DDGS on carcass fat IV. However, we did observe numerical reductions (0.7 to 2.1 percentage units) in belly fat and backfat IV. One reason for the lack of a larger change could be the inclusion level used of crude glycerol (2.5 to 5%) in the present study compared to previous research where differences were found.

In conclusion, feeding 20% DDGS to finishing pigs increased ADFI, reduced G:F, and increased carcass fat IV, whereas feeding crude glycerol did not influence growth performance, and carcass characteristics. Also, we observed minor differences for carcass fat to be more saturated in pigs fed crude glycerol. Both of these biofuel coproducts can be used in combination without affecting finishing pig performance or carcass characteristics, but feeding crude glycerol did not mitigate the increased unsaturation of carcass fat observed when feeding DDGS.

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Table 1.1 Analyzed composition of crude glycerol (as fed basis)

Item	Analyzed[1]
Total glycerol, %[2]	82.2
Methanol, mg/kg[3]	136
Moisture, %[4]	9.7 (9.1 – 10.5)
CP,%[4]	1.9 (0.2 – 2.8)
Ether extract, %[4]	2.7 (1.1 – 7.1)
Ash, %[4]	5.4 (5.1 – 5.6)

[1]Values represent the mean of 4 samples of glycerol (Minnesota Soybean Processors, Brewster, MN) with the value range in parenthesis.

[2]Determined within the Minnesota Processors laboratory as: 100 - % total fatty acid - % moisture - % methanol - % ash.

[3]Values reported by Minnesota Soybean Processors, Brewster, MN.

[4]Analysis by Ward Laboratories, Inc., Kearney, NE.

Table 1.2 Assumed and analyzed composition of dried distillers grains with solubles (DDGS; as-fed basis)

		Analyzed	
Item, %	Assumed[1]	Agri-Energy[2]	VeraSun Energy[3]
DM	93.0	91.7	91.6
CP	27.2	26.1	28.0
Crude fiber	---	9.0	9.3
Ether extract	10.7	11.9	11.1
Ash	---	3.7	4.1
Total amino acids			
Lys	0.78	0.76	0.89
Ile	1.01	0.97	1.03
Leu	3.17	2.93	3.05
Met	0.55	0.49	0.53
Cys	0.55	0.47	0.47
Thr	1.06	0.97	1.00
Trp	0.21	0.19	0.22
Val	1.35	1.30	1.38

[1]Represents assumed values used in diet formulation.

[2]Values represent the mean of 2 samples of DDGS (Agri-Energy, LLC, Luverne, MN) that was fed from d 0 to 70.

[3]Values represent the mean of 3 samples of DDGS (VeraSun Energy, Aurora, SD). Fed from d 70 to 97.

Table 1.3 Phase 1 diet composition (as-fed basis)[1]

	Dried distillers grains with solubles, %					
	0			20		
	Crude glycerol, %					
Item	0	2.5	5	0	2.5	5
Ingredient, %						
Corn	68.17	65.46	62.76	55.14	52.44	49.74
Soybean meal, 46.5% CP	26.63	26.83	27.03	19.69	19.89	20.09
Crude glycerol	---	2.50	5.00	---	2.50	5.00
Dried distillers grains with solubles	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.63	0.63	0.63	0.18	0.18	0.18
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.30	0.30	0.30
DL-Met	0.01	0.02	0.02	---	---	---
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.98	0.98	0.98	0.98	0.98	0.98
Met:Lys	28	28	29	30	30	29
Met+Cys:Lys	57	57	57	61	61	60
Thr:Lys	60	60	60	61	61	60
Trp:Lys	19	19	19	18	18	18
CP, %	18.33	18.20	18.06	19.57	19.44	19.30
Total Lys, %	1.10	1.10	1.10	1.13	1.13	1.13
ME, kcal/kg	3,479	3,479	3,479	3,488	3,488	3,488
Lys:ME, g/Mcal	2.82	2.82	2.82	2.81	2.81	2.81
Ca, %	0.55	0.55	0.55	0.55	0.55	0.55
P, %	0.51	0.50	0.49	0.47	0.46	0.46
Available P, %[5]	0.28	0.28	0.28	0.28	0.28	0.28

[1]Fed from 31.0 to 54.4 kg.

[2]Provided per kilogram of diet: 6,614 IU of vitamin A; 827 IU of vitamin D; 26 IU of vitamin E; 2.6 mg of vitamin K; 0.02 mg of vitamin B_{12}; 30 mg of niacin; 17 mg of pantothenic acid; and 5 mg of riboflavin.

[3]Provided per kilogram of diet: 16.53 mg of Cu from Cu sulfate; 0.298 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 39.7 mg of Mn from Mn oxide, 0.298 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.

[4] OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[5]Includes expected P release of 0.10% from added phytase.

Table 1.4 Phase 2 diet composition (as-fed basis)[1]

	Dried distillers grains with solubles, %					
	0			20		
	Crude glycerol, %					
Item	0	2.5	5	0	2.5	5
Ingredient, %						
Corn	74.27	71.57	68.87	61.20	58.50	55.80
Soybean meal, 46.5% CP	20.66	20.86	21.06	13.72	13.92	14.12
Crude glycerol	---	2.50	5.00	---	2.50	5.00
Dried distillers grains with solubles	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.55	0.55	0.55	0.13	0.13	0.13
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.06	0.06	0.06	0.06	0.06	0.06
Trace mineral premix[3]	0.08	0.08	0.08	0.08	0.08	0.08
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.83	0.83	0.83	0.83	0.83	0.83
Met:Lys	29	29	28	32	32	32
Met+Cys:Lys	60	59	58	66	65	64
Thr:Lys	61	61	61	62	62	61
Trp:Lys	19	19	19	17	17	17
CP, %	16.06	15.93	15.79	17.31	17.17	17.04
Total Lys, %	0.93	0.93	0.93	0.97	0.96	0.96
ME, kcal/kg	3,483	3,483	3,483	3,494	3,494	3,494
Lys:ME, g/Mcal	2.38	2.38	2.38	2.38	2.38	2.38
Ca, %	0.52	0.52	0.52	0.52	0.52	0.52
P, %	0.47	0.46	0.45	0.43	0.43	0.42
Available P, %[5]	0.25	0.24	0.24	0.25	0.25	0.25

[1]Fed from 54.4 to 77.1 kg.

[2]Provided per kilogram of diet: 5,511 IU of vitamin A; 689 IU of vitamin D; 22 IU of vitamin E; 2.2 mg of vitamin K; 0.02 mg of vitamin B_{12}; 25 mg of niacin; 14 mg of pantothenic acid; and 4 mg of riboflavin.

[3]Provided per kilogram of diet: 13.64 mg of Cu from Cu sulfate; 0.246 mg of I from Ca iodate; 136 mg of Fe from Fe sulfate; 32.7 mg of Mn from Mn oxide, 0.246 mg of Se from Na selenite; and 136 mg of Zn from Zn oxide.

[4] OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[5]Includes expected P release of 0.10% from added phytase.

Table 1.5 Phase 3 diet composition (as-fed basis)[1]

	Dried distillers grains with solubles, %					
	0			20		
	Crude glycerol, %					
Item	0	2.5	5	0	2.5	5
Ingredient, %						
Corn	78.67	75.97	73.27	64.12	61.42	58.72
Soybean meal, 46.5% CP	16.28	16.48	16.68	10.90	11.10	11.30
Crude glycerol	---	2.50	5.00	---	2.50	5.00
Dried distillers grains with solubles	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.55	0.55	0.55	0.10	0.10	0.10
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix[3]	0.07	0.07	0.07	0.07	0.07	0.07
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.72	0.72	0.72	0.72	0.72	0.72
Met:Lys	31	30	30	35	35	35
Met+Cys:Lys	63	62	61	72	71	71
Thr:Lys	62	62	62	66	66	65
Trp:Lys	19	19	19	17	17	17
CP, %	14.40	14.27	14.13	16.20	16.06	15.93
Total Lys, %	0.81	0.81	0.81	0.85	0.85	0.85
ME, kcal/kg	3,488	3,488	3,488	3,496	3,496	3,496
Lys:ME, g/Mcal	2.06	2.06	2.06	2.06	2.06	2.06
Ca, %	0.50	0.50	0.50	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P, %[5]	0.23	0.23	0.23	0.23	0.23	0.23

[1]Fed from 77.1 to 99.8 kg.

[2]Provided per kilogram of diet: 4,409 IU of vitamin A; 551 IU of vitamin D; 18 IU of vitamin E; 1.8 mg of vitamin K; 0.02 mg of vitamin B_{12}; 20 mg of niacin; 11 mg of pantothenic acid; and 3 mg of riboflavin.

[3]Provided per kilogram of diet: 10.75 mg of Cu from Cu sulfate; 0.193 mg of I from Ca iodate; 107 mg of Fe from Fe sulfate; 25.8 mg of Mn from Mn oxide, 0.193 mg of Se from Na selenite; and 107 mg of Zn from Zn oxide.

[4] OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[5]Includes expected P release of 0.10% from added phytase.

Table 1.6 Phase 4 diet composition (as-fed basis)[1]

	Dried distillers grains with solubles, %					
	0			20		
	Crude glycerol, %					
Item	0	2.5	5	0	2.5	5
Ingredient, %						
Corn	80.64	77.93	75.23	66.09	63.39	60.69
Soybean meal, 46.5% CP	14.29	14.50	14.70	8.91	9.11	9.31
Crude glycerol	---	2.50	5.00	---	2.50	5.00
Dried distillers grains with solubles	---	---	---	20.00	20.00	20.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.60	0.60	0.60	0.15	0.15	0.15
Limestone	0.85	0.85	0.85	1.13	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.04	0.04	0.04	0.04	0.04	0.04
Trace mineral premix[3]	0.05	0.05	0.05	0.05	0.05	0.05
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	0.64	0.64	0.64	0.64	0.64	0.64
Met:Lys	31	31	31	37	36	36
Met+Cys:Lys	65	64	63	75	74	73
Thr:Lys	63	62	62	67	67	66
Trp:Lys	19	19	18	17	17	17
CP, %	13.65	13.51	13.37	15.44	15.31	15.17
Total Lys, %	0.76	0.76	0.76	0.79	0.79	0.79
ME, kcal/kg	3,488	3,488	3,488	3,496	3,496	3,496
Lys:ME, g/Mcal	1.92	1.92	1.92	1.92	1.92	1.92
Ca, %	0.51	0.51	0.51	0.51	0.51	0.51
P, %	0.45	0.44	0.44	0.42	0.41	0.41
Available P, %[5]	0.22	0.22	0.22	0.22	0.22	0.22

[1]Fed from 99.8 to 123.8 kg.

[2]Provided per kilogram of diet: 4,409 IU of vitamin A; 551 IU of vitamin D; 18 IU of vitamin E; 1.8 mg of vitamin K; 0.02 mg of vitamin B_{12}; 20 mg of niacin; 11 mg of pantothenic acid; and 3 mg of riboflavin.

[3]Provided per kilogram of diet: 10.75 mg of Cu from Cu sulfate; 0.193 mg of I from Ca iodate; 107 mg of Fe from Fe sulfate; 25.8 mg of Mn from Mn oxide, 0.193 mg of Se from Na selenite; and 107 mg of Zn from Zn oxide.

[4] OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[5]Includes expected P release of 0.10% from added phytase.

Table 1.7 Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) on growing-finishing pig performance[1]

	DDGS, %							Probability, *P* <				
	0			20								
	Crude glycerol, %										Glycerol	
Item	0	2.5	5	0	2.5	5	SEM	DDGS × Glycerol	DDGS	Glycerol	Linear	Quadratic
d 0 to 97												
Initial wt, kg	30.8	30.9	31.3	31.0	31.2	30.9	1.12	0.95	0.98	0.98	0.84	0.94
ADG, kg	0.97	0.96	0.96	0.97	0.96	0.96	0.01	0.99	0.73	0.44	0.38	0.35
ADFI, kg	2.43	2.39	2.40	2.45	2.46	2.51	0.03	0.29	0.02	0.59	0.63	0.37
G:F	0.40	0.40	0.40	0.40	0.39	0.38	0.003	0.13	0.01	0.33	0.15	0.75
Final wt, kg	124.1	123.4	123.3	124.2	124.2	123.4	1.45	0.96	0.76	0.87	0.60	0.98
Removals[2]	6	7	6	6	10	6	---	---	---	---	---	---

[1]A total of 1,160 barrows with an initial BW of 31.0 ± 1.1 kg were used in a 97-d experiment with 27 or 28 pigs per pen and 7 replications per treatment.

[2]Removal from the study for lameness, death, tail biting, ulcers, light weight cull, or hemorrhagic bowel.

Table 1.8 Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on carcass characteristics[1,2]

	DDGS, %							Probability, *P* <				
	0			20								
	Crude glycerol, %							DDGS ×			Glycerol	
Item	0	2.5	5	0	2.5	5	SEM	Glycerol	DDGS	Glycerol	Linear	Quadratic
Carcass wt, kg	93.1	92.9	92.1	91.4	91.9	92.7	1.08	0.63	0.45	0.99	0.92	0.98
Carcass wt CV, %	9.0	9.4	9.2	8.8	8.1	8.9	0.67	0.67	0.35	0.94	0.82	0.76
Yield, %	75.1	75.5	75.7	74.5	75.9	75.7	0.47	0.56	0.93	0.17	0.11	0.37
Backfat, mm	19.9	19.7	19.8	19.3	19.0	19.6	0.48	0.87	0.18	0.81	0.86	0.54
Loin depth, mm	62.9	62.8	60.7	60.9	61.2	62.0	0.79	0.12	0.27	0.77	0.57	0.62
FFLI, %[3]	49.2	49.1	49.1	49.3	49.4	49.3	0.24	0.93	0.32	0.96	0.81	0.89

[1]A total of 1,160 barrows with an initial BW of 31.0 ± 1.1kg were used in a 97-d experiment with 27 or 28 pigs per pen and 7 replications per treatment.

[2]A total of 1,119 barrows were marketed with 23 to 26 pigs per pen.

[3]Fat-free lean index.

Table 1.9 Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on jowl fat quality[1,2]

	DDGS, %							Probability, *P* <				
	0			20								
	Glycerol, %							DDGS ×			Glycerol	
Item	0	2.5	5	0	2.5	5	SEM	Glycerol	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.32	1.48	1.46	1.31	1.30	1.35	0.04	0.10	0.005	0.06	0.03	0.35
Palmitic acid (16:0), %	21.40	22.10	22.14	20.78	20.91	20.89	0.29	0.51	0.0002	0.27	0.16	0.43
Palmitoleic acid (16:1), %	2.75	3.02	2.97	2.48	2.44	2.46	0.12	0.40	0.0001	0.61	0.43	0.55
Margaric acid (17:0), %	0.53	0.49	0.56	0.53	0.50	0.53	0.03	0.73	0.63	0.14	0.52	0.07
Stearic acid (18:0), %	9.30	8.95	9.22	8.93	9.09	8.75	0.26	0.47	0.29	0.88	0.63	0.89
Oleic acid (18:1c9), %	41.28	42.17	41.21	39.50	40.19	39.99	0.45	0.63	0.0001	0.29	0.89	0.12
Vaccenic acid (18:1n7), %	3.29	3.60	3.45	2.99	3.03	3.02	0.08	0.28	0.0001	0.13	0.25	0.10
Linoleic acid (18:2n6), %	14.48	13.04	13.61	18.63	17.04	17.70	0.68	0.99	0.0001	0.11	0.20	0.09
α-linolenic acid (18:3n3), %	0.71	0.65	0.69	0.73	0.73	0.72	0.73	0.48	0.11	0.64	0.64	0.42
γ-linolenic acid (18:3n6), %	0.47	0.30	0.36	0.23	0.40	0.33	0.47	0.57	0.68	0.99	0.99	0.99
Arachidic acid (20:0), %	0.35	0.31	0.36	0.26	0.33	0.29	0.06	0.60	0.35	0.92	0.69	0.89
Eicosadienoic acid (20:2), %	0.85	0.76	0.79	0.95	0.97	0.97	0.03	0.23	0.0001	0.57	0.51	0.41
Arachidonic acid (20:4n6), %	0.12	0.12	0.10	0.12	0.12	0.12	0.01	0.22	0.42	0.55	0.33	0.64
Other fatty acids, %	1.57	1.48	1.52	1.20	1.46	1.37	0.20	0.66	0.28	0.92	0.79	0.76
Total SFA, %[3]	33.39	33.79	34.22	32.22	32.58	32.25	0.47	0.64	0.0007	0.61	0.37	0.69
Total MUFA, %[4]	49.15	50.69	49.46	46.55	47.40	47.24	0.50	0.56	0.0001	0.08	0.36	0.04
Total PUFA, %[5]	17.46	15.52	16.32	21.23	20.02	20.51	0.72	0.88	0.0001	0.11	0.21	0.09
Total *trans* fatty acids, %[6]	0.61	0.55	0.60	0.41	0.58	0.52	0.13	0.69	0.45	0.90	0.70	0.79
UFA:SFA ratio[7]	2.00	1.96	1.93	2.11	2.08	2.11	0.04	0.70	0.0007	0.66	0.41	0.71
PUFA:SFA ratio[8]	0.53	0.46	0.48	0.66	0.62	0.64	0.03	0.91	0.0001	0.19	0.23	0.17
Iodine value, g/100 g[9]	70.5	68.6	68.9	74.1	73.3	74.0	0.88	0.69	0.01	0.33	0.36	0.24

[1]A total of 1,160 barrows, initial BW 31.0 ± 1.1 kg, were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.
[2]A total of 84 barrows were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.
[3]Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[4]Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[5]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[6]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[7]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[8]PUFA:SFA ratio = Total PUFA / Total SFA.
[9]Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 1.10 Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on belly fat quality[1,2]

	DDGS, %							Probability, *P* <				
	0			20								
	Glycerol, %							DDGS ×			Glycerol	
Item	0	2.5	5	0	2.5	5	SEM	Glycerol	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.32	1.39	1.43	1.26	1.24	1.27	0.04	0.26	0.0002	0.22	0.09	0.82
Palmitic acid (16:0), %	23.20	23.12	23.62	21.60	21.95	21.57	0.33	0.42	0.0001	0.84	0.56	0.89
Palmitoleic acid (16:1), %	2.16	2.26	2.37	2.01	1.95	1.93	0.08	0.19	0.0001	0.75	0.47	0.85
Margaric acid (17:0), %	0.54	0.53	0.57	0.54	0.49	0.55	0.02	0.76	0.30	0.11	0.35	0.06
Stearic acid (18:0), %	11.81	11.30	11.55	10.32	10.90	10.49	0.35	0.31	0.002	0.98	0.90	0.85
Oleic acid (18:1c9), %	39.09	39.49	39.21	37.16	38.41	37.84	0.36	0.35	0.0001	0.40	0.79	0.18
Vaccenic acid (18:1n7), %	2.72	2.83	2.85	2.53	2.51	2.51	0.04	0.32	0.0001	0.59	0.33	0.76
Linoleic acid (18:2n6), %	14.51	14.08	13.52	19.88	17.86	18.82	0.66	0.42	0.0001	0.16	0.14	0.23
α-linolenic acid (18:3n3), %	0.65	0.66	0.65	0.72	0.68	0.71	0.03	0.53	0.04	0.90	0.83	0.68
γ-linolenic acid (18:3n6), %	0.25	0.33	0.29	0.22	0.25	0.29	0.12	0.94	0.67	0.87	0.64	0.79
Arachidic acid (20:0), %	0.34	0.35	0.36	0.29	0.33	0.32	0.04	0.91	0.25	0.75	0.55	0.66
Eicosadienoic acid (20:2), %	0.78	0.77	0.75	0.94	0.90	0.98	0.03	0.15	0.0001	0.54	0.96	0.28
Arachidonic acid (20:4n6), %	0.10	0.12	0.11	0.11	0.10	0.11	0.01	0.20	0.51	0.99	0.86	0.97
Other fatty acids, %	1.12	1.32	1.28	1.11	1.13	1.21	0.12	0.76	0.37	0.56	0.32	0.69
Total SFA, %[3]	37.61	37.12	38.00	34.42	35.30	34.59	0.60	0.38	0.0001	0.90	0.65	0.93
Total MUFA, %[4]	45.60	46.32	46.12	43.18	44.43	43.91	0.39	0.55	0.0001	0.35	0.41	0.20
Total PUFA, %[5]	16.79	16.56	15.87	22.40	20.27	21.50	0.72	0.33	0.0001	0.25	0.22	0.26
Total *trans* fatty acids, %[6]	0.43	0.55	0.52	0.42	0.48	0.51	0.10	0.96	0.72	0.57	0.38	0.57
UFA:SFA ratio[7]	1.67	1.70	1.63	1.91	1.84	1.90	0.05	0.41	0.0001	0.89	0.66	0.86
PUFA:SFA ratio[8]	0.45	0.45	0.42	0.65	0.58	0.63	0.03	0.35	0.0001	0.37	0.30	0.35
Iodine value, g/100 g[9]	66.7	66.8	65.5	73.6	71.5	72.9	1.07	0.40	0.01	0.60	0.40	0.58

[1]A total of 1,160 barrows, initial BW 31.0 ± 1.1 kg, were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.
[2]A total of 84 barrows were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.
[3]Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[4]Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[5]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[6]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[7]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[8]PUFA:SFA ratio = Total PUFA / Total SFA.
[9]Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 1.11 Effects of feeding crude glycerol and dried distillers grains with solubles (DDGS) to finishing pigs on backfat quality[1,2]

	DDGS, %							Probability, $P <$				
	0			20								
	Glycerol, %							DDGS ×			Glycerol	
Item	0	2.5	5	0	2.5	5	SEM	Glycerol	DDGS	Glycerol	Linear	Quadratic
Myristic acid (14:0), %	1.36	1.44	1.46	1.31	1.27	1.34	0.04	0.30	0.0006	0.19	0.08	0.70
Palmitic acid (16:0), %	23.62	23.78	24.54	22.12	22.38	22.40	0.34	0.51	0.0001	0.22	0.09	0.78
Palmitoleic acid (16:1), %	2.24	2.28	2.36	1.92	1.95	1.95	0.09	0.81	0.0001	0.69	0.40	0.98
Margaric acid (17:0), %	0.54	0.54	0.57	0.54	0.50	0.54	0.03	0.76	0.34	0.44	0.65	0.23
Stearic acid (18:0), %	11.97	11.70	12.25	10.86	11.11	10.93	0.38	0.63	0.003	0.87	0.66	0.78
Oleic acid (18:1c9), %	38.55	39.01	38.89	36.62	37.99	37.23	0.35	0.43	0.0001	0.07	0.26	0.04
Vaccenic acid (18:1n7), %	2.69	2.78	2.76	2.41	2.46	2.46	0.05	0.95	0.0001	0.41	0.30	0.41
Linoleic acid (18:2n6), %	14.59	14.10	12.98	19.99	18.03	18.80	0.76	0.44	0.0001	0.16	0.08	0.44
α-linolenic acid (18:3n3), %	0.65	0.64	0.59	0.70	0.66	0.68	0.03	0.45	0.02	0.37	0.16	0.91
γ-linolenic acid (18:3n6), %	0.19	0.16	0.17	0.13	0.14	0.16	0.03	0.64	0.29	0.90	0.97	0.64
Arachidic acid (20:0), %	0.33	0.29	0.31	0.24	0.25	0.25	0.02	0.64	0.003	0.76	0.80	0.49
Eicosadienoic acid (20:2), %	0.74	0.73	0.68	0.88	0.86	0.89	0.02	0.18	0.0001	0.51	0.25	0.98
Arachidonic acid (20:4n6), %	0.10	0.09	0.09	0.11	0.11	0.09	0.008	0.40	0.21	0.32	0.15	0.70
Other fatty acids, %	1.13	1.18	1.03	0.96	1.06	1.01	0.06	0.45	0.05	0.25	0.70	0.11
Total SFA, %[3]	38.24	38.17	39.55	35.44	35.89	35.84	0.66	0.56	0.0001	0.42	0.21	0.69
Total MUFA, %[4]	44.98	45.60	45.52	42.33	43.85	43.10	0.41	0.53	0.0001	0.05	0.12	0.05
Total PUFA, %[5]	16.78	16.22	14.93	22.23	20.26	21.06	0.82	0.44	0.0001	0.16	0.08	0.48
Total *trans* fatty acids, %[6]	0.38	0.40	0.33	0.30	0.37	0.34	0.04	0.52	0.31	0.42	0.99	0.20
UFA:SFA ratio[7]	1.62	1.62	1.53	1.83	1.80	1.80	0.05	0.63	0.0001	0.46	0.24	0.74
PUFA:SFA ratio[8]	0.44	0.43	0.38	0.63	0.57	0.59	0.03	0.52	0.0001	0.23	0.10	0.64
Iodine value, g/100 g[9]	66.1	65.7	63.5	73.1	71.0	71.8	1.22	0.48	0.01	0.27	0.11	0.79

[1]A total of 1,160 barrows, initial BW 31.0 ± 1.1 kg, were used in a 97-d experiment with 27 to 28 pigs per pen and 7 replications per treatment.
[2]A total of 84 barrows were used for fat sample collection with 2 pigs per pen and 7 replications per treatment.
[3]Total saturated fatty acids = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[4]Total monounsaturated fatty acids = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[5]Total polyunsaturated fatty acids = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[6]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[7]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[8]PUFA:SFA ratio = Total PUFA / Total SFA.
[9]Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Chapter 2 - Effects of Crude Glycerol and Ractopamine HCl on the Growth Performance, Carcass Characteristics, Carcass Fat and Loin Quality of Finishing Pigs

Abstract

A study was conducted to determine the effects of dietary crude glycerol and ractopamine HCl (RAC) on finishing pig performance, carcass characteristics, and loin and fat quality measures. The experiment was conducted at a commercial swine research facility in southwest Minnesota. A total of 1,054 barrows and gilts (initial BW 94.3 kg, PIC) were used in a 28-d study. Pigs were blocked by initial BW and randomly allotted to 1 of 4 dietary treatments with 10 replications per treatment. Pigs were fed corn-soybean meal-based diets arranged in a 2 × 2 factorial with main effects of glycerol (0 or 5%) and RAC (0 or 7.5 ppm). There were no glycerol × RAC interactions ($P > 0.16$) observed for overall growth performance. Feeding glycerol had no effect ($P > 0.36$) on ADG or ADFI but tended to improve ($P = 0.07$) G:F. Feeding RAC increased ($P < 0.01$) ADG and G:F and decreased ($P = 0.05$) ADFI. For carcass characteristics, there were glycerol × RAC interactions ($P = 0.05$) for percentage yield and fat-free lean index (FFLI). Adding RAC to the diet increased yield and FFLI; however, the combination with glycerol reduced yield and FFLI. Pigs fed RAC had increased ($P < 0.04$) hot carcass weight and loin depth and a tendency ($P = 0.09$) for decreased backfat. Feeding RAC did not affect ($P = 0.33$) percentage lean. Feeding dietary glycerol did not affect ($P > 0.27$) carcass characteristics. For loin quality characteristics, there was a glycerol × RAC interaction ($P < 0.01$) observed for loin chop drip loss and for connective tissue amount. These interactions were caused by increased loin chop drip loss and connective tissue amounts when glycerol was added to the diet without RAC, but both numerically decreased when glycerol was fed in combination with RAC. Feeding dietary glycerol did not affect ($P > 0.13$) other loin quality characteristics. Pigs fed RAC tended to have greater ($P < 0.08$) sirloin chop a* value, indicating the loin had more redness, but RAC did not affect ($P > 0.16$) other loin quality characteristics. Feeding dietary RAC or glycerol did not influence ($P > 0.17$) iodine value of belly, jowl, or back fat or fatty acid composition. Pigs fed RAC tended to have increased ($P < 0.07$) total *trans* fatty acids

in jowl fat and backfat while pigs fed crude glycerol tended to have decreased ($P = 0.10$) total *trans* fatty acids in backfat. In conclusion, feeding pigs 5% crude glycerol tended to improve G:F, while pigs fed RAC had improved growth and carcass characteristics and a tendency for improved a* color.
Key Words: finishing pig, glycerol, iodine value, ractopamine HCl, swine

Introduction

Ractopamine HCl (**RAC**;Elanco Animal Health, Indianapolis, IN) is a widely used feed additive fed to finishing pigs before marketing to improve growth rate, G:F, yield, loin depth, and fat free lean index (**FFLI**) (See et al., 2004; Weber et al., 2006; and Webster et al., 2007). However, pigs fed RAC have been shown to have increased levels of PUFA and increased iodine value (**IV**) in carcass fat (Apple et al., 2008).

Crude glycerol is the primary coproduct from the production of biodiesel (Thompson and He, 2006). There are currently 176 biodiesel production facilities operating in the United States producing over 9.88 billion liters of biodiesel (National Biodiesel Board, 2009). This level of production will produce approximately 7.81×10^8 kg of crude glycerol (Thompson and He, 2006) to be included as a potential feedstuff in swine diets. Crude glycerol has been shown to have a minimal impact on growth performance and carcass characteristics (Lammers et al., 2008). However Mourot et al. (1994) reported an increase in the saturation of carcass fat from pigs fed crude glycerol.

Thus, combining RAC, a feed additive that has been shown to worsen carcass fat firmness, with glycerol may provide a means to mitigate this effect prior to slaughter. Glycerol may be a preferred energy source when feeding RAC. Therefore, the objective of this trial was to evaluate the effect of dietary glycerol and ractopamine HCl on finishing pig performance, carcass characteristics, loin quality, and fatty acid composition belly fat, jowl fat, and backfat.

Materials and Methods

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

The trial was conducted at a commercial research facility in southwestern Minnesota. The facility is made up of 4 individual barns, each 12.5 × 76.2 m, with 48, 3.05 × 5.49 m pens with approximately 0.69 m^2 provided per pig. All pens contain 1, 4-hole dry self feeder and 1 cup waterer to allow for *ad-libitum* access to feed and water. Each barn has a deep pit for manure storage with completely slatted floors. They operate on natural ventilation during the summer and mechanically assisted ventilation during the winter. All barns are curtain sided. The experiment was conducted in 1of the barns at the research site in the winter of 2008.

A total of 1,054 pigs (Line 337 × 1050, PIC, Hendersonville, TN) with an initial BW of 94.3 kg were used in a 28-d growth assay. Pigs were randomly allotted to pens, then pens arranged into blocks based on pen weight and then pens of pigs were allotted to 1 of 4 dietary treatments with 10 pens per treatment. Each pen contained 25 to 27 pigs, approximately ½ barrows and ½ gilts.

Pigs were fed corn-soybean meal-based diets (Table 2.1) in meal form. The treatments were arranged in a 2 × 2 factorial with main effects of crude glycerol (0 or 5%) and RAC (0 or 7.5 ppm). A single lot of crude glycerol from a soybean biodiesel production facility (Minnesota Soybean Processors, Brewster, MN) was used in the trial. All experimental diets were balanced to maintain a constant ME; with the control pigs fed 0.70 % standardized ileal digestible (SID) Lys and RAC pigs fed 0.90% SID Lys (Table 2.1). The glycerol ME value used is diet formulation was the NRC (1998) ME value of corn (3,420 kcal/kg). Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to determine the response criteria of ADG, ADFI, and G:F.

At the end of the 28-d experiment, pigs from each pen were individually tattooed with pen number and shipped approximately 96 km to the JBS Swift & Company processing plant (Worthington, MN). Pigs were slaughtered under commercial conditions; carbon dioxide stunning was used. Standard carcass criteria of BW, loin and backfat (**BF**) depth, hot carcass weight (**HCW**), lean percentage, FFLI, and yield were collected. Yield was calculated as HCW divided by BW. Fat depth and loin depth were measured with an optical probe (Fat-O-Meater, SFK Technology A/S, Herlev, Denmark) inserted between the 3rd and 4th rib from the last rib (counting from the ham end of the carcass) and 7 cm from the dorsal midline of the hot carcass. Lean percentage was provided from the packing plant by using a proprietary equation, and the fat-free lean index was calculated according the National Pork Producers Council (2000) procedures.

After exiting the kill floor, carcasses were sent through deep chill chambers (approximately -40^{o}C) for approximately 90 min. After deep chill, carcasses were segregated on an outside rail in a holding cooler. Approximately 2 h after exiting deep chill, the right side jowl was removed with a perpendicular cut flush with the carcass shoulder from 1 randomly selected barrow and gilt from each pen. Backfat and belly samples were collected from the same barrow and gilt. A small (approximately 20 g) sample of backfat was removed from the 10th rib area off the carcass midline. An attempt was made to remove all layers of backfat. The jowl and backfat sample were placed in a vacuum bag, vacuum sealed and stored at approximately 4^{o} C. Then carcasses were allowed to chill overnight. At approximately 18 h post-stick, the bellies were removed and collected from the right side of the carcass. A belly strip (approximately 5 cm wide and 70 cm long) was removed from the scribe side of each belly. Belly strips were vacuum-packaged and stored at 4^{o} C then transported to Kansas State University under chilled conditions. Samples were frozen at -18° C until sample preparation and fatty acid analysis.

Loin Quality

At approximately 18 hours post-stick, a boneless, center-cut loin (NAMP #412B) was removed with minimal fat from the left side of each carcass. Loins were numbered, vacuum packaged, and boxed. Loins were transported and stored at Kansas State University Meat Laboratory at 1 to 2° C. At 10-d postmortem, the loin was evaluated for purge loss, drip loss, visual color, marbling score, and instrumental color according to the procedure of Gipe et al. (2008) in addition, loin chop pH was evaluated at the blade, middle, and sirloin location and instrumental color was evaluated at both the center cut chop and sirloin chop. The Warner-Bratzler Shear Force (**WBSF**) and sensory evaluation were also performed according to the procedure of Gipe et al. (2008).

Fatty Acid Analysis

Fat samples were thawed and dissected to separate adipose tissue from skin and lean tissue. Adipose tissue was sub sampled and ground. Grinding was performed by cutting fat samples into approximately 1 cm^{3} pieces, frozen in a bath of liquid N_2, and ground to very fine particles in a stainless steel grinding tub powered by a Waring Commercial Blender (Dynamics Corporation of America, New Hartford, CT). Ground fat (50µg) was then weighed into screw cap tubes with Teflon lined caps. Fat was combined with 3 mL of methanolic-HCl and 2 mL of

internal standard (2 mg/mL of methyl tridecanoic acid (C13:0) in benzene) and subsequently was heated in a water bath for 135 min at 70°C for transmethylation, while vortexing the tubes at 45 and 90 min. Upon cooling, the addition of 2 mL of benzene and 5 mL of K_2CO_3 allowed the methyl esters to be extracted and transferred to a vial for subsequent quantification of the methylated fatty acids by gas chromatography for fatty acid analysis. From the fatty acid analysis, an IV was calculated from the following equation (AOCS, 1998):
IV=[C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (percentage) of the fatty acid (AOCS, 1998).

Saturated fatty acid percentage was determined by adding the percentage of each individual fatty acid.
Saturated, %= {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0].

The fatty acids results are represented as a percentage of the total fatty acids in the sample.

Statistical Analysis

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC), with pen as the experimental unit. Main effects and interactions between pigs fed crude glycerol and RAC were tested. Statistical significance and tendencies were set at $P < 0.05$ and $P < 0.10$ for all statistical tests, respectively.

Results

From d 0 to 14, there was a glycerol × RAC interaction ($P < 0.01$) for ADG and ADFI and a tendency for a glycerol × RAC interaction ($P = 0.07$) for G:F (Table 2.2). This effect was caused by pigs fed dietary glycerol having numerically decreased ADG, ADFI, and G:F and adding RAC to the control diet having increased ($P < 0.02$) ADG, ADFI, and G:F. When glycerol and RAC was added to the diet in combination; ADG and G:F increased.

From d 14 to 28 there was a glycerol × RAC interaction ($P < 0.03$) observed for ADFI. Adding either RAC or glycerol to the control diet numerically increased ADFI; however, when

added together ADFI decreased. Feeding pigs glycerol or RAC did not influence (P > 0.12) ADG or G:F from d 14 to d 28.

Overall (d 0 to 28), there were no glycerol × RAC interactions ($P > 0.16$) observed for growth performance. Glycerol tended to improve ($P = 0.07$) G:F, but did not influence ($P > 0.36$) ADG or ADFI. Feeding RAC increased ($P < 0.01$) ADG and G:F and decreased ($P = 0.05$) ADFI.

For carcass characteristics, there were glycerol × RAC interactions ($P = 0.05$) for percentage yield and fat-free lean index (FFLI). Adding either RAC or glycerol to the diet increased yield and FFLI; however, the effects were not additive. Feeding dietary glycerol did not affect ($P > 0.27$) other carcass characteristics. Pigs fed RAC had increased ($P < 0.04$) hot carcass weight, yield, loin depth, and FFLI and a tendency ($P = 0.09$) for decreased backfat. Feeding RAC did not affect ($P = 0.33$) percentage lean.

For loin quality characteristics, there was a glycerol × RAC interaction ($P < 0.01$) observed for loin chop drip loss (Table 2.3). This interaction was caused by increased loin chop drip loss percentage when glycerol was added to the diet without RAC, but numerically decreased when glycerol was fed in combination with RAC. There was a tendency for a glycerol × RAC interaction ($P < 0.10$) observed for sirloin chop L* color. When glycerol or RAC was added to the diet individually, the L* value numerically increased; when glycerol and RAC was added in combination, L* value numerically decreased, surpassing the control level. Glycerol did not affect ($P > 0.13$) other loin quality characteristics. Pigs fed RAC tended to have increased ($P < 0.08$) sirloin chop a* color, indicating the loin had more redness when RAC was included in the diet, but did not affect ($P > 0.14$) other loin quality characteristics.

For loin sensory characteristics, there was a glycerol × RAC interaction ($P < 0.01$) observed for connective tissue amount. This interaction was caused by increased connective tissue amount when glycerol was added to the diet without RAC, but numerically decreased when glycerol was fed in combination with RAC. There was a tendency for a glycerol × RAC interaction ($P < 0.09$) observed for pork flavor intensity. When glycerol or RAC was added to the diet individually, the pork flavor intensity numerically decreased; when glycerol and RAC was added in combination, pork flavor intensity numerically returned to the control level. Glycerol and RAC did not affect ($P > 0.37$) other loin sensory characteristics.

Neither RAC nor glycerol influenced ($P > 0.17$) iodine value of belly, jowl, or back fat (Table 2.4, 2.5, 2.6). However, there was a glycerol × RAC interaction ($P < 0.03$) observed for margaric acid and vaccenic acid concentration in belly fat. When glycerol or RAC was added to the diet individually, the margaric acid concentration numerically decreased; when glycerol and RAC was added in combination, margaric acid percentage numerically returned nearly to the control level. The vaccenic acid concentration interaction was caused by increased vaccnic acid percentage when glycerol and RAC was added to the diet individually, but numerically decreased when glycerol was fed in combination with RAC. There was a tendency for a glycerol × RAC interaction ($P < 0.09$) observed for palmitoleic acid and total MUFA concentration in belly fat and myristic acid and arachidic acid concentration in backfat. These interactions were caused by increases in fatty acid concentration when glycerol or RAC was added to the diet individually; however, when glycerol and RAC was added in combination, fatty acid concentration numerically decreased. Pigs fed RAC had increased ($P < 0.02$) vaccenic acid in belly fat and decreased ($P < 0.02$) other fatty acids in backfat. Pigs fed RAC tended to have increased ($P < 0.07$) total *trans* fatty acids in jowl fat and backfat while pigs fed crude glycerol tended to have decreased ($P = 0.10$) total *trans* fatty acids in backfat. In addition, pigs fed RAC had a tendency ($P = 0.10$) for decreased margaric acid in backfat.

Discussion

Feeding pigs crude glycerol and RAC provided a means to evaluate the effects of feeding a widely used feed additive, RAC, and a potentially widely available biofuel coproduct, crude glycerol, in combination. Our results agree with results from previous trials evaluating growth performance of growing and finishing pigs fed crude glycerol in corn-soybean meal diets (Duttlinger et al., 2008; Lammers et al., 2008; Lammers et al, 2009), barley-soybean meal diets (Kijora et al., 1997; Kijora and Kupsch, 2006), and wheat-soybean meal diets (Mourot et al., 1994) that crude glycerol had no effect on ADG and ADFI. However, Schieck et al. (2009) and Stevens et al. (2008) reported an increase in growth rate in finishing pigs fed crude glycerol.

It has been well documented that feeding pigs RAC increases ADG and G:F (Carr et al., 2005a; Webster et al., 2007; and Apple et al., 2008). Our results are consistent with these improvements; however our data showed a decrease in ADFI. Watkins et al. (1990) reported

RAC decreased ADFI in multiple trials where RAC was fed for longer durations, 45 to 50 d. Feeding RAC did not influence ADFI where RAC was fed for 21 to 35 d (Carr et al., 2005a; Apple et al., 2008; and Main et al., 2009).

The improvements in G:F when pigs were fed dietary crude glycerol occurred in the combination with RAC was most dramatic during d 0 to 14. James et al. (2002) evaluated feeding RAC and choice white grease in combination. James et al. (2002) reported an improvement in G:F when RAC and choice white grease were fed separately and an additive response when RAC and choice white grease were fed in combination. Dunshea et al. (1998) reported an increase in ADG and G:F as dietary DE intake increases in the presence of RAC. These trials give rise to the idea that increased dietary energy improves G:F in the presence of RAC. It is hypothesized that crude glycerol is a more available source of energy than corn creating the additive response to G:F in the presence of RAC or the source of glycerol used for this trial contained higher ME levels than expected.

In agreement with other research (Kijora and Kupsch, 2006; Duttlinger et al., 2008; and Lammers et al., 2008), the inclusion of glycerol in the diet did not alter carcass measurements of HCW, percentage yield, BF and loin depth, FFLI, and percentage lean. Feeding RAC is generally thought to repartition nutrients from lipogenesis to increased protein synthesis and accretion, and the majority of literature indicates that feeding RAC effectively improves carcass characteristics (Apple et al., 2008). Therefore, in agreement with our research, Carr et al., (2005b) and Apple et al. (2008) reported the inclusion of RAC improved HCW, percentage yield, and loin depth and decreased backfat.

Our results that feeding pigs crude glycerol did not influence loin quality characteristics agree with results from Gipe et al. (2008). However, Della Casa et al. (2009) reported improvements in color, marbling, buttery flavor, and tenderness in pigs fed glycerol as compared to pigs not fed glycerol, but dietary glycerol did not influence drip loss, cook loss, or WBSF. Mourot et al. (1994) reported a decrease in drip loss in pigs fed glycerol. The effect of dietary crude glycerol on loin quality appears to be variable and the differences that are observed appear to be minimal.

Fernández-Dueñas et al. (2008) reported the inclusion of RAC did not affect the loin quality traits of pH, marbling score, color score, L* and a* color values, cook loss, tenderness, juiciness, and flavor. In contrast to our research, Fernández-Dueñas et al. (2008) reported a

decrease in b* and an increase in WBSF. Carr et al. (2005a) and Carr et al. (2005b) reported a decrease in a* color value and tenderness score and an increase in WBSF due to feeding RAC. Carr et al. (2005a) reported a decrease in drip loss and Carr et al. (2005b) also reported a decrease in b* color value. However, consistent with our trial, no difference was reported for the other loin quality traits evaluated (Carr et al., 2005a and Carr et al., 2005b).

Mourot et al. (1994) observed finishing pigs fed glycerol had decreased linoleic and linolenic acid levels in backfat, resulting in more saturated carcass fat. Schieck et al. (2009) reported that feeding 8% glycerol for the final 8 weeks or duration of a 14 wk trial resulted in a greater degree of belly firmness as compared to bellies from pigs that were not fed crude glycerol. Duttlinger et al. (2008) reported feeding pigs crude glycerol tended to decrease linoleic acid, total polyunsaturated fatty acids, and polyunsaturated:saturated fatty acid ratio; however, there was no change in iodine value. These data demonstrate that feeding crude glycerol does appear to have an effect on increasing the saturation of adipose tissue in pork carcasses; however, the magnitude of increase in saturation appears to be small and difficult to detect by measuring iodine value, the most common method of measuring saturation by commercial processors. Our results did not show a shift in fatty acid profile of pigs fed crude glycerol. A growth assay of 28 days compared to longer growth trials may be one reason why crude glycerol did not affect fat quality in finishing pigs in our trial.

Weber et al. (2006) and Carr et al. (2005b), in agreement with our trial, did not observe a change in iodine value in belly fat and backfat for pigs fed RAC. Furthermore Weber et al. (2006), consistent with our data, did not observe a change in total monounsaturated fatty acid (MUFA), total polyunsaturated fatty acid (PUFA) and linoleic acid of belly fat for pigs fed RAC; however did observe a decrease in steric acid, an increase in arachidonic acid, and a tendency for a decrease in total saturated fatty acid (SFA). Furthermore, Weber et al., (2006) found an increase in iodine value and a tendency for increased total PUFA in the inner-layer backfat. In contrast to our trial, Apple et al., (2008) observed an increase in iodine value, total PUFA, and linoleic acid and a decrease in total SFA and total MUFA of backfat and Carr et al. (2005a) showed more unsaturated bellies through the belly flop test due to feeding RAC. It appears that the research of fat quality in pigs fed RAC is variable; however, it appears that feeding finishing pigs RAC increases the unsaturation of fat as there is an increase in PUFA and a decrease in SFA. This also may be a result of leaner pork carcasses. It has been documented that when lean

percentage increases, saturated fatty acids decrease and unsaturated fatty acids increase, especially linolenic acid (Banon et al., 2000).

In conclusion, feeding pigs 5% crude glycerol improved G:F when fed in combination with RAC. As expected, pigs fed ractopamine HCl had improved growth and carcass characteristics and a tendency for improved sirloin chop a* color. Neither ractopamine HCl nor glycerol influenced iodine value at the locations measured.

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Table 2.1 Diet composition (as-fed basis)[1]

	Ractopamine HCl, ppm			
	0		7.5	
	Crude glycerol, %			
Item	0%	5%	0%	5%
Ingredient, %				
Corn	82.75	77.35	74.79	69.40
Soybean meal, 46.5% CP	15.24	15.64	23.19	23.59
Crude glycerol	---	5.00	---	5.00
Monocalcium P, 21% P	0.48	0.48	0.43	0.45
Limestone	0.90	0.90	0.88	0.85
Salt	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.04	0.04	0.04	0.04
Trace mineral premix[3]	0.05	0.05	0.05	0.05
Phytase[4]	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15	0.15
DL-Met	---	---	0.02	0.02
L-Thr	0.01	0.01	0.03	0.03
Ractopamine HCl, 20 g/kg	---	---	0.04	0.04
Total	100.00	100.00	100.00	100.00
Calculated composition				
Standardized ileal digestible (SID) amino acids, %				
Lys	0.70	0.70	0.90	0.90
Met:Lys	31	31	30	30
Met & Cys:Lys	65	63	61	59
Thr:Lys	64	64	64	64
Trp:Lys	19	19	19	19
CP, %	14.27	14.00	17.32	17.05
Total Lys, %	0.79	0.79	1.01	1.01
ME, kcal/kg	3,353	3,353	3,351	3,351
Lys:ME, g/Mcal	2.09	2.09	2.69	2.69
Ca, %	0.51	0.51	0.51	0.51
P, %	0.44	0.42	0.46	0.45
Available P, %[5]	0.22	0.22	0.22	0.22

[1]Fed from 94.3 to 117.5 kg.
[2]Provided per kilogram of diet: 3,307 IU of vitamin A; 413 IU of vitamin D; 13 IU of vitamin E; 1.3 mg of vitamin K; 0.01 mg of vitamin B_{12}; 15 mg of niacin; 8 mg of pantothenic acid; and 2 mg of riboflavin.
[3]Provided per kilogram of diet: 8.27 mg of Cu from Cu sulfate; 0.149 mg of I from Ca iodate; 83 mg of Fe from Fe sulfate; 19.8 mg of Mn from Mn oxide, 0.149 mg of Se from Na selenite; and 83 mg of Zn from Zn oxide.
[4] OptiPhos 2000 (Phytex LLC, Sheridan, IN).
[5]Includes expected P release of 0.10% from added phytase.

Table 2.2 Influence of crude glycerol and ractopamine HCl (RAC) on finishing pig performance and carcass characteristics[1,2]

RAC, ppm:	0		7.5			Probability, *P* <		
Item Crude glycerol, %:	0%	5%	0%	5%	SEM	RAC × Glycerol	RAC HCl	Glycerol
D 0 to 14								
Initial wt, kg	94.4	94.2	94.2	94.4	0.92	0.85	0.96	0.97
ADG, kg	0.952	0.896	1.074	1.149	0.0271	0.01	0.01	0.71
ADFI, kg	3.099	2.964	2.903	2.968	0.0594	0.01	0.02	0.38
G:F	0.307	0.302	0.369	0.387	0.0059	0.07	0.01	0.29
D 14 to 28								
ADG, kg	0.794	0.857	0.864	0.814	0.0355	0.12	0.70	0.87
ADFI, kg	2.786	2.897	2.859	2.655	0.0715	0.03	0.24	0.52
G:F	0.285	0.295	0.302	0.305	0.0091	0.70	0.12	0.46
D 0 to 28								
ADG, kg	0.877	0.877	0.975	0.990	0.0216	0.70	0.01	0.72
ADFI, kg	2.950	2.931	2.883	2.820	0.0525	0.62	0.05	0.36
G:F	0.297	0.299	0.338	0.351	0.0100	0.16	0.01	0.07
Final wt, kg	116.3	116.2	118.7	119.0	1.19	0.88	0.04	0.91
Hot carcass wt, kg	85.9	87.1	90.5	89.8	0.94	0.31	0.01	0.75
Yield, %	74.63	75.85	76.26	75.91	0.37	0.05	0.04	0.27
Backfat depth, mm	17.95	17.65	16.92	17.58	0.34	0.14	0.09	0.57
Loin depth, mm	57.68	58.64	61.28	61.46	1.01	0.68	0.01	0.54
FFLI, %[3]	49.47	49.67	50.25	49.87	0.14	0.05	0.01	0.53
Lean, %	54.59	54.62	54.99	55.05	0.42	0.96	0.33	0.93

[1]A total of 1,054 pigs, initial BW 94.3 kg, were used in a 28-d experiment with 25 to 27 pigs per pen with 10 pens per treatment.
[2]A total of 854 pigs were marketed on d 28 with 19 to 23 pigs per pen.
[3]Fat-free lean index.

Table 2.3 Influence of crude glycerol and ractopamine HCl (RAC) on loin characteristics[1]

RAC, ppm:	0		7.5			Probability, $P <$		
Item Crude glycerol, %:	0%	5%	0%	5%	SEM	RAC × Glycerol	RAC HCl	Glycerol
Loin chop pH								
Blade	5.89	5.92	5.89	5.85	0.05	0.41	0.41	0.90
Middle	5.70	5.67	5.66	5.67	0.03	0.52	0.60	0.65
Sirloin	5.70	5.71	5.69	5.68	0.02	0.76	0.40	0.93
NPPC marbling score[2]	1.50	1.70	1.45	1.42	0.12	0.33	0.17	0.48
NPPC color score[3]	3.1	3.13	3.15	3.36	0.09	0.34	0.14	0.22
Instrumental color								
Center cut chop color								
L*[4]	55.45	56.03	55.54	54.54	0.62	0.15	0.20	0.70
a*[5]	9.54	9.73	10.20	9.66	0.34	0.28	0.37	0.60
b*[6]	14.41	14.56	14.72	14.16	0.39	0.38	0.90	0.62
Sirloin chop color								
L*	58.78	59.51	59.29	58.10	0.56	0.10	0.43	0.68
a*	9.32	9.04	9.78	9.71	0.31	0.74	0.08	0.59
b*	14.59	14.69	14.84	14.44	0.38	0.51	0.99	0.69
Purge loss, %	1.34	1.49	1.59	1.44	0.20	0.65	0.46	0.77
Drip loss, %	1.89	2.61	2.47	2.03	0.18	0.01	0.99	0.45
Cooking loss, %	25.63	24.65	25.20	24.13	0.66	0.95	0.47	0.13
WBSF, kg[7]	3.95	3.81	3.67	3.92	0.24	0.41	0.74	0.81
Sensory traits								
Myofibrillar tenderness[8]	5.6	5.8	5.7	5.6	0.16	0.23	0.94	0.74
Connective tissue amount[9]	7.2	7.4	7.5	7.3	0.08	0.01	0.37	0.76
Overall tenderness[8]	5.8	6.1	6.1	5.9	0.15	0.15	0.89	0.73
Juiciness[10]	5.1	5.0	5.0	5.2	0.13	0.21	0.62	0.83
Pork flavor intensity[11]	5.4	5.3	5.3	5.4	0.09	0.09	0.64	0.86
Off-flavor intensity[9]	7.4	7.5	7.5	7.6	0.09	0.89	0.16	0.20

[1]A total of 80 loins were used in the experiment with 2 loins per pen and 10 pens per treatment. Values are the mean of 1 gilt and 1 barrow per pen (10 barrows and 10 gilts per treatment).

[2]Visual scale, which approximates the percentage of intramuscular fat content (NPPC, 1999).

[3]1 = pale pinkish gray to white, 2 = grayish pink, 3 = reddish pink, 4 = dark reddish pink, 5 = purplish red, 6 = dark purplish red (NPPC, 1999).

[4]0 = black, 100 = white.
[5]Positive = reddness, negative = greenness.
[6]Positive = yellowness, negative = blueness.
[7]Warner-Bratzler Sheer Force.
[8]1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, 8 = extremely tender.
[9]1 = abundant, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate, 5 = slight, 6 = traces, 7 = practically none, 8 = none.
[10]1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, 8 = extremely juicy.
[11]1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, 8 = extremely intense.

Table 2.4 Influence of glycerol and ractopamine HCl (RAC) on finishing pig jowl fat quality[1,2]

RAC, ppm:	0		7.5			Probability, $P <$		
Item Crude glycerol, %:	0%	5%	0%	5%	SEM	RAC × Glycerol	RAC HCl	Glycerol
Myristic acid (14:0), %	1.35	1.38	1.39	1.34	0.03	0.18	0.82	0.76
Palmitic acid (16:0), %	21.90	22.00	21.89	21.52	0.25	0.36	0.33	0.58
Palmitoleic acid (16:1), %	2.73	2.76	2.87	2.72	0.08	0.26	0.57	0.49
Margaric acid (17:0), %	0.48	0.51	0.48	0.49	0.02	0.65	0.62	0.24
Stearic acid (18:0), %	9.24	9.48	9.08	9.08	0.22	0.57	0.22	0.59
Oleic acid (18:1c9), %	41.98	41.96	41.86	41.89	0.30	0.94	0.75	0.99
Vaccenic acid (18:1n7), %	3.64	3.74	3.79	3.63	0.12	0.11	0.78	0.68
Linoleic acid (18:2n6), %	14.38	13.97	14.37	15.03	0.40	0.19	0.20	0.75
α-linolenic acid (18:3n3), %	0.62	0.60	0.62	0.64	0.02	0.28	0.15	0.93
γ-linolenic acid (18:3n6), %	0.62	0.60	0.62	0.64	0.02	0.28	0.15	0.93
Arachidic acid (20:0), %	0.20	0.20	0.20	0.18	0.01	0.29	0.15	0.66
Eicosadienoic acid (20:2), %	0.85	0.83	0.86	0.88	0.02	0.47	0.20	0.89
Arachidonic acid (20:4n6), %	0.11	0.10	0.11	0.11	0.01	1.00	0.29	0.35
Other fatty acids, %	2.45	2.39	2.40	2.43	0.05	0.32	0.97	0.74
Total SFA, %[3]	33.57	33.99	33.44	33.03	0.43	0.34	0.21	1.00
Total MUFA, %[4]	50.03	50.11	50.16	49.87	0.35	0.61	0.88	0.76
Total PUFA, %[5]	16.39	15.91	16.40	17.10	0.44	0.18	0.18	0.80
Total *trans* fatty acids, %[6]	41.03	40.95	42.16	42.81	0.80	0.65	0.07	0.73
UFA:SFA ratio[7]	1.98	1.95	1.99	2.03	0.04	0.33	0.21	0.98
PUFA:SFA ratio[8]	0.49	0.47	0.49	0.52	0.02	0.21	0.18	0.81
Iodine value, g/100 g[9]	69.6	68.9	69.7	70.7	0.7	0.22	0.17	0.87

[1]A total of 1,054 pigs, initial BW 94.3 kg, were used in a 28-d experiment with 25 to 27 pigs per pen with 10 pens per treatment.

[2]A total of 854 pigs were marketed on d 28 with 19 to 23 pigs per pen and 10 pens per treatment. Values are the mean of 1 gilt and 1 barrow per pen (10 barrows and 10 gilts per treatment).

[3]Total SFA = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[4]Total MUFA = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[5]Total PUFA = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.

[6]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[7]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[8]PUFA:SFA ratio = Total PUFA / Total SFA.

[9]Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 2.5 Influence of glycerol and ractopamine HCl (RAC) on finishing pig belly fat quality[1,2]

RAC, ppm:	0		7.5			Probability, *P* <		
Item Crude glycerol, %:	0%	5%	0%	5%	SEM	RAC × Glycerol	RAC HCl	Glycerol
Myristic acid (14:0), %	1.29	1.30	1.32	1.30	0.04	0.65	0.82	0.89
Palmitic acid (16:0), %	22.73	22.16	22.53	22.26	0.50	0.72	0.90	0.33
Palmitoleic acid (16:1), %	1.99	2.27	2.30	2.24	0.11	0.07	0.14	0.22
Margaric acid (17:0), %	0.61	0.55	0.46	0.58	0.04	0.03	0.10	0.35
Stearic acid (18:0), %	11.45	10.43	10.47	10.74	0.58	0.20	0.49	0.45
Oleic acid (18:1c9), %	38.63	39.63	39.60	39.24	0.65	0.22	0.58	0.55
Vaccenic acid (18:1n7), %	2.70	3.11	3.18	3.04	0.14	0.01	0.02	0.11
Linoleic acid (18:2n6), %	16.29	16.27	15.99	16.35	0.80	0.78	0.88	0.80
α-linolenic acid (18:3n3), %	0.67	0.68	0.66	0.66	0.03	0.91	0.65	0.95
γ-linolenic acid (18:3n6), %	0.67	0.68	0.66	0.66	0.03	0.91	0.65	0.95
Arachidic acid (20:0), %	0.26	0.23	0.23	0.22	0.02	0.70	0.19	0.22
Eicosadienoic acid (20:2), %	0.88	0.89	0.87	0.90	0.04	0.87	0.98	0.61
Arachidonic acid (20:4n6), %	0.10	0.09	0.11	0.11	0.02	0.80	0.33	0.63
Other fatty acids, %	2.29	2.31	2.29	2.31	0.06	0.90	0.96	0.58
Total SFA, %[3]	36.72	35.11	35.40	35.49	1.05	0.34	0.60	0.40
Total MUFA, %[4]	44.85	46.56	46.59	46.06	0.77	0.07	0.29	0.32
Total PUFA, %[5]	18.34	18.34	18.00	18.45	0.86	0.76	0.88	0.76
Total *trans* fatty acids, %[6]	44.56	45.13	48.01	44.94	1.67	0.21	0.26	0.38
UFA:SFA ratio[7]	1.73	1.85	1.83	1.83	0.08	0.37	0.60	0.39
PUFA:SFA ratio[8]	0.50	0.53	0.51	0.52	0.04	0.84	0.97	0.57
Iodine value, g/100 g[9]	68.6	70.0	69.6	69.7	1.49	0.62	0.80	0.54

[1]A total of 1,054 pigs, initial BW 94.3 kg, were used in a 28-d experiment with 25 to 27 pigs per pen with 10 pens per treatment.

[2]A total of 854 pigs were marketed on d 28 with 19 to 23 pigs per pen and 10 pens per treatment. Values are the mean of 1 gilt and 1 barrow per pen (10 barrows and 10 gilts per treatment).

[3]Total SFA = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.

[4]Total MUFA = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.

[5]Total PUFA = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.

[6]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.

[7]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.

[8]PUFA:SFA ratio = Total PUFA / Total SFA.

[9]Calculated as IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Table 2.6 Influence of glycerol and ractopamine HCl (RAC) on finishing pig backfat quality[1,2]

RAC, ppm:	0		7.5			Probability, *P* <		
Item Crude glycerol, %:	0%	5%	0%	5%	SEM	RAC × Glycerol	RAC HCl	Glycerol
Myristic acid (14:0), %	1.30	1.37	1.35	1.31	0.03	0.09	0.83	0.67
Palmitic acid (16:0), %	22.83	23.21	23.31	23.08	0.28	0.28	0.52	0.79
Palmitoleic acid (16:1), %	2.08	2.22	2.25	2.11	0.10	0.12	0.75	0.94
Margaric acid (17:0), %	0.60	0.59	0.56	0.58	0.03	0.57	0.30	0.92
Stearic acid (18:0), %	11.36	11.56	11.44	11.71	0.27	0.91	0.68	0.40
Oleic acid (18:1c9), %	38.05	38.05	38.24	38.04	0.33	0.77	0.79	0.76
Vaccenic acid (18:1n7), %	2.85	2.95	2.99	2.86	0.13	0.17	0.79	0.83
Linoleic acid (18:2n6), %	16.73	15.97	15.85	16.37	0.43	0.14	0.58	0.79
α-linolenic acid (18:3n3), %	0.68	0.66	0.64	0.66	0.02	0.35	0.35	0.85
γ-linolenic acid (18:3n6), %	0.68	0.66	0.64	0.66	0.02	0.35	0.35	0.85
Arachidic acid (20:0), %	0.24	0.26	0.24	0.22	0.01	0.09	0.11	0.83
Eicosadienoic acid (20:2), %	0.84	0.79	0.81	0.80	0.02	0.51	0.68	0.13
Arachidonic acid (20:4n6), %	0.11	0.09	0.10	0.09	0.01	0.51	0.29	0.12
Other fatty acids, %	2.26	2.20	2.16	2.11	0.04	0.89	0.02	0.16
Total SFA, %[3]	36.75	37.45	37.30	37.27	0.48	0.45	0.69	0.48
Total MUFA, %[4]	44.49	44.64	44.94	44.41	0.42	0.43	0.80	0.67
Total PUFA, %[5]	18.76	17.91	17.77	18.32	0.46	0.14	0.53	0.74
Total *trans* fatty acids, %[6]	42.45	41.90	44.43	42.59	0.69	0.36	0.06	0.10
UFA:SFA ratio[7]	1.73	1.67	1.68	1.69	0.03	0.41	0.70	0.48
PUFA:SFA ratio[8]	0.51	0.48	0.48	0.49	0.02	0.17	0.54	0.66
Iodine value, g/100 g[9]	69.0	67.8	67.8	68.3	0.70	0.23	0.61	0.64

[1]A total of 1,054 pigs, initial BW 94.3 kg, were used in a 28-d experiment with 25 to 27 pigs per pen with 10 pens per treatment.
[2]A total of 854 pigs were marketed on d 28 with 19 to 23 pigs per pen and 10 pens per treatment. Values are the mean of 1 gilt and 1 barrow per pen (10 barrows and 10 gilts per treatment).
[3]Total SFA = {[C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]}, where the brackets indicate concentration.
[4]Total MUFA = {[C14:1] + [C16:1] + [C18:1c9] + [C18:1n7] + [C20:1] + [C24:1]}, where the brackets indicate concentration.
[5]Total PUFA = {[C18:2n6] + [C18:3n3] + [C18:3n6] + [C20:2] + [C20:4n6]}, where the brackets indicate concentration.
[6]Total *trans* fatty acids = {[C18:1t] + [C18:2t] + [C18:3t]}, where the brackets indicate concentration.
[7]UFA:SFA ratio = [Total MUFA + Total PUFA] / Total SFA.
[8]PUFA:SFA ratio = Total PUFA / Total SFA.
[9]Calculated as IV= [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 +[C18:3] × 2.616 + [C20:1] × 0.785+[C22:1] × 0.723, where the brackets indicate concentration (AOCS, 1998).

Chapter 3 - Determination of the Limiting Amino Acids in Growing and Finishing Diets Containing NutriDense Corn

Abstract

Two, 28-d studies were conducted to determine the fourth-limiting AA in finishing diets containing NutriDense corn. A total of 1,134, (initial BW 37.2 kg), and 1,090 (initial BW 77.3 kg) pigs were used in Exp. 1 and 2, respectively. Pigs were blocked by BW and randomly allotted to 1 of 6 diets with 7 replications in each experiment. Dietary standardized ileal digestible (SID) lysine was 0.91% in Exp. 1 and 0.72% in Exp. 2. Treatments were 1) positive control containing 0.15% L-Lys HCl; 2) negative control with 0.45% L-Lys HCl, 0.085% DL-Met, and 0.15% L-Thr; 3) diet 2 with 0.05% L-Ile; 4) diet 2 with 0.05% L-Val; 5) diet 2 with 0.05% L-Trp and 6) diet 2 with 0.05% L-Ile, 0.05% L-Val, and 0.05% L-Trp. Pigs fed the positive control and the diet with the combination of added Ile, Trp, and Val had greater ADG ($P < 0.05$) than all other treatments. Pigs fed added Ile or Trp had greater ADG ($P < 0.05$) than pigs fed the negative control. Pigs fed the combination of added Ile, Trp, and Val had greater ADFI ($P < 0.05$) then pigs fed the negative control. There were no differences ($P > 0.05$) in G:F. In Exp. 2, pigs fed the positive control, added Trp, or the combination of added Ile, Trp and Val had greater ($P < 0.05$) ADG then pigs fed the negative control or pigs fed either Ile or Val. Pigs fed the positive control had greater ($P < 0.05$) G:F then pigs fed all other diets. Pigs fed the combination of added Ile, Trp, and Val had greater ($P < 0.05$) G:F compared to pigs fed the negative control or added Val. These results suggest that in diets containing NutriDense corn, Trp and Ile are the co-fourth limiting AA for 36 to 59 kg pigs, while Trp is fourth limiting for 77 to 100 kg pigs.

Key Words: amino acids, corn, growth, NutriDense, swine

Introduction

NutriDense corn (Exseed Genetics LLC, BASF Plant Science, Research Triangle Park, NC) is a commercially available hybrid that has been genetically engineered to contain greater amounts of oil and AA than yellow dent corn. Specifically, it contains greater concentrations of Lys, TSAA, Thr, and Trp compared with yellow dent corn (Hastad et al., 2005 Pedersen et al.,

2007). Furthermore, Pedersen et al. (2007) observed greater standardized ileal digestibility (**SID**) coefficients for Arg, Lys, and Met in NutriDense corn than yellow dent corn. Hastad et al. (2006) concluded that there is a greater concentration of AA in NutriDense corn compared with yellow dent corn. In their study, as dietary L-Lys HCl, L-Thr, and DL-Met concentrations increased as a replacement for soybean meal, ADG and G:F worsened at an accelerated rate in yellow dent corn compared with NutriDense corn. They speculated NutriDense corn contains greater amounts of other AA, specifically Trp, and assumed it was the 4th limiting AA.

From an energy concentration standpoint, ether extract and GE in NutriDense corn is greater than yellow dent corn; however apparent total tract digestibility was not different between NutriDense and yellow dent corn (Pedersen et al., 2007). Hastad et al. (2005) confirmed the greater ME content of NutriDense corn in 15 kg pigs (4.5%) and 50 kg finishing pigs (5.3%) than in yellow dent corn.

In order to formulate diets using the highest levels of L-Lys HCl, L-Thr and DL-Met, the 4th limiting AA in NutriDense corn must be determined. Therefore, the objective of these studies was to determine the 4th limiting amino acid in diets containing NutriDense corn and to evaluate whether pig performance could be maintained with the inclusion of high levels of synthetic amino acids in diets containing NutriDense corn.

Materials and Methods

General

The experimental protocol used in these experiments was approved by the Kansas State University Animal Care and Use Committee. The two experiments were conducted at a commercial research facility in southwestern Minnesota. The facility is made up of four individual barns, each 12.5 × 76.2 m, with 48, 3.05 × 5.49 m pens with approximately 0.69 m^2 provided per pig. All pens contain 1, 4-hole dry self feeder and 1 cup waterer to allow for *ad-libitum* access to feed and water. Each barn has a deep pit for manure storage with completely slatted floors. They operate on natural ventilation during the summer and mechanically assisted ventilation during the winter. All barns are curtain sided.

In both studies, pigs (Line 337 × 1050, PIC, Hendersonville, TN) were randomly allotted to pens then pens of pigs were blocked to 1 of 6 dietary treatments with 7 pens per treatment. Samples of ND corn were collected and analyzed for GE, DM, EE, CP, Crude fiber, Ca, P, and

AA (AOAC, 1995; Table 3.1) and the values used in diet formulation. All dietary treatments were formulated using analyzed values for NutriDense corn with SID coefficients provided by the NRC (1998) for yellow dent corn. Pigs and feeders were weighed on d 0, 14, and 28 to determine the response criteria of ADG, ADFI, and G:F. All pigs were fed meal diets containing NutriDense or yellow dent corn ground with a roller mill to approximately 600 μm. A single lot (140,000 kg) of NutriDense corn was stored and used in both trials.

Experiment 1

A total of 1,134 pigs with an initial BW of 37.2 kg were used in a 28-d growth assay. Each pen contained 26 to 28 pigs with an equal distribution of barrows and gilts in each pen with 7 replicate pens per experimental diet.

Pigs were fed NutriDense corn-soybean meal-based diets (Table 3.2). Diets were formulated to 0.91% SID Lys. This level of Lys was calculated to be slightly deficient for these pigs in this commercial facility (Main et al., 2008). The treatments were: 1) a positive control diet containing 0.15% added L-Lys HCl and 0.015% added L-Thr; 2) a negative control diet with 0.45% added L-Lys HCl, 0.085% added DL-Met, and 0.15% added L-Thr; 3) treatment 2 with 0.05% added L-Ile; 4) treatment 2 with 0.05% added L-Val; 5) treatment 2 with 0.05% added L-Trp; and 6) treatment 2 with a combination of 0.05% added L-Ile, 0.05% L-Trp, and L-Val, 0.05%. All experimental diets were balanced to the same SID Lys:ME ratio and available P level. The ME value for NutriDense (3,591 kcal/kg) was assumed to be 5% greater than the ME value of yellow dent (3,420 kcal/kg) provided by the NRC (1998), as reported by Hastad et al. (2005).

Experiment 2

A total of 1,090 pigs with an initial BW of 77.3 kg were used in a 28-d growth assay. Each pen contained 23 to 25 pigs with an equal distribution of barrows and gilts in each pen with 7 replicate pens per experimental diet.

Experimental diets (Table 3.3) were based on the same formulation concept as Exp. 1. The treatments were: 1) a positive control diet containing 0.15% added L-Lys HCl and 0.02% added L-Thr; 2) a negative control diet containing 0.40% added L-Lys HCl, 0.03% added DL-Met, and 0.13% added L-Thr; 3) treatment 2 with 0.05% added L-Ile; 4) treatment 2 with 0.05% added L-Val; 5) treatment 2 with 0.05% added L-Trp; 6) treatment 2 with a combination of

0.05% added L-Ile, 0.05% L-Trp and 0.05% L-Val. All other procedures were identical to Exp. 1.

Statistical Analysis

Data from both experiments were analyzed as a randomized complete-block design using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC), with pen as the experimental unit. Pens were blocked based on average initial pen weight. Means were separated using the LSMeans statement in SAS. Probability values ≤ 0.10 and ≥ 0.06 were considered trends, whereas $P \leq 0.05$ was considered significant.

Results

Experiment 1

Overall (d 0 to 28), pigs fed the positive control diet and the diet with the combination of added Ile, Trp, and Val had greater ADG ($P < 0.05$) than pigs fed all other treatments (Table 3.4). Pigs fed added Ile or Trp had greater ADG ($P < 0.05$) then pigs fed the negative control diet with those fed added Val being intermediate. Also, pigs fed the combination of added Ile, Trp, and Val had greater ADFI ($P < 0.05$) then pigs fed the negative control diet with those fed the other dietary treatments intermediate. There were no significant differences in G:F ($P > 0.05$) but with numerical differences following the ADG response. Final weight reflected the differences in ADG with pigs fed the positive control diet or the diet with the combination of added Ile, Trp, and Val being heavier ($P < 0.05$) than those fed the negative control diet with those fed the other treatments being intermediate.

Experiment 2

Overall (d 0 to 28), pigs fed the positive control diet, added Trp, or the combination of added Ile, Trp and Val had greater ($P < 0.05$) ADG than pigs fed the negative control or pigs fed either Ile or Val (Table 3.5). There were no differences observed in ADFI ($P > 0.05$). Pigs fed the positive control diet had greater ($P < 0.05$) G:F than pigs fed all other diets. Pigs fed the combination of added Ile, Trp, and Val had greater ($P < 0.05$) G:F compared to pigs fed the negative control or added Val with those fed the diet with added Trp also having greater ($P < 0.05$) G:F than pigs fed the negative control. Pigs fed the positive control diet had greater ($P <$

0.05) final BW then pigs fed diets with added Val with pigs fed the other diets being intermediate.

Discussion

Hastad et al. (2006) speculated that Trp was the fourth limiting AA in diets containing NutriDense corn as trials were performed to evaluate the effects of high levels of crystalline Lys, Thr, and Met additions. Performance worsened as L-Lys HCl concentration increased while DL-Met and L-Thr were added to the diet to maintain the minimum AA ratios. For those AA, this gives rise to another AA is limiting in diets containing NutriDense corn. These trials conducted herein expand on Hastad et al. (2006) trials to determining the 4th limiting AA in diets containing NutriDense corn.

In Exp. 1, the negative control diet was calculated to be deficient in Trp (14% of Lys), and marginally deficient in Ile (51% of Lys) and Val (63% of Lys) as the recommended SID AA ratios for Trp, Ile, and Val for growing and finishing pigs are 17, 51 and 64% relative to Lys, respectively (NRC, 2008). Adding Trp or Ile to the diet increased ADG to a similar extent with only a minor numerical increase in ADG with the addition of Val. Adding all three AA together allowed performance to return to the level achieved by the positive control diet. Therefore for this weight range of pig (37 to 59 kg), these data suggest that Trp and Ile are the co-4th limiting AA for diets containing NutriDense corn as a response was found to either amino acid added separately and when added in combination performance returned to that of the positive control. Russell et al., (1983) reported that adding Trp to a corn-based diet supplemented with Lys, Met, and Thr increased growth performance in the growing pig. Furthermore, high levels of synthetic AA (0.45% L-Lys HCl with other AA) can be added to diets formulated with NutriDense corn for grower pigs without sacrificing performance as long as minimum AA ratios are maintained.

As SID Lys levels were lowered in Exp. 2 to match the AA requirements, more NutriDense corn and less soybean meal was used in the diets. Thus, the ratios of AA also changed. The negative control diet for Exp. 2 were calculated to be most deficient in Trp (12.5% of Lys), deficient in Ile (51% of Lys), and adequate in Val (66% of Lys), consequently a Val response was not expected. Adding Trp to the negative control diet resulted in the greatest improvement in ADG and G:F with the addition of Ile providing a small benefit over the negative control. Adding Val to the diet did not influence performance. Adding all three AA

provided only a small benefit over the addition of Trp alone and was not successful in returning G:F back to the level achieved by the positive control diet. Therefore for this weight range of pig (initial BW 77.3 kg), these data suggest that Trp is the 4th limiting AA for diets containing NutriDense corn.

The lack of completely returning performance of the Trp supplemented treatments diets does not appear to be because of a Trp, Ile, or Val deficiency. These results are similar to Gaines et al. (2005) where additions of high levels (0.40% in this experiment and greater than 0.50% in the trial by Gaines et al. (2005) of L-Lys HCl with L-Thr, DL-Met or methionine hydroxy analog, L-Trp, L-Ile, and L-Val were not able to equal the performance of finishing pigs fed diets with lower levels of synthetic amino acids. When more than 0.15% L-Lys HCl is added to a yellow dent corn-soybean meal diet without the supplementation of additional AA, deficiencies of other AA limit growth performance (De la Llata et al., 2002). However, the results in this trial indicate that the use of NutriDense corn allows performance to be returned closer to the performance of the control pigs than previous research with yellow dent corn.

In conclusion, these results suggest that in the 37 to 59 kg growing pig, Trp and Ile are the co-limiting 4th amino acid in diets containing ND corn. In 77 to 100 kg pigs, Trp appears to be the 4th limiting amino acid followed by Ile.

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Table 3.1 Analyzed chemical composition of NutriDense corn source used in diet formulation[1]

Item	NutriDense Corn
DM, %	86.36
EE, %	6.16
CP, %	7.98
GE, kcal/kg	3,773
Crude fiber, %	3.06
Ca, %	0.01
P, %	0.32
AA,%	
Lys	0.30
Cys	0.20
Ile	0.29
Leu	0.97
Met	0.20
Trp	0.07
Thr	0.30
Val	0.42

[1]Nutrient values are reported on an as-fed basis and represent the mean of 2 samples analyzed in duplicate of NutriDense corn. (ExSeed Genetics, LLC, BASF Plant Science, Research Triangle Park, NC).

Table 3.2 Diet composition (Exp. 1; as-fed basis)

Item	Positive Control	Negative Control	Added Ile	Added Val	Added Trp	Added Ile, Val and Trp
Ingredient, %						
Nutridense corn	75.02	83.90	83.85	83.85	83.85	83.75
Soybean meal, 46.5% CP	22.70	13.25	13.25	13.25	13.25	13.25
Monocalcium P, 21% P	0.65	0.70	0.70	0.70	0.70	0.70
Limestone	0.90	0.90	0.90	0.90	0.90	0.90
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[1]	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[2]	0.10	0.10	0.10	0.10	0.10	0.10
Phytase[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.45	0.45	0.45	0.45	0.45
DL-Met	---	0.09	0.09	0.09	0.09	0.09
L-Thr	0.02	0.15	0.15	0.15	0.15	0.15
L-Trp	---	---	---	---	0.05	0.05
L-Ile	---	---	0.05	---	---	0.05
L-Val	---	---	---	0.05	---	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible (SID) amino acids, %[4]						
Lys	0.91	0.91	0.91	0.91	0.91	0.91
Ile:Lys	69	51	57	51	51	57
Leu:Lys	154	129	129	129	129	129
Met:Lys	30	34	34	34	34	34
Met & Cys:Lys	60	60	60	60	60	59
Thr:Lys	62	62	62	62	62	62
Trp:Lys	19	14	14	14	19	19
Val:Lys	80	63	63	68	63	68
Lys:ME, g/Mcal	2.62	2.61	2.61	2.61	2.61	2.61
ME, kcal/kg	3,470	3,492	3,490	3,490	3,492	3,490
Total Lys, %	1.03	1.01	1.01	1.01	1.01	1.01
CP, %	16.8	13.5	13.5	13.5	13.6	13.6
Ca, %	0.55	0.52	0.52	0.52	0.52	0.52
P, %	0.53	0.51	0.51	0.51	0.51	0.51
Available P, %[5]	0.25	0.26	0.26	0.26	0.26	0.26

[1]Provided per kilogram of diet: 6,614 IU of vitamin A; 827 IU of vitamin D; 26 IU of vitamin E; 2.6 mg of vitamin K; 0.02 mg of vitamin B_{12}; 30 mg of niacin; 17 mg of pantothenic acid; and 5 mg of riboflavin.
[2]Provided per kilogram of diet: 16.53 mg of Cu from Cu sulfate; 0.298 mg of I from Ca iodate; 165 mg of Fe from Fe sulfate; 39.7 mg of Mn from Mn oxide, 0.298 mg of Se from Na selenite; and 165 mg of Zn from Zn oxide.
[3] OptiPhos 2000 (Phytex LLC, Sheridan, IN).
[4]Calculated SID values were derived by multiplying analyzed amino acid values by NRC (1998) SID values for corn.
[5]Includes expected P release of 0.10% from added phytase.

Table 3.3 Diet composition (Exp. 2; as-fed basis)

Item	Positive Control	Negative Control	Added Ile	Added Val	Added Trp	Added Ile, Val and Trp
Ingredient, %						
Nutridense corn	82.95	90.31	90.26	90.26	90.26	90.16
Soybean meal, 46.5% CP	15.00	7.15	7.15	7.15	7.15	7.15
Monocalcium P, 21% P	0.45	0.50	0.50	0.50	0.50	0.50
Limestone	0.95	1.00	1.00	1.00	1.00	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[1]	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix[2]	0.05	0.05	0.05	0.05	0.05	0.05
Phytase[3]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.15	0.40	0.40	0.40	0.40	0.40
DL-Met	---	0.03	0.03	0.03	0.03	0.03
L-Thr	0.02	0.13	0.13	0.13	0.13	0.13
L-Trp	---	---	---	---	0.05	0.05
L-Ile	---	---	0.05	---	---	0.05
L-Val	---	---	---	0.05	---	0.05
Total	100	100	100	100	100	100
Calculated composition						
Standardized ileal digestible (SID) amino acids, %[4]						
Lys	0.72	0.72	0.72	0.72	0.72	0.72
Ile:Lys	69	51	58	51	51	58
Leu:Lys	170	144	144	144	144	144
Met:Lys	33	32	32	32	32	32
Met & Cys:Lys	66	60	60	60	60	60
Thr:Lys	65	65	65	65	65	65
Trp:Lys	18	12.7	12.7	12.7	19	19
Val:Lys	84	66	66	73	66	72
Lys:ME, g/Mcal	2.06	2.05	2.05	2.05	2.05	2.05
ME, kcal/kg	3,494	3,510	3,508	3,508	3,512	3,508
Total Lys, %	0.82	0.80	0.80	0.80	0.80	0.80
CP, %	13.8	11.1	11.1	11.1	11.2	11.2
Ca, %	0.5	0.51	0.51	0.51	0.51	0.51
P, %	0.46	0.44	0.44	0.44	0.44	0.44
Available P, %[5]	0.21	0.21	0.21	0.21	0.21	0.21

[1]Provided per kilogram of diet: 4,409 IU of vitamin A; 551 IU of vitamin D; 18 IU of vitamin E; 1.8 mg of vitamin K; 0.02 mg of vitamin B_{12}; 20 mg of niacin; 11 mg of pantothenic acid; and 3 mg of riboflavin.
[2]Provided per kilogram of diet: 8.27 mg of Cu from Cu sulfate; 0.149 mg of I from Ca iodate; 83 mg of Fe from Fe sulfate; 19.8 mg of Mn from Mn oxide, 0.149 mg of Se from Na selenite; and 83 mg of Zn from Zn oxide.
[3] OptiPhos 2000 (Phytex LLC, Sheridan, IN).[4]Calculated SID values were derived by multiplying analyzed amino acid values by NRC (1998) SID values for corn.
[5]Includes expected P release of 0.10% from added phytase.

Table 3.4 Determination of the fourth-limiting amino acid in swine diets containing NutriDense corn (Exp. 1)[1]

Item	Positive Control	Negative Control	Added Ile	Added Val	Added Trp	Added Ile, Val and Trp	SEM
D 0 to 28							
ADG, kg	0.87[a]	0.77[c]	0.82[b]	0.80[bc]	0.82[b]	0.87[a]	0.016
ADFI, kg	2.26[ab]	2.10[b]	2.21[ab]	2.12[ab]	2.18[ab]	2.29[a]	0.059
G:F, kg/kg	0.39	0.37	0.37	0.38	0.38	0.38	0.010
Final wt, kg	61.9[a]	59.1[b]	60.4[ab]	59.6[ab]	60.1[ab]	61.7[a]	0.83

[1]A total of 1,134 pigs, initial BW 37.2 kg, were used in a 28-d experiment. Experimental diets were formulated to contain 0.91% SID Lys using either 0.15% added L-lys HCl (Control), 0.45% added L-lys HCl (Negative Control), 0.45% added L-lys HCl + 0.05% added L-Ile (NC + Ile), 0.45% added L-
Lys HCl + 0.05% added L-Val (NC + Val), 0.45% added L-Lys HCl + 0.05% L-Trp (NC + Trp), or 0.45% added L-Lys HCl + 0.05% added L-Ile + 0.05% added L-Val + 0.05% added L-Trp (NC + Ile + Val + Trp).

[abc]Means within a row containing different superscripts are different ($P < 0.05$).

Table 3.5 Determination of the fourth-limiting amino acid in swine diets containing NutriDense corn (Exp. 2)[1]

Item	Positive Control	Negative Control	Added Ile	Added Val	Added Trp	Added Ile, Val and Trp	SEM
D 0 to 28							
ADG, kg	0.88[a]	0.74[b]	0.78[b]	0.75[b]	0.84[a]	0.85[a]	0.017
ADFI, kg	2.65	2.63	2.67	2.61	2.72	2.74	0.049
G:F, kg/kg	0.33[a]	0.28[d]	0.29[bcd]	0.29[cd]	0.31[bc]	0.31[b]	0.007
Final wt, kg	102.5[a]	99.2[ab]	99.2[ab]	98.2[b]	100.7[ab]	101.7[ab]	1.24

[1]A total of 1,090 pigs, initial BW 77.3kg, were used in a 28-d experiment. Experimental diets were formulated to contain 0.72% SID Lys using either 0.15% added L-Lys HCl (Control), 0.40% added L-Lys HCl (Negative Control), 0.40% added L-Lys HCl + 0.05% added L-Ile (NC + Ile), 0.40% added L-Lys HCl + 0.05% added L-Val (NC + Val), 0.40% added L-Lys HCl + 0.05% L-Trp (NC + Trp), or 0.40% added L-Lys HCl + 0.05% added L-Ile + 0.05% added L-Val + 0.05% added L-Trp (NC + Ile + Val + Trp).

[abcd]Means within a row containing different superscripts are different ($P < 0.05$).

Chapter 4 - Effects of Feeder Adjustment on Growth Performance of Growing-Finishing Pigs

Abstract

Two studies were conducted to determine the effects of different feeder settings on growth performance of growing and finishing pigs and whether diet composition influenced the optimal feeder setting. Both experiments were conducted at a commercial swine research facility in southwest Minnesota. In Exp. 1, 1,170 barrows and gilts (PIC, initial BW 58.5 kg) were used in a 70-d study. Pigs were blocked by initial BW and pens randomly allotted to 1 of 5 treatments with 9 replications per treatment. Treatments were feeder settings of 1, 2, 3, 4, or 5 with 1 being the most open and 5 being the most closed. The feeders used were STACO® stainless steel 5-hole dry feeders with setting 1 being the most open and 5 being the most closed. Overall, feeder setting did not affect ($P > 0.18$) ADG or G:F but decreased (linear, $P < 0.03$) ADFI. As feeder setting increased from open to closed, the feeder gap opening decreased (linear, $P < 0.01$) as expected. Furthermore, as feeder setting increased or feeder gap opening decreased, percent pan coverage increased (linear, $P < 0.01$) for week 2 and increased (quadratic, $P < 0.03$) for weeks 4, 7, and 10. In Exp. 2, 1,250 barrows and gilts (PIC, initial BW 35.1 kg) were used in a 69-d study to determine the effect of feeder setting and diet type. Pigs were blocked by initial BW and pens randomly allotted to 1 of 6 treatments with 8 replications per treatment. Treatments were arranged in a 3 × 2 factorial with main effects of feeder setting (1, 3, or 5 open to closed) and diet type (corn-soybean meal based diet or corn-soybean meal containing 15% DDGS and 5% bakery byproduct). Overall, there were no feeder setting × diet interactions ($P > 0.31$). Diet type did not affect ($P > 0.75$) pig performance. Widening feeder openings increased ADG (quadratic, $P < 0.03$) and ADFI (linear, $P < 0.01$). Feeder setting tended to improve G:F (quadratic, $P > 0.08$) with the best G:F observed at feeder setting 3. As feeder setting increased from open to closed, the feeder gap opening decreased (linear, $P < 0.01$). Furthermore, as feeder setting increased, percent pan coverage increased (linear, $P < 0.01$) for week 2 and increased (quadratic, $P < 0.04$) for week 6. Diet type tended to increase ($P < 0.10$) percent pan coverage for weeks 2 and 6. In conclusion, feeder adjustment of dry feeders used in this study can influence growth performance, with optimal growth when feed covers slightly more than half of the feed pan.

Key Words: dried distiller grains with solubles, growth, feeder adjustment, finishing pig

Introduction

Proper feeder adjustment is often an area of focus for improvement of feed efficiency in many production systems. It has been theorized that having feeder openings too wide can lead to feed wastage and operating feeders openings too tight leads to more plugged feeders and out-of-feed events that could adversely affect performance (Brumm et al., 2006). Furthermore, if accessing feed is difficult, individual pigs spend more time at the feeder, and the number of pigs able to obtain sufficient feed diminishes (Gonyou and Lou, 2000).

In an attempt to reduce diet cost, byproducts are often included in swine diets (National Pork Board, 2008). However, many byproducts such as dried distiller grains with solubles (**DDGS**), due to physical characteristics, have reduced flowability (Bhadra, 2009). Due to differences in feed characteristics such as particle size, and crude fat levels in byproducts, complete diets containing them may have to be managed differently when adjusting feeders; however, there is no data to support this idea.

Therefore, the objectives of these trials were to determine the effect of different feeder settings on growth performance of growing and finishing pigs and whether diet type influenced the optimal feeder setting.

Materials and Methods

General

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

The trial was conducted at a commercial research facility in southwestern Minnesota. The facility is made up of four individual barns, each 12.5 × 76.2 m, with 48, 3.05 × 5.49 m pens with approximately 0.69 m^2 provided per pig. All pens contained a single STACO® Generation 3 (Schaefferstown, PA) stainless steel single sided 5-hole dry self feeder with a feed pan dimension of 152.4 cm × 17.8 cm × 14.6 cm (length × width × height) and 1 cup waterer to allow for *ad-libitum* access to feed and water.

Each barn has a deep pit for manure storage with completely slatted floors. The barns operate on natural ventilation during the summer and mechanically assisted ventilation during

the winter. All barns are curtain sided. Experiment 1 and 2 were conducted in one of the barns at the research site in the summer of 2007 and the late winter of 2008, respectively.

Feeder settings were based on the factory-cut holes in the side of the feeder (Figure 4-1). Moving a dial from one hole to the next adjusted the feeder gate via a rod that connected the dial to the agitation gate in the feed pan. The feeders had 10 possible feeder settings. Feeder setting 1 was the most open setting while feeder setting 5 was the most closed setting.

Experiment 1

A total of 1,170 pigs (PIC, Line 337 × 1050, Hendersonville, TN) with an initial BW of 58.5 kg were used in a 70-d growth assay. Pigs were randomly allotted to pens, and then pens of pigs were blocked to 1 of 5 dietary treatments with 9 pens per treatment. Pens were blocked based on average initial pen weight. Each pen contained 23 to 28 pigs with 9 replicate pens per experimental diet.

Pigs were fed corn-soybean meal-based diets (Table 4.1) in 3 phases (59 to 77 kg, 77 to 101 kg, and 101 to 115 kg, respectively) in meal form. The treatments were feeder settings of 1, 2, 3, 4, or 5. Feeder settings were positioned at their respective setting for the duration of the trial. Pigs and feeders were weighed on d 0, 14, 28, 50, and 70 to determine the response criteria of ADG, ADFI, and G:F.

During the week of each weigh day (wk 2, 4, 7, and 10), a digital photo of each feed pan was taken (Figures 4-2, 4-3 and 4-4). The pictures were analyzed separately by a trained panel of six people; every picture was scored individually for pan coverage percentage. Using computer software, each feeder space (hole) in the digital pictures of the feed pans was divided into 4 equal quadrants. Thus there were 20 total sections in all (5 feeder spaces × 4 quadrants) for each feeder. Each of the 20 sections then equaled 5% of the total pan coverage. The panelists scored each section independently of the other sections. The scale used was 0 = no feed covering the feeder pan and 5 = complete feed coverage of the feed pan with 1, 2, 3, and 4 being intermediate. The scores were then summed from each of the 20 sections resulting in percent pan coverage.

After the trial was started, the distance between the feeder trough and the top of the feed plate was measured on both the left and right side of the feeder. The width of the feed plate (9.21 cm) was subtracted from the height measurement to determine gap opening. The feed gate was designed to have some flexibility in the feed gate to allow for feed agitation. Thus, the gap opening of the feeder had a low and high position. The gap opening was measured when the feed

plate was in both the lowest and highest position possible. Thus, 2 measurements (right and left side of feeder) of gap opening were obtained and averaged for each respective position (low or high) for each feeder. A regression equation was then generated by plotting the high gap opening measurement and percentage of pan coverage.

Experiment 2

A total of 1,250 pigs (PIC, Line 337 × 1050, Hendersonville, TN) with an initial BW of 35.1 kg were used in a 69-d growth assay. Pigs were randomly allotted to pens, and then pens of pigs were blocked to 1 of 6 dietary treatments with 8 (feeder setting 1 and 3 for both diet types) or 7 (feeder setting 5 for both diet types) pens per treatment. Pens were blocked based on average initial pen weight. Each pen contained 23 to 28 pigs.

Treatments were arranged in a 3 × 2 factorial with main effects of STACO feeder setting (1, 3, or 5) and diet type (corn-soybean meal based diet or corn-soybean meal based diet containing 15% DDGS and 5% bakery). The experimental diets contained 3% choice white grease (Table 4.2) and were fed in 3 phases (35 to 57 kg, 57 to 79 kg, and 79 to 99 kg, respectively) in meal form.

Similar to Exp. 1, feeder settings remained at their respective setting for the duration of the trial. Pigs and feeders were weighed on d 0, 15, 30, 42, 55, and 69 to determine the response criteria of ADG, ADFI, and G:F.

During wks 2 and 6 of the trial, a digital photo of each feed pan was taken. Procedures for photo analysis were similar to those previously described in Exp. 1. Also, gap opening was measured and pictures were analyzed for pan coverage percentage using the same procedures as in Exp. 1 and high gap opening and percent pan coverage were regressed, similar to Exp. 1.

Statistical Analysis

Data were analyzed as a randomized complete block design by using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC), with pen as the experimental unit. For both experiments, linear and quadratic polynomial contrasts were used to determine the effects of feeder setting. For Exp. 2, main effects and interactions between feeder setting and diet type were tested. Statistical significance and tendencies were set at $P < 0.05$ and $P < 0.10$ for all statistical tests, respectively.

Results

Experiment 1

From d 0 to 28, pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.04$) ADG and increased (linear, $P < 0.01$) ADFI (Table 4.3). From d 28 to 70, increasing feeder setting tended to increase (quadratic, $P < 0.10$) ADG. Increasing feeder setting did not affect ($P > 0.21$) ADFI or G:F. Overall (d 0 to 70), pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.03$) ADFI. Changing feeder setting did not affect ($P > 0.17$) ADG, G:F, or final BW.

The various feeder settings provided a wide range of feeder gap openings and corresponding pan coverage. As feeder setting increased from 1 to 5, low and high gap opening decreased (linear, $P < 0.01$) as expected (Table 4.4). Furthermore, as feeder setting increased or feeder gap opening decreased, percent feeder pan coverage decreased (linear, $P < 0.01$) for weeks 2, 4, 7, and 10 of the trial (Table 4.5). Over the duration of the trial, the percent pan coverage, at each respective feeder setting, numerically increased. A regression equation was then generated by plotting the high gap opening measurement (cm) on the *x*-axis and percent pan coverage on the *y*-axis. The resulting equation is: $y = -15.296x^2 + 125.209x - 176.743$ with an R^2 value of 0.84.

Experiment 2

From d 0 to 30 and d 30 to 69, there were no feeder setting × diet type interactions ($P > 0.22$) for growth performance; however, pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.01$) ADG and ADFI (Table 4.6). Overall (d 0 to 69), there were no feeder setting × diet type interactions ($P > 0.31$) for growth performance. Diet type did not affect ($P > 0.75$) growth performance (Table 4.7). Pigs fed from feeders with increasing feeder openings had increased (quadratic, $P < 0.03$) ADG. The pigs on feeder setting 1 grew the fastest; there was a slight reduction in growth rate for pigs fed with feeders on setting 3 and a larger decrease in ADG from feeder setting 3 to 5. Pigs fed from feeders with increasing feeder openings had increased (linear, $P < 0.01$) ADFI. Feeder setting tended to influence (quadratic, $P > 0.07$) G:F with optimal G:F for pigs with feeders on setting 3.

As expected, as feeder setting increased, low gap opening and high gap opening decreased (linear, $P < 0.01$; Table 4.8). As feeder gap opening decreased; feeder pan coverage

percentage decreased for week 2 (linear, $P < 0.01$) and week 6 (quadratic, $P < 0.01$) of the trial (Table 4.9). Feed pan coverage at each gap opening was similar to coverage in Exp. 1. Diet type tended to increase ($P < 0.10$) percent pan coverage for week 2 and 6. There was numerically a greater percent pan coverage observed at the wider feeder settings (1 and 3) for the diet containing by-products, but similar percent pan coverage for both diet types at the tightest feeder setting. Similar to Exp. 1, a regression equation was then generated by plotting the high gap opening measurement (cm) on the *x*-axis and percent pan coverage on the *y*-axis. The resulting equation is: $y = -16.279x^2 + 137.515x - 202.666$ with an R^2 value of 0.79.

Discussion

Feeder adjustment impacted growth rate in these trials as pigs fed from feeders with wider feeder settings (more open) had the ability to consume feed more readily. In Exp. 1, ADFI increased as the feeder gap opening increased similar to results of Smith et al. (2004). In our first trial, ADG and G:F was not different. This may be due to the fact that the treatments were feeder settings of the feeder and not fixed feeder gap openings. There may not have been enough differences between the feeder settings to detect significant differences. Moreover, when the feeder gap openings were measured, some of the feeder gap opening measurements overlapped between the feeder setting treatments, indicating some feeder differences due to manufacturing.

In Exp. 2, our data show that ADFI and ADG increased as feeder opening increased similar to Liptrap et al. (1985) and Smith et al. (2004), whereas G:F tended to improve at the middle feeder adjustment setting. These differences may be explained by increased feed wastage at a very open setting and restricted feed intake resulting in poorer ADG and G:F when feeders are adjusted too tightly. The 42-d trial by Smith et al. (2004) utilized nursery age pigs with an initial BW of 6.4 kg. The diets were wheat-soybean-meal based diets and fed as crumbles. The trial utilized STACO® Generation 3 nursery feeders, the same feeder manufacturer as our trial, with 1 feeder space per 4 pigs. While Smith et al. (2004) used nursery pigs and we utilized grow-finish pigs, the results showed similar growth responses to feeder adjustment levels. To determine potential behavior differences, Smith et al. (2004) recorded the duration that pigs spent eating per day. Pigs eating from feeders with the tightest feeder setting spent more time eating than pigs eating from feeders with more open feeder settings. This suggests that feed

availability was difficult for pigs fed from feeders with tight feeder settings and more time was required to consume sufficient amounts of feed.

As discussed by Liptrap et al. (1985) and Taylor et al. (1989), ADFI is truly a measurement of daily feed disappearance as ADFI does not account for feed that is wasted and is not consumed. Liptrap et al. (1985) found that as feeder opening increased with the Marting Mfg. feeders evaluated, ADFI increased but percentage wasted increased as well. Interestingly enough, feed efficiency was not affected as percent wasted increased. Gonyou (1998) stated small and large pigs spilled a similar amount of feed, but since large pigs eat more than small pigs, feed spillage as a percentage of total feed disappearance differed significantly (4.4% for small pigs, 2.4% for large pigs). Rooting was the most common behavior associated with feed wastage for all pig sizes (Gonyou, 1998).

These trials illustrate the importance of proper feeder management and adjustment. However, to apply this data to other dry feeder types, feeder gap opening was measured. The average gap opening from our experiments for feeder setting 3, which showed to be optimal in our studies, from the feed trough to the bottom of the feed plate when the feed plate is in the high position was approximately 2.92 cm. The amount of feed covering the bottom surface of the feeder pan for this setting averaged 61%, calculated from the values of both trials. Our data agrees with Smith et al. (2004) in that percent feeder pan coverage increased as feeder gap increased. Smith et al. (2004) stated the optimal feeder gap was obtained when 44 to 74% of the feed trough is covered with feed. However, the range of feed pan coverage for individual feeders on setting 3 was large with a range of 14 to 93%. The large range in percent pan coverage within one feeder setting provides evidence that identical pens of pigs managed their feed troughs differently. Over the duration of the trial, the percent pan coverage, at each respective feeder setting, numerically increased. Feeders need to be adjusted in order to maintain the proper percent pan coverage Feeder settings cannot be held constant during a pig's growing cycle and achieve the same pan coverage.

Diet type in this trial was not expected to influence growth performance. Linneen et al. (2008) reported there was no difference in pig growth performance between pigs fed 0 and 15% DDGS at this research site. The corn-soybean meal-byproduct based diet tended to have greater percent pan coverage as compared to the corn-soybean meal based diet. This result was not expected due to reduced flowability associated with DDGS and higher fat content due to the

relatively high fat content in both DDGS and bakery byproduct. Distillers dried grains with solubles have been shown to decrease flowability (Bhadra, 2009) as well as diets higher in fat. Therefore, it is suggested that the pigs did more sorting of the byproduct based diet at the feed pan resulting in increased pan coverage. Furthermore, this indicates that the feeder gap required maintaining a certain pan coverage changes with dietary ingredients. The increased pan coverage for the byproduct based diet occurred at more open feeder settings (1 and 3) compared to the corn-soybean meal based diet.

In conclusion, on the basis of this data, dry feeders for growing-finishing pigs should be adjusted to allow feed to cover slightly more than half of the feed pan without feed accumulating in the corners.

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Table 4.1 Diet Composition (Exp. 1; as-fed basis)[1]

Item	Phase 1	Phase 2	Phase 3
Ingredient, %			
Corn	68.74	72.49	65.09
Soybean meal, 46.5% CP	23.30	19.65	26.90
Choice white grease	6.00	6.00	6.00
Monocalcium P, 21% P	0.45	0.40	0.55
Limestone	0.85	0.80	0.80
Salt	0.35	0.35	0.35
Vitamin premix[2]	0.06	0.06	0.03
Trace mineral premix[3]	0.07	0.07	0.04
Phytase[4]	0.03	0.03	0.03
L-Lys HCl	0.15	0.15	0.15
L-Thr	---	---	0.03
Ractopamine HCl, 20 g/kg	---	---	0.03
Total	100.00	100.00	100.00
Calculated composition			
Standardized ileal digestible (SID) amino acids, %			
Lys	0.90	0.81	0.97
Met:Lys	27	28	27
Met & Cys:Lys	57	59	56
Thr:Lys	60	60	64
Trp:Lys	19	19	20
CP, %	16.82	15.44	18.21
Total Lys, %	1.00	0.90	1.10
ME, kcal/kg	3,624	3,628	3,622
Lys:ME, g/Mcal	2.48	2.23	2.68
Ca, %	0.51	0.47	0.52
P, %	0.45	0.42	0.48
Available P, %[5]	0.25	0.23	0.23

[1]Phase 1 fed from 59 to 77 kg, Phase 2 fed from 77 to 101 kg, Phase 3 fed from 101 to 115 kg.
[2]Provided per kilogram of diet for Phase 1 and 2: 5,511 IU of vitamin A; 689 IU of vitamin D; 22 IU of vitamin E; 2.2 mg of vitamin K; 0.02 mg of vitamin B12; 25 mg of niacin; 14 mg of pantothenic acid; and 4 mg of riboflavin. Provided per kilogram of diet for Phase 3: 2,646 IU of vitamin A; 331 IU of vitamin D; 11 IU of vitamin E; 1.1 mg of vitamin K; 0.01 mg of vitamin B12; 12 mg of niacin; 7 mg of pantothenic acid; and 2 mg of riboflavin.
[3]Provided per kilogram of diet for Phase 1 and 2: 10.75 mg of Cu from Cu sulfate; 0.193 mg of I from Ca iodate; 107 mg of Fe from Fe sulfate; 25.8 mg of Mn from Mn oxide, 0.193 mg of Se from Na selenite; and 107 mg of Zn from Zn oxide. Provided per kilogram of diet for Phase 3: 5.79 mg of Cu from Cu sulfate; 0.104 mg of I from Ca iodate; 58 mg of Fe from Fe sulfate; 13.9 mg of Mn from Mn oxide, 0.104 mg of Se from Na selenite; and 58 mg of Zn from Zn oxide.
[4]OptiPhos 2000 (Phytex LLC, Sheridan, IN).
[5]Includes expected P release of 0.10% from added phytase.

Table 4.2 Diet Composition (Exp. 2; as-fed basis)[1]

Item	Phase 1		Phase 2		Phase 3	
Ingredient, %	Corn-soy	By-product	Corn-soy	By-product	Corn-soy	By-product
Corn	69.37	52.68	73.70	57.03	78.80	61.95
Soybean meal, 46.5% CP	25.05	22.04	20.99	17.86	16.11	13.14
Dried distillers grains with solubles	---	15.00	---	15.00	---	15.00
Bakery by-product	---	5.00	---	5.00	---	5.00
Choice white grease	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium P, 21% P	0.55	0.20	0.40	0.05	0.35	0.03
Limestone	0.90	1.00	0.88	1.05	0.80	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.15	0.15	0.13	0.13	0.10	0.10
Trace mineral premix[3]	0.15	0.15	0.13	0.13	0.10	0.10
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03
L-Lys HCl	0.30	0.35	0.28	0.33	0.27	0.31
DL-Met	0.06	---	0.04	---	0.02	---
L-Thr	0.09	0.05	0.07	0.04	0.07	0.04
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated composition						
Standardized ileal digestible (SID) amino acids, %						
Lys	1.06	1.06	0.94	0.94	0.81	0.81
Met:Lys	30	27	29	29	29	31
Met & Cys:Lys	56	56	56	59	58	63
Thr:Lys	62	62	62	62	64	64
Trp:Lys	17	17	17	17	17	17
CP, %	17.93	19.72	16.36	18.11	14.51	16.32
Total Lys, %	1.17	1.21	1.05	1.07	0.90	0.93
ME, kcal/kg	3,479	3,501	3,485	3,507	3,494	3,514
Lys:ME, g/Mcal	3.04	3.04	2.70	2.68	2.32	2.30
Ca, %	0.55	0.52	0.50	0.50	0.45	0.44
P, %	0.48	0.46	0.44	0.41	0.41	0.39
Available P, %[5]	0.18	0.18	0.25	0.25	0.23	0.24

[1]Phase 1 fed from 35 to 57 kg, Phase 2 fed from 57 to 79 kg, Phase 3 fed from 79 to 99 kg.

[2]Provided per kilogram of diet for Phase 1: 13,228 IU of vitamin A; 1653 IU of vitamin D; 53 IU of vitamin E; 5.3 mg of vitamin K; 0.05 mg of vitamin B12; 60 mg of niacin; 33 mg of pantothenic acid; and 10 mg of riboflavin. Provided per kilogram of diet for Phase 2: 11,023 IU of vitamin A; 1378 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K; 0.04 mg of vitamin B12; 50 mg of niacin; 28 mg of pantothenic acid; and 8 mg of riboflavin. Provided per kilogram of diet for Phase 3: 8,818 IU of vitamin A; 1102 IU of vitamin D; 35 IU of vitamin E; 3.5 mg of vitamin K; 0.03 mg of vitamin B12; 40 mg of niacin; 22 mg of pantothenic acid; and 7 mg of riboflavin.

[3]Provided per kilogram of diet for Phase 1: 24.80 mg of Cu from Cu sulfate; 0.446 mg of I from Ca iodate; 248 mg of Fe from Fe sulfate; 59.5 mg of Mn from Mn oxide, 0.446 mg of Se from Na selenite; and 248 mg of Zn from Zn oxide. Provided per kilogram of diet for Phase 2: 20.67 mg of Cu from Cu sulfate; 0.372 mg of I from Ca iodate; 207 mg of Fe from Fe sulfate; 49.6 mg of Mn from Mn oxide, 0.372 mg of Se from Na selenite; and 207 mg of Zn from Zn oxide. Provided per kilogram of diet for Phase 3: 16.53 mg of Cu from Cu sulfate; 0.298 mg of I from Ca iodate; 124 mg of Fe from Fe sulfate; 29.8 mg of Mn from Mn oxide, 0.223 mg of Se from Na selenite; and 124 mg of Zn from Zn oxide.

[4]OptiPhos 2000 (Phytex LLC, Sheridan, IN).

[5]Includes expected P release of 0.10% from added phytase.

Table 4.3 Influence of feeder adjustment on growing-finishing pig performance (Exp. 1)[1]

	Feeder Setting						Probability, *P* <	
Item	1	2	3	4	5	SEM	Linear	Quadratic
D 0 to 28								
Initial BW, kg	58.5	58.6	58.2	58.4	58.8	0.71	0.82	0.60
ADG, kg	0.837	0.835	0.815	0.817	0.806	0.0131	0.04	0.92
ADFI, kg	2.045	2.025	1.960	1.949	1.951	0.0279	0.01	0.32
G:F	0.410	0.412	0.415	0.419	0.414	0.0100	0.30	0.44
D 28 to 70								
ADG, kg	0.782	0.807	0.823	0.784	0.788	0.0161	0.80	0.10
ADFI, kg	2.198	2.238	2.213	2.146	2.159	0.0450	0.23	0.57
G:F	0.356	0.362	0.372	0.365	0.367	0.0064	0.21	0.29
D 0 to 70								
ADG, kg	0.805	0.818	0.819	0.797	0.795	0.0110	0.22	0.18
ADFI, kg	2.135	2.151	2.108	2.063	2.068	0.0319	0.03	0.84
G:F	0.377	0.382	0.389	0.386	0.385	0.0050	0.17	0.26
Final BW, kg	114.1	115.1	116.3	114.1	114.5	1.02	0.96	0.21

[1]A total of 1,170 pigs (PIC initially 58.5 kg) were used in a 70-d experiment with 23 to 28 pigs per pen with 9 pens per treatment.

Table 4.4 Influence of feeder adjustment on feeder gap opening (Exp. 1)[1]

	Feeder Setting						Probability, $P <$		
Gap opening, cm^2	1	2	3	4	5	SEM	Treatment	Linear	Quadratic
Low	2.88	2.63	2.26	1.99	1.71	0.086	0.01	0.01	0.92
High	3.60	3.28	2.95	2.65	2.20	0.074	0.01	0.01	0.45

[1]A total of 1,170 pigs (PIC initially 58.5 kg) were used in a 70-d experiment with 23 to 28 pigs per pen with 9 pens per treatment.
[2]Measured from the bottom of the feed pan to the bottom of the feed plate with the feed plate at the lowest (low) and highest (high) possible positions.

Table 4.5 Influence of feeder adjustment on feeder pan coverage (Exp. 1)[1]

	Feeder setting						Probability, *P* <		
Pan coverage, %	1	2	3	4	5	SEM	Treatment	Linear	Quadratic
Week 2	74.0	71.3	57.0	34.3	20.6	4.63	0.01	0.01	0.09
Week 4	73.1	65.9	62.9	41.9	24.9	4.28	0.01	0.01	0.03
Week 7	78.0	67.0	63.7	46.3	24.8	3.39	0.01	0.01	0.01
Week 10	78.9	73.9	64.6	45.2	26.1	3.04	0.01	0.01	0.01

[1]A total of 1,170 pigs (PIC initially 58.5 kg) were used in a 70-d experiment with 23 to 28 pigs per pen with 9 pens per treatment.

Table 4.6 Influence of feeder adjustment and diet type on growing-finishing pig performance (Exp. 2)[1]

								Probability, *P*<				
	Diet:	Corn-Soybean meal			By-Product				Diet ×			Feeder setting
Item	Feeder Setting:	1	3	5	1	3	5	SEM	Feeder Setting	Diet	Feeder Setting	Linear	Quadratic
D 0 to 30													
Initial BW, kg		35.1	35.1	35.0	35.0	35.2	35.0	1.00	1.00	0.97	0.99	0.93	0.89
ADG, kg		0.946	0.925	0.865	0.912	0.926	0.893	0.0180	0.22	0.92	0.01	0.01	0.16
ADFI, kg		1.974	1.888	1.830	1.976	1.944	1.839	0.0349	0.68	0.42	0.01	0.01	0.70
G:F		0.484	0.489	0.468	0.460	0.480	0.487	0.0114	0.14	0.61	0.42	0.57	0.25
D 30 to 69													
ADG, kg		0.957	0.934	0.878	0.949	0.938	0.881	0.0140	0.90	0.97	0.01	0.01	0.08
ADFI, kg		2.490	2.383	2.281	2.464	2.387	2.284	0.0327	0.86	0.81	0.01	0.01	0.83
G:F		0.385	0.393	0.385	0.386	0.393	0.385	0.0055	1.00	0.90	0.24	0.96	0.10
D 0 to 69													
ADG, kg		0.951	0.931	0.873	0.933	0.932	0.885	0.0113	0.37	0.87	0.01	0.01	0.03
ADFI, kg		2.262	2.165	2.080	2.247	2.193	2.089	0.0294	0.74	0.75	0.01	0.01	0.69
G:F,		0.423	0.429	0.416	0.415	0.427	0.425	0.0060	0.33	0.87	0.18	0.73	0.07
Final BW, kg		101.4	100.1	96.2	100.4	99.9	97.2	1.48	0.81	0.97	0.02	0.01	0.33

[1]A total of 1,250 pigs (PIC initially 35.1 kg) were used in a 69-d experiment with 27 to 28 pigs per pen with 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.

Table 4.7 Main effects of feeder adjustment on growing-finishing pig performance (Exp. 2)[1]

	Feeder setting				Probability, $P <$ Feeder setting	
Item	1	3	5	SEM	Linear	Quadratic
D 0 to 30						
Initial BW, kg	35.1	35.1	35.0	0.71	0.93	0.89
ADG, kg	0.929	0.926	0.879	0.0127	0.01	0.16
ADFI, kg	1.975	1.916	1.835	0.0247	0.01	0.70
G:F, kg/kg	0.472	0.484	0.478	0.0082	0.57	0.25
D 30 to 69						
ADG, kg	0.953	0.936	0.880	0.0099	0.01	0.08
ADFI, kg	2.477	2.385	2.282	0.0231	0.01	0.83
G:F, kg	0.385	0.393	0.385	0.0100	0.96	0.10
D 0 to 69						
ADG, kg	0.942	0.931	0.879	0.0080	0.01	0.03
ADFI, kg	2.255	2.179	2.085	0.0208	0.01	0.69
G:F, kg/kg	0.419	0.428	0.421	0.0100	0.73	0.07
Final BW, kg	100.9	100.0	96.7	1.05	0.01	0.33

[1]A total of 1,250 pigs (PIC initially 35.1 kg) were used in a 69-d experiment with 27 to 28 pigs per pen with 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.

Table 4.8 Influence of feeder adjustment on gap opening (Exp. 2)[1]

	Feeder setting				Probability, $P <$ Feeder setting	
Gap opening, cm^2	1	3	5	SEM	Linear	Quadratic
Low	2.86	2.16	1.55	0.062	0.01	0.50
High	3.59	2.89	2.20	0.050	0.01	0.83

[1]A total of 1,250 pigs (PIC initially 35.1 kg) were used in a 69-d experiment with 27 to 28 pigs per pen with 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.
[2]Measured from the bottom of the feed pan to the bottom of the feed plate with the feed plate at the lowest (low) and highest (high) possible positions.

Table 4.9 Influence of feeder adjustment and diet type on feeder pan coverage (Exp. 2)[1]

									Probability, P<				
	Diet:	Corn-soybean meal			By-product				Diet ×			Feeder setting	
Feeder pan coverage, %	Feeder setting:	1	3	5	1	3	5	SEM	Feeder Setting	Diet	Feeder setting	Linear	Quadratic
Week 2		73.3	46.9	19.4	85.5	63.2	17.8	6.87	0.37	0.10	0.01	0.01	0.28
Week 6		74.7	53.3	25.9	85.3	70.3	22.4	6.34	0.17	0.10	0.01	0.01	0.04

[1]A total of 1,250 pigs (PIC initially 35.1 kg) were used in a 69-d experiment with 27 to 28 pigs per pen with 8 pens per treatment for the treatments of feeder setting 1 and 3 for both diet types and 7 pens per treatment for the treatments of feeder setting 5 for both diet types.

Figure 4.1 STACO stainless steel dry feeder on feeder setting 3

Figure 4.2 The effect of feeder gap opening, manufacturer's feeder setting 1, on percent feeder pan coverage in multispace, trough-type dry feeders (STACO, Shafferstown, PA). The mean percent pan coverage of feeder setting 1 is 80 % (Figure 2B). The mean percent pan coverage of feeder setting 1 plus 1 SD is 95 % (Figure 2A). The mean percent pan coverage of feeder setting 1 minus 1 SD is 65 % (Figure 2C).

2A

2B

2C

Figure 4.3 The effect of feeder gap opening, manufacturer's feeder setting 3, on percent feeder pan coverage in multispace, trough-type dry feeders (STACO, Shafferstown, PA). The mean percent pan coverage of feeder setting 1 is 55 % (Figure 3B). The mean percent pan coverage of feeder setting 1 plus 1 SD is 75 % (Figure 3A). The mean percent pan coverage of feeder setting 1 minus 1 SD is 35 % (Figure 3C).

3A

3B

3C

Figure 4.4 The effect of feeder gap opening, manufacturer's feeder setting 5, on percent feeder pan coverage in multispace, trough-type dry feeders (STACO, Shafferstown, PA). The mean percent pan coverage of feeder setting 1 is 15 % (Figure 4B). The mean percent pan coverage of feeder setting 1 plus 1 SD is 25 % (Figure 4A). The mean percent pan coverage of feeder setting 1 minus 1 SD is 5 % (Figure 4C).

4A

4B

4C

Figure 4.5 Percentage of pan covered with feed at different high gap opening measurements (Exp. 1). High gap opening is the maximum distance from the feed pan to the bottom of the feeder agitation gate.

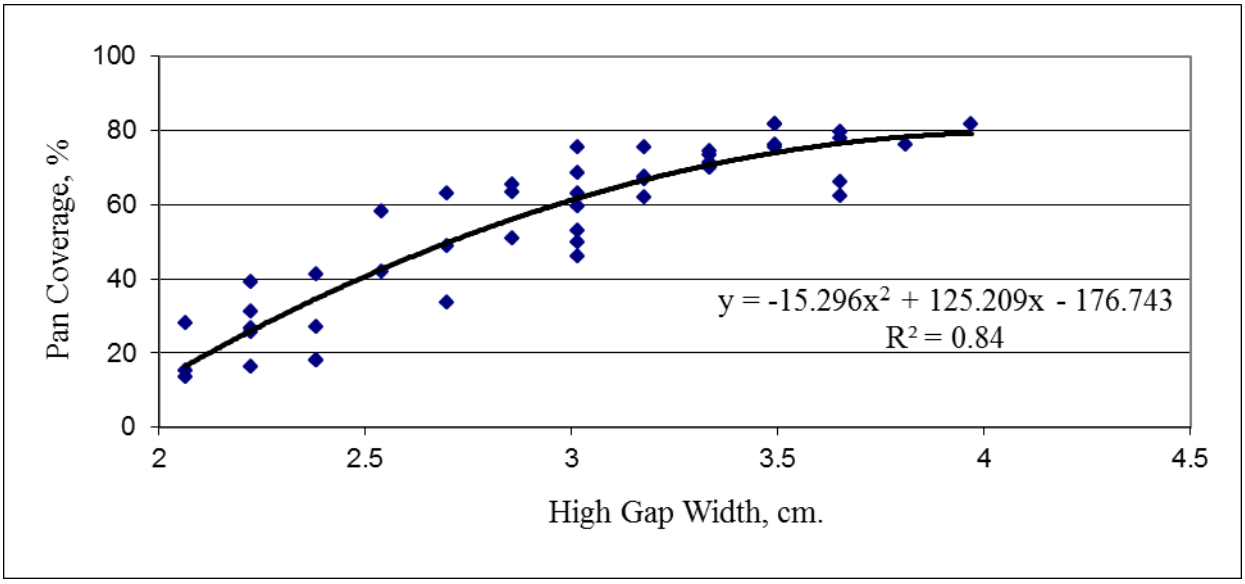

Figure 4.6 Percentage of pan covered with feed at different high gap opening measurements (Exp. 2). High gap opening is the maximum distance from the feed pan to the bottom of the feeder agitation gate.