EVALUATION OF CORN GERM AND DDGS IN DIETS FED TO PIGS

BY

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THESIS

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ABSTRACT

Evaluation of Corn Germ and Distillers Dried Grains with
Solubles (**DDGS**) in Diets Fed to Pigs

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Two experiments were conducted to determine effects of inclusion of distillers dried grains with solubles (**DDGS**) and corn germ to diets fed to growing-finishing pigs on pig growth performance, carcass composition, and pork fat quality. The first experiment was conducted to investigate if negative impacts of DDGS on carcass fat quality may be ameliorated by addition of corn germ, tallow, palm kernel oil, or glycerol to growing-finishing pig diets. The second experiment was conducted to determine the optimal inclusion rate of corn germ in growing-finishing pig diets that contained 0 or 30% DDGS. In Exp 1, a total of 36 gilts and 36 barrows (initial BW: 43.7 ± 2.0 kg) were randomly allotted to 1 of 6 dietary treatments and housed individually. A corn-soybean meal control diet and a corn-soybean meal diet containing 30% DDGS were formulated. Four additional DDGS based diets containing 15% corn germ, 3% tallow, 3% palm kernel oil, or 5% glycerol were also formulated. There were no differences among diets in ADG, ADFI, or G:F of the pigs. However, gilts had less ($P < 0.05$) ADG and ADFI and greater ($P < 0.05$) G:F than barrows. Most carcass characteristics were not affected by dietary treatments, but pigs fed diets containing the control diet had greater ($P < 0.05$) loin eye area compared with pigs fed the DDGS diet. It was observed that BW, HCW, and back fat thickness were greater ($P < 0.05$) for barrows than for gilts, but fat free lean percentage was greater ($P < 0.05$) for gilts than for barrows. There were no dietary effects on loin muscle quality, but barrows had greater ($P < 0.05$) marbling and 24-h loin pH than gilts. Belly quality was not influenced by dietary treatments, but gilts had lighter ($P < 0.05$) bellies than barrows. Belly flop distance was greater ($P < 0.05$) for pigs fed the control diet than for pigs fed the 5 DDGS-containing diets. However, there were no differences among pigs fed the DDGS diets. Belly flop distance was greater ($P < 0.05$) for barrows than for gilts. There was a tendency ($P = 0.07$) for gilts to have greater backfat iodine value (**IV**) and greater ($P = 0.05$) belly fat IV than barrows. It was concluded that inclusion of corn germ, tallow, palm kernel oil, or glycerol to growing-finishing diets did not ameliorate the negative effects of DDGS on carcass fat quality. In Exp 2, a total of 280 pigs (initial BW: 42.5 ± 4.6 kg) were randomly allotted to 1 of 8 dietary treatments in a 2 × 4 factorial design with 2 levels of DDGS (0 or 30%) and 4 levels of corn germ (0, 10, 20, or 30%). Each diet was fed to 10 pens and either 3 or 4 pigs were housed in each pen. The pig from each pen that had a BW closest to the average BW for the pen was harvested at the conclusion of the experiment. Inclusion of corn germ to the diet did not affect pig growth performance regardless of the inclusion rate of DDGS, but ADG, ADFI, and final BW were reduced ($P < 0.05$) by inclusion of 30% DDGS to the diet. Carcass composition, muscle quality, and fat quality were not affected by inclusion of corn germ to the diets, but there was a reduction in LM marbling and firmness by inclusion of DDGS in the diets ($P < 0.05$). The L* value for back fat was reduced ($P < 0.05$) by inclusion of DDGS in the diet, but corn germ did not influence back fat color measures. Belly flop distance was reduced (linear, $P < 0.001$) as corn germ was added to diets containing no DDGS, but belly flop distance was not affected by inclusion of corn germ to diets containing 30% DDGS. However, there was a reduction ($P < 0.001$) in belly flop distance for pigs fed diets containing DDGS. It was concluded that pig growth performance, carcass composition, and muscle quality were not negatively affected by addition of up to 30% corn germ to diets containing 0 or 30% DDGS, but there was a reduction in belly firmness by inclusion of corn germ in diets containing no DDGS.

Key words: corn germ, distillers dried gains with solubles, fat quality, glycerol, oil, pigs

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LIST OF ABBREVIATIONS

%	Percent
±	Plus or minus
AA	Amino acid
Abstr	Abstract
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily gain
Ala	Alanine
AOAC	Association of Official Analytical Chemists
Arg	Arginine
Asp	Aspartic acid
BW	Body weight
°C	Degrees Celsius
Ca	Calcium
cal	Calorie
CG	Corn germ
CP	Crude protein
Cu	Copper
Cys	Cysteine
d	Day
DDGS	Distillers dried grains with solubles
DM	Dry matter
EE	Ether extract

Fe	Iron
G:F	Gain to feed ratio
GE	Gross energy
Glu	Glutamine
Gly	Glycine
h	Hour
His	Histidine
I	Iodine
IV	Iodine value
Ile	Isoleucine
LEA	Loin eye area
Leu	Leucine
Lys	Lysine
Met	Methionine
NDF	Neutral detergent fiber
P	Phosphorus
P	*P*-value
Pro	Proline
SAS	Statistical analysis software
Se	Selenium
SEM	Standard error of the mean
Ser	Serine
Thr	Threonine
Trp	Tryptophan
Tyr	Tyrosine

Val	Valine
Zn	Zinc

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CHAPTER 1

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) is a co-product from the ethanol industry, which may be fed to livestock. It was reported that DDGS contains approximately 88.9% DM, 30.2% CP, 10.9% fat, 5.8% ash, 8.8% crude fiber, 16.2% ADF, and 42.1% NDF (Spiehs et al., 2002). Distillers dried grains with solubles is a valuable feed ingredient, which may be included in swine diets because the ME of DDGS is similar to that of corn (Stein and Shurson, 2009). Many swine producers include DDGS in diets fed to growing-finishing pigs because of the attractive cost of DDGS compared with corn and soybean meal. If the quantity of digestible Lys is sufficient in the diet, up to 30% DDGS may be added to the diet (Stein and Shurson, 2009). However, PUFA concentrations in DDGS are high, especially linoleic (C18:2) acid (Stein and Shurson, 2009; Xu et al., 2010). When feed ingredients with high concentrations of PUFA are fed to growing-finishing pigs, de novo lipid synthesis may be suppressed and dietary fatty acids may be deposited and directly incorporated into fat depots (Clarke et al., 1990; Madsen et al., 1992). High concentrations of PUFA in back fat and belly fat result in increased iodine values (**IV**) and increased fat softness. Therefore, inclusion of DDGS in diets fed to growing-finishing pigs may result in reduced belly fat firmness and increased IV of back fat and belly fat (Whitney et al., 2006; Benz et al., 2010; Xu et al., 2010). It is possible to reduce belly softness and IV of back fat and belly fat by addition of dietary saturated fatty acids such as beef tallow or palm kernel oil to the diet fed to pigs (Averette Gatlin et al., 2002; Teye et al., 2006). The IV of muscle fat and back fat may also be reduced by inclusion of glycerol to the diet, and carcass firmness may be improved by adding glycerol to the diet prior to slaughter (Mourot et al., 1994, Schieck et al., 2010). Belly fat IV was also reduced by inclusion of corn germ to a corn-soybean meal diet (Widmer et al., 2008). It was, therefore, hypothesized that supplementing DDGS-based diets with corn germ, tallow, palm kernel oil, or glycerol may ameliorate the negative impacts of DDGS on pork fat quality.

Ethanol plants that fractionate the corn kernel prior to fermentation also produce corn germ, which may be used and included in swine diets. Corn germ contains approximately 92.20 DM, 14.00% CP, 17.60% fat, 3.30% ash, 5.60% ADF, and 20.40% NDF (Widmer et al., 2007). There were no negative effects of inclusion of 10% corn germ on pig growth performance of growing-finishing pigs (Widmer et al., 2008). Pig growth performance and fat quality of pigs fed diets containing 30% DDGS and 15% corn germ were also not different from that of pigs fed a corn-soybean meal diet (Lee et al., 2011). It was, therefore, hypothesized that greater quantities of corn germ may be included in diets without or with DDGS without negatively impacting pig growth performance and pork fat quality.

The objectives of this thesis, therefore, were to test the hypothesis that the negative impacts of inclusion of DDGS on pork fat quality of growing-finishing pigs can be ameliorated by adding corn germ, tallow, palm kernel oil, or glycerol to grower-finisher diets and to determine the optimal inclusion rate of corn germ in growing-finishing pig diets containing 0 or 30% DDGS.

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CHAPTER 2

CORN GERM AND DISTILLERS DRIED GRAINS WITH SOLUBLES (DDGS) IN SWINE NUTRITION: LITERATURE REVIEW

Introduction

Production of ethanol from corn results in production of distillers dried grains with solubles (**DDGS**), which is widely used in swine diets where it is a valuable feed ingredient because it contains the same quantity of ME as corn and also contains AA, digestible P, and fat (Stein and Shurson, 2009). Up to 30% inclusion of DDGS in diets fed to growing-finishing pigs often results in acceptable pig performance (Drescher et al., 2009; Lammers et al., 2009). The cost of DDGS is often attractive compared with corn and soybean meal and many swine producers, therefore, prefer to include greater amounts of DDGS in diets and only minimal reduction in performance is observed if 45% DDGS is used in diets fed to growing-finishing pigs (Cromwell et al., 2011). However, inclusion of DDGS in diets fed to growing-finishing pigs may create problems with pork quality because the dominant fatty acid in DDGS fat is linoleic acid (C18:2; Stein and Shurson, 2009). This unsaturated fatty acid can be directly incorporated into fat depots in pigs, which may result in soft back fat and increased belly softness (Whitney et al., 2006; Benz et al., 2010: Xu et al., 2010b). Gilts are more susceptible to these negative effects of DDGS than barrows because gilts have softer bellies than barrows (Benz et al., 2010) The negative effects of DDGS on fat quality are, therefore, considered the main reason for limiting the addition of DDGS in diets fed to growing-finishing pigs (Stein and Shurson, 2009). The iodine value (**IV**) of fat depots in pigs can be used as an indicator of the degree of unsaturation of fatty acids (Benz et al., 2010). A high IV indicates that increased amounts of unsaturated fatty acids are deposited in the fat. Feeding diets containing DDGS will, therefore, result in increases in the IV of backfat and belly fat (Whitney et al., 2006; Widmer et al., 2008; Benz et al. 2010). It is possible that nutritional approaches to ameliorate the negative effects of DDGS on fat quality can be identified, but at this point, research to identify such approaches have not been reported..

Whole corn grain may be fractionated into corn hulls, corn germ, and endosperm. The endosperm may be used to produce ethanol, which results in production of high protein distillers dried grains. The corn hulls is usually fed to ruminants, but corn germ can be directly included in swine diets. Corn germ contains approximately 18% fat, 15% CP, and 20% NDF (Widmer et al., 2007). Up to 10% corn germ can be included in diets fed to growing-finishing pigs without negatively affecting pig growth performance or carcass or fat quality (Widmer et al., 2008). There are, however, no reports on effects of including more than 10% corn germ to diets fed to pigs.

USE OF DDGS IN DIETS FED TO GROWING-FINISHING PIGS

Effects of Inclusion of Distillers Dried Grains with Solubles on Pig Performance

Effects of including DDGS in diets fed to growing-finishing pigs on performance have been studied in many experiments. There were no negative effects on pig growth performance of including 15% DDGS in the diet compared with pigs fed diets containing no DDGS (Linneen et al., 2008). However, growth performance of growing-finishing pigs was greater for pigs fed 20% DDGS with a highly digestible Lys than for pigs fed 20% DDGS with a reduced quality of digestible Lys, but pigs fed DDGS from the high digestible Lys source had growth performance that was not different from that of pigs fed the control diet without DDGS (Drescher et al., 2009). This observation indicates that the quality of DDGS, and specifically the concentration of digestible Lys in DDGS, has important impacts on the performance obtained by pigs fed DDGS. It was also observed that there are no negative effects on pig growth performance of including up to 30% DDGS in the diets (Cook et al., 2005; DeDecker et al., 2005; Lammers et al., 2009). These observations were confirmed by Xu et al. (2010b) who also concluded that it is possible to include 30% DDGS in corn soybean meal based diets without influencing growth performance of growing-finishing pigs (Xu et al., 2010b). Recently, it was reported that ADG of pigs was slightly reduced by inclusion of up to 45% DDGS in growing-finishing diets, but the G:F was not changed (Cromwell et al., 2011).

However, in some other studies, which evaluated effects on growth performance of including DDGS to diets for growing-finishing pigs, pig performance was reduced by inclusion of DDGS in diets fed to growing-finishing pigs. Whitney et al. (2006) conducted an experiment evaluating dietary effects of DDGS on growth performance and characteristics of growing-finishing pigs. A total of 240 crossbred pigs were fed diets containing up to 30% DDGS and it was concluded that feeding 30% DDGS resulted in reduced ADG and decreased G:F compared with feeding a corn-soybean meal diet and pig growth performance was negatively influenced by inclusion of DDGS in the diet. Likewise, Linneen et al. (2008) used 1,038 pigs that were fed diets containing up to 30% DDGS during a 56-d study and concluded that there was a linear reduction in ADG and ADFI as graded levels of DDGS was included in the diet. It is not clear why different results have been obtained when DDGS is included in diets fed to growing-finishing pigs, but it is possible that these differences reflect differences in the quality of DDGS that was used.

Effects of withdrawing DDGS during the later stages of the finishing period on growth performance of growing-finishing pigs has also been evaluated in pigs fed diets containing 30% DDGS. However, withdrawing DDGS from the diets for 0, 3, or 6 weeks prior to slaughter (Gaines et al., 2007) or for 0, 3, 6, or 9 weeks prior to slaughter (Xu et al., 2010a) did not have any impact on pig growth performance.

Effects of Inclusion of Distillers Dried Grains with Solubles on Pork Fat Quality

Belly fat firmness of growing-finishing pigs is often reduced when pigs are fed corn soybean meal diets containing DDGS (Whitney et al., 2006; Benz et al., 2010: Xu et al., 2010b). There is approximately 10% fat in DDGS, which is mainly composed of unsaturated fatty acids, and the deposition of more unsaturated fat in pork fat from feeding DDGS may cause softness in body fat depots. A linear increase in IV of carcass fat and a reduction in belly firmness in pigs fed diets containing up to 20 or 30% DDGS compared with pigs fed no DDGS has been reported (Whitney et al., 2006; Benz et al., 2010). The IV of back fat, belly fat, and LM intramuscular fat was also linearly increased by including up to 30% DDGS in diets fed to growing-finishing pigs (Xu et al., 2010b). There was also a linear increase in the PUFA concentration, especially linoleic acid (C18:2), in belly fat, back fat, and LM intramuscular fat when increasing levels of DDGS were included in the diet (Xu et al., 2010b). It was concluded that feeding up to 30% DDGS may reduce fat quality of growing-finishing pigs. These negative effects of including

DDGS on fat quality may be ameliorated by withdrawal of DDGS from the growing-finishing diets prior to slaughter. Although a linear increase in the IV of belly fat as graded levels of DDGS was included in the diet was observed, the IV of belly fat was in an acceptable range if DDGS was withdrawn during the last 3 to 4 weeks prior to slaughter (Hill et al., 2008). The linoleic acid (C18:2) concentration of belly fat for pigs fed up to 30% DDGS was also linearly reduced by withdrawal of DDGS from the growing-finishing diets for 0 to 9 weeks prior to slaughter (Xu et al., 2010a). It is, therefore, concluded that detrimental effects of adding DDGS to growing-finishing diets on fat quality may be ameliorated by withdrawing DDGS from the diets for at least 3 weeks prior to marketing.

USE OF CORN GERM IN DIETS FED TO GROWING-FINISHING PIGS

Effects of including corn germ to diets fed to growing-finishing pigs on growth performance, carcass quality, and the pork palatability has been investigated in only 1 experiment (Widmer et al., 2008). It was concluded that 5 or 10% corn germ may be added to diets fed during the growing, the early finishing, and the late finishing phases without affecting growth performance compared with pigs fed a corn soybean meal diet. The IV of belly fat was less for pigs fed diets containing corn germ than for pigs fed diets containing DDGS or high protein distillers dried grains, but the palatability of pork chops and bacon was not affected by the inclusion of corn germ in the diets (Widmer et al., 2008). It has also been reported that inclusion of 15% corn germ in growing-finishing pig diets containing 30% DDGS had no negative effects on pig growth performance and fat quality of growing-finishing pigs (Lee et al., 2011). As the reported research has shown no negative effects of adding corn germ to diets fed to pigs, research to investigate effects of using greater levels of DDGS in diets without or with

DDGS is needed. The optimal inclusion level of corn germ in growing-finishing diets containing up to 30% DDGS also needs to be established, and dietary effects of inclusion of corn germ to DDGS based diets on fat quality need to be evaluated. Corn germ contains approximately 18% fat (Widmer et al., 2007), because the majority of corn oil from the corn kernel is stored in corn germ. If corn germ is defatted, corn germ meal is produced. However, solvent-extracted corn germ meal contains only around 2% fat (Weber et al., 2009). Corn germ meal is, therefore, very different from corn germ in terms of nutritional quality and the 2 ingredients should not be confused.

POSSIBLE NUTRITIONAL INTERVENTIONS TO REDUCE NEGATIVE IMPACTS OF DDGS ON PORK FAT QUALITY

Addition of Saturated Fatty Acids (Tallow, Palm Kernel Oil)

A possible mechanism for ameliorating negative impacts of DDGS on pork fat quality is to add tallow or palm kernel oil to diets containing DDGS because both tallow and palm kernel oil contain saturated fatty acids that may be directly incorporated into body fat, and thereby change the fatty acid composition of pork fat (Lizardo et al., 2002). This may prevent a reduction in fat quality of growing-finishing pigs fed diets containing elevated levels of unsaturated fatty acids (Averette Gatlin et al, 2002; Teye et al., 2006). Inclusion of 5% tallow resulted in reduced linoleic acid (C18:2) concentration in back fat and the IV in back fat was less for pigs fed 5% beef tallow than for pigs fed 2.5% tallow (Averette Gatlin et al., 2002). It was concluded that reduced concentration of PUFA in diets fed to pigs during the last 6 weeks before slaughter resulted in reduced linoleic acid (C18:2) concentration and IV in back fat.. It has also been reported that inclusion of palm kernel oil in diets fed to finishing pigs results in reduced PUFA: SFA ratio in longissimus muscle and increased concentrations of lauric (C12:0), myristic (C14:0), palmitic (C16:0), and stearic (C18:0) fatty acids (Teye et al., 2006). The concentration of linoleic acid (C18:2) in longissimus muscle was also reduced and it was concluded that inclusion of palm kernel oil in diets fed to finishing pigs may improve pork fat quality by reducing the IV values of pork fat. It is, therefore, possible that inclusion of tallow or palm kernel oil in diets containing DDGS can contribute to an improvement in quality and contribute to deposition of fat with reduced IV values.

Addition of Glycerol to DDGS-containing Diets

Inclusion of glycerol in a diet fed to pigs may increase the level of lipogenic substrates synthesized during glycerol metabolism. The concentration of oleic acid (C18:1) in muscle fat for pigs fed 5% glycerol was increased compared with that of pigs fed no glycerol (Mourot et al., 1994). The oleic acid (C18:1) concentration in back fat of pigs fed 5% glycerol was also greater than for pigs fed no glycerol. It was concluded that the calculated unsaturation index is less for pigs fed 5% glycerol than for pigs fed no glycerol, indicating that degree of unsaturation in backfat was reduced by inclusion of glycerol in the diet. Inclusion of 0, 2.5, or 5% glycerol also resulted in reduced linoleic acid (C18:2) and PUFA content in jowl fat (Duttlinger et al., 2011) and the concentration of myristic acid (C14:0) in belly fat was increased by inclusion of glycerol in the diet. It was concluded that inclusion of glycerol in the diet resulted in an increase in degree of saturation in fatty acid composition of body fat compared with pigs fed no glycerol. Inclusion of 8% glycerol to corn soybean meal diets also results in an increase in belly firmness (Schieck et al., 2010).

Conclusions

Effects of inclusion of DDGS and corn germ on pig growth performance and fat quality were evaluated in many previous studies. It was concluded from many experiments that there is no negative impacts of inclusion of up to 30% DDGS in corn soybean meal diets on growth performance of growing-finishing pigs. However, inclusion of 30% DDGS in growing-finishing diets resulted in reduced pig growth performance in some experiments. Feeding up to 30% DDGS to growing-finishing pigs also results in reduced belly firmness and a linear increase in the IV of backfat, belly fat, and LM intramuscular fat. An increase in the concentration of linoleic acid (C18:2) in belly fat, backfat, and LM intramuscular fat with inclusion of DDGS in growing-finishing diets has also been documented. Withdrawing DDGS from the diet during the final 0 to 9 weeks prior to slaughter did not influence pig growth performance, but may result in reduced IV values of fat. Pig growth performance was not influenced by inclusion of up to 10% corn germ in diets fed to growing-finishing pigs, but pigs fed corn germ had lower IV in belly fat compared with pigs fed DDGS based diets. A possible nutritional strategy to ameliorate the negative effects of including DDGS in growing-finishing pig diets may be that dietary saturated fatty acids or glycerol may be included in diets containing DDGS. More research is needed to determine potential sources of dietary saturated fatty acids that can be fed to pigs and possible optimal inclusion levels of these fat sources.

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CHAPTER 3

NEGATIVE EFFECTS OF DISTILLERS DRIED GRAINS WITH SOLUBLES ON CARCASS FAT QUALITY OF PIGS ARE NOT AMELIORATED BY THE ADDITION OF CORN GERM, BEEF TALLOW, PALM KERNEL OIL, OR GLYCEROL TO FINISHING DIETS

ABSTRACT: The objective of this experiment was to determine if negative effects of distillers dried grains with solubles (**DDGS**) on carcass fat quality can be ameliorated by adding corn germ, tallow, palm kernel oil, or glycerol to diets fed to pigs. A total of 36 barrows and 36 gilts (initial BW: 43.7 ± 2.0 kg) were individually housed and randomly allotted to 1 of 6 dietary treatments in a 2 × 6 factorial design with sex and diet as factors. Each treatment had 12 replicate pigs. A corn-soybean meal control diet and a diet containing corn, soybean meal, and 30% DDGS were formulated. Four additional diets were formulated by adding 15% corn germ, 3% tallow, 3% palm kernel oil, or 5% glycerol to the DDGS-containing diet. Growth performance, carcass characteristics, and loin muscle quality were determined, and backfat and belly fat samples were collected for fatty acid analysis. There was no significant sex × diet interaction for all response variables measured. Diet had no effect on ADG, ADFI, or G:F, but barrows had greater ($P < 0.05$) ADG and ADFI and less ($P < 0.05$) G:F than gilts. There was no effect of diet on carcass characteristics, but pigs fed the DDGS diet had reduced ($P < 0.05$) loin eye area compared with pigs fed the control diet. Barrows had greater ($P < 0.05$) final BW, HCW, and backfat thickness, but less ($P < 0.05$) fat free lean percentage than gilts. Diet had no effect on loin muscle quality, but gilts had less ($P < 0.05$) marbling and 24-h loin pH than barrows. There was no effect of diet on a* and b* values of backfat, but backfat of pigs fed the 5 DDGS-containing diets had lower ($P < 0.05$) L* value than pigs fed the control diet. Backfat of gilts had greater ($P < 0.05$) a* and b* values than barrows. Diet had no effect on belly quality, but barrows had heavier ($P < 0.05$) bellies than gilts. Pigs fed the control diet had greater ($P < 0.05$) belly flop distance compared with those fed the 5 DDGS-containing diets; however, no differences were observed among pigs fed the diets containing DDGS. Barrows had greater ($P < 0.05$) belly flop distance than gilts. Diet had no effect on carcass fat IV. Gilts tended ($P = 0.07$) to have greater backfat IV and greater ($P = 0.05$) belly fat IV than barrows. In conclusion, the negative effect of DDGS on carcass fat quality were not ameliorated by including corn germ, tallow, palm kernel oil, or glycerol to the diet.

Key words: corn germ, distillers dried grains with solubles, fat quality, glycerol, oil, pigs

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) contains high levels of PUFA, especially linoleic (C18:2) acid (Stein and Shurson, 2009; Xu et al., 2010). High concentration of PUFA may suppress de novo lipid synthesis by promoting deposition of dietary fatty acids in adipose tissue (Clarke et al., 1990; Madsen et al., 1992). Therefore, feeding DDGS-based diets may increase deposition of PUFA in backfat and bellies, which may result in increased fat iodine values (**IV**) and reduced belly fat firmness in finishing pigs (Whitney et al., 2006; Widmer et al., 2008; Benz et al., 2010). Pork quality may also be affected including reduced shelf life, increased susceptibility to oxidative damage, and reduced belly sliceability (NPPC, 1999; Sheard et al., 2000; Averette Gatlin et al., 2002).

It is possible that the increase in pork fat IV caused by inclusion of DDGS may be prevented if saturated fats such as beef tallow or palm kernel oil is added to the diet (Averette Gatlin et al., 2002; Teye et al., 2006). Addition of corn germ to a corn-soybean meal diet resulted in reduced belly fat IV (Widmer et al., 2008), but there are no reports on inclusion of corn germ in diets containing DDGS. Crude glycerol is a co-product of biodiesel production (Thompson and He, 2006). It was previously observed that inclusion of glycerol to diets fed to growing pigs may reduce IV in muscle fat and backfat (Mourot et al., 1994) and carcass firmness was improved when glycerol was fed prior to slaughter (Schieck et al., 2010). Adding glycerol to DDGS-containing diet may potentially improve carcass fat quality.

Therefore, the objective of this experiment was to test the hypothesis that the negative effects of DDGS on pork fat quality can be ameliorated by supplementing DDGS-based diets with corn germ, tallow, palm kernel oil, or glycerol.

MATERIALS AND METHODS

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Pigs used in the experiment were the offspring of G-performer boars mated to F-25 females (Genetiporc, Alexandria, MN).

Animals, Housing, Experimental Design, and Diets

A total of 36 barrows and 36 gilts with an initial BW of 43.7 ± 2.0 kg were used in the experiment. All pigs were housed individually in pens (0.9 × 1.8 m) with fully slatted concrete floors. A feeder and a nipple drinker were installed in each pen. Pigs were allowed ad libitum access to feed and water throughout the experiment. The Experimental Animal Allotment Program (Kim and Lindemann, 2007) was used to randomly allot pigs to 1 of 6 dietary treatments in a 2 × 6 factorial design with sex (barrows and gilts) and diet as factors. There were 12 replicate pigs per diet (6 barrows and 6 gilts). The 6 dietary treatments were: 1) a corn-soybean meal-based control diet with no DDGS and no added fat; 2) the control diet with 30% DDGS; 3) the DDGS diet with 15% corn germ; 4) the DDGS diet with 3% tallow; 5) the DDGS diet with 3% palm kernel oil; and 6) the DDGS diet with 5% glycerol. The major ingredients used to formulate diets were corn, soybean meal, DDGS, corn germ, tallow, palm kernel oil, and glycerol (Tables 3.1 and 3.2). Experimental diets were fed in 2 phases. Early finisher diets (Table 3.3) were fed during the initial 42 d, and late finisher diets (Table 3.4) were fed during the final 46 d of the experiment. All diets were formulated to meet or exceed current estimates for nutrient requirements (NRC, 1998).

Feeding and Growth Performance

The 72 pigs that were used in the experiment were divided into 2 groups of 36 pigs and each group consisted of 18 barrows and 18 gilts. The 2 groups were allotted to treatment diets with a 1-wk interval and pigs in each group were harvested 1 wk apart to maintain the same number of days on feed for all pigs. Pigs were weighed at the beginning of the experiment, on d 42, and at the conclusion of the experiment (d 88). Daily allotments of feed were recorded and feed left in the feeders was recorded on d 42 and at the conclusion of the experiment. Data for

ADG, ADFI, and G:F were also calculated for each pig and summarized within each phase and overall for each sex and diet.

Slaughter and Carcass Evaluation

On the last day of the experiment, feed was removed from the feeders and the final BW of each pig was recorded. After an overnight fast, pigs were transported to the Meat Science Laboratory at the University of Illinois (Urbana, IL). Pigs were kept in the holding pens at the Meat Science Laboratory for 0 to 3 h before being slaughtered. They were allowed free access to water during this time. The live BW of each pig was recorded just prior to slaughter. Pigs were killed by electrical stunning, lifted off the floor, and exsanguinated. After reflex action had ended, pigs were scalded and washed. The HCW was then recorded and carcasses were chilled for 24 h. At 24 h post-mortem, the pH of the LM was measured at the 10^{th} rib by a handheld pH star probe fitted with a glass electrode (SFK Technologies Inc., Cedar Rapids, IA; 2-point calibration; pH 4 and 7). Backfat was measured perpendicular to the skin at the 3/4 point of the loin eye area (**LEA**) at the 10^{th} rib (NPPC, 1991). Loin eye area was measured by tracing the face of LM on double-matted acetate paper. Loin tracings were traced in duplicate using a Super Planix α polar planimeter (Tamaya Technics Inc., Tokyo, Japan), and the average of the 2 measurements was reported as LEA for each carcass.

Subjective LM color scores on a scale from 1 to 6 (1 = pale pinkish gray to white and 6 = dark purplish red) and LM marbling scores on a scale from 1 to 10 (1 = devoid and 10 = abundant) were determined (NPPC, 1999). Subjective LM firmness scores on a scale from 1 to 5 (1 = very soft and watery and 5 = very firm and dry) was also determined (NPPC, 1991). Objective CIE L* (lightness), a* (redness), and b* (yellowness; CIE, 1978) values of the loin muscle and of the fat obtained from the second layer were collected with a Minolta chromameter

(CR-400; Minolta Camera Co., Osaka, Japan). A 2.5-cm chop was collected at the 10th rib from the loin muscle by removing the loin muscle from the left of the carcasses 24 h post-mortem. The loin chop was placed in a plastic Whirl-Pak bag and suspended from a fish hook for 24 h. Drip loss was calculated by comparing the final and the initial weights of the chop.

At 24 h postmortem, the belly of each pig was removed from the left side of the carcass and laid flat on a stainless steel table at 2°C for 24 h. Belly length was then measured from the cranial to the caudal end of each belly and belly width was measured from the dorsal to the ventral edge. A flop test was performed by draping a centered belly lengthwise over a suspended, stainless steel rod with the skin side down. The distance from skin surface to skin surface was measured at a standardized point, 10 cm down from the stainless steel rod, for each belly (Leick et al., 2010).

Chemical Analysis and Calculations

Corn, soybean meal, DDGS, corn germ, and all diets were analyzed for DM by oven drying at 135°C for 2 h (method 930.15; AOAC Int., 2007), and dry ash (method 942.05; AOAC Int., 2007). Gross energy was determined using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. The CP in all samples was analyzed using a combustion procedure (method 990.03; AOAC Int., 2007) on an Elemental Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Aspartic acid was used as a calibration standard and CP was calculated as N ×6.25. The concentration of ether extract in the ingredients and diets was also analyzed (method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Analyses of AA in diets and ingredients were conducted on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc; Pleasaton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Prior to analysis, samples were hydrolyzed with 6*N* HCl for 24 h at 110°C (method 982.30 E(a); AOAC Int., 2007). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (method 982.30 E(b); AOAC Int., 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30 E(c); AOAC Int., 2007). Acid detergent fiber (method 973.18; AOAC Int., 2007) and NDF (Holst, 1973) were analyzed in all diets.

Fatty acid analysis of ingredients, diets, belly fat, and backfat samples was conducted according to Meadus et al. (2010) using gas chromatography (Hewlett Packard, Avondale, PA). Iodine value (**IV**) of ingredients, diets, belly fat, and backfat were calculated using the following equation (AOCS, 1998): IV = ([16:1] × 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 using the MIXED procedure (SAS Inst. Inc., Cary, NC) as a 2 × 6 factorial design with sex and diet as factors. Pig was the experimental unit for all analyses. The model included sex, diet, and sex × diet interaction as fixed effects and block as the random effect. However, interactions between sex and diet were not significant for any of the response variables analyzed, and therefore, the interaction was removed from the final model. Least squares means were calculated for each independent variable. When treatment effect was a significant source of variation, the PDIFF option of SAS was used to separate means. Significance and tendencies were set at $P \leq 0.05$ and $P \leq 0.10$, respectively, for all statistical tests.

RESULTS

Growth Performance

There were no differences in ADG among the dietary treatments in both the early and late finisher phases and the overall period (Table 3.5). As a result, there were no differences in BW at the end of both finisher phases. There were no differences in ADFI among the dietary treatments during the early finisher phase; however, ADFI of pigs fed the control diet was greater ($P < 0.05$) than for pigs fed the diet with 3% palm kernel oil during the late finisher phase. Overall, there was a tendency ($P = 0.06$) for greater ADFI for pigs fed the control compared with pigs fed the diet containing palm kernel oil. There was also a tendency ($P = 0.08$) for pigs fed diets containing tallow or palm kernel oil to have greater G:F than pigs fed DDGS or glycerol diets, but there were no differences in G:F in the late finisher phase. However, for the entire finisher period, there was a tendency ($P = 0.10$) for pigs fed the diet containing palm kernel oil to have greater G:F than pigs fed the control diet or the glycerol diet.

Barrows were heavier ($P < 0.01$) than gilts at the start of the experiment and at the end of both the early and late finisher phases. Barrows had greater ADG ($P < 0.05$) than gilts during the early finisher phase and the overall period. This is due to greater ($P < 0.001$) ADFI by barrows compared with gilts in both phases and the overall period. Gilts tended ($P = 0.07$) to have greater G:F during the early finisher phase and greater ($P < 0.001$) G:F than barrows during the late finisher phase and the overall period.

Carcass Characteristics

Except for LEA, there were no differences in carcass characteristics among the dietary treatments (Table 3.6). Loin eye area of pigs fed the control or the corn germ diet was greater ($P < 0.05$) than those fed the DDGS or the palm kernel oil diet. Pigs fed the tallow or glycerol diet also had greater ($P < 0.05$) LEA than pigs fed the DDGS diet. Barrows had greater ($P < 0.001$) live BW, HCW, and backfat thickness, but less ($P < 0.001$) fat free lean percentage than gilts. No differences were observed in the dressing percentage and LEA of barrows and gilts.

Muscle Quality

Diet had no effect on subjective color, marbling, firmness, 24-h pH, 48-h drip loss, and objective color (L*, a*, b*) of the LM (Table 3.6). There were no differences in a* and b* values of backfat among the dietary treatments, but the L* value of backfat from pigs fed the control diet was greater ($P < 0.001$) than for pigs fed the 5 DDGS-containing diets. Gilts had less ($P < 0.05$) marbling and reduced ($P < 0.001$) 24-h LM pH compared with barrows. Gilts had greater ($P < 0.001$) a* and b* values of backfat than barrows, but L* was not different between barrows and gilts. There were also no differences between barrows and gilts for the other loin muscle quality characteristics.

Belly Quality

There were no differences in belly length, belly width, or belly weight among the dietary treatments (Table 3.7). However, belly flop distance was greater ($P < 0.001$) in pigs fed the control diet than bellies of pigs fed the 5 DDGS-containing diets. There were no differences in belly flop distance among pigs fed the diets containing DDGS. Barrows had heavier ($P < 0.001$) bellies and greater ($P < 0.001$) belly flop distance than gilts.

Carcass Fat Composition and Quality

Except for a tendency ($P = 0.06$) in C20:1, no differences were observed in the fatty acid composition of backfat from pigs fed the different dietary treatments (Table 3.8). As a result, there was no effect of dietary treatment on backfat IV. Likewise, there were no differences in the fatty acid composition of belly fat among the dietary treatments except for C18:1 (Table 3.9). The C18:1 concentration of belly fat was greater ($P < 0.01$) in pigs fed the control diet than those fed the other dietary treatments except for the tallow diet. Pigs fed the tallow diet also had greater ($P < 0.01$) C18:1 concentration in belly fat than those fed the DDGS, corn germ, or glycerol diet. The concentration of total MUFA was greater ($P = 0.04$) in belly fat of pigs fed the control diet compared with those fed the other dietary treatments except those fed the tallow or the palm kernel oil diet. Pigs fed the tallow diet also had greater ($P < 0.05$) total MUFA in belly fat than those fed the DDGS or glycerol diet. However, there was no effect of dietary treatment on belly fat IV.

Backfat of barrows contained more ($P < 0.05$) C16:0 and C16:1 than those of gilts, and there was a tendency ($P = 0.07$) for barrows to have a greater concentration of total SFA in the backfat compared with gilts. In contrast, there was a tendency ($P = 0.09$) for gilts to have greater concentrations of C:18:2n-6 and total PUFA in the backfat than barrows. Belly fat from barrows contained more ($P < 0.05$) C16:0, but less ($P < 0.05$) C18:3n-3 and a tendency ($P = 0.07$) for lower UFA:SFA ratio than gilts. Gilts tended ($P = 0.07$) to have greater backfat IV and greater ($P = 0.05$) belly fat IV than barrows.

DISCUSSION

Growth Performance

The concentration of Lys in the DDGS used in this experiment was greater than the average for DDGS (Stein and Shurson, 2009). This resulted in a Lys:CP ratio of 3.58%, which is also greater than for average DDGS. This indicates that the DDGS used in this experiment was of a good quality. The fact that pigs fed the DDGS-containing diets had ADG and G:F that was not different from that of pigs fed the control diet indicates that if a good quality DDGS is used, growth performance is not reduced. This observation is in agreement with previous data (Stein and Shurson, 2009).

Inclusion of 10% corn germ in corn-soybean meal diets fed to growing-finishing pigs does not affect growth performance (Widmer et al., 2008), but to our knowledge, data for the effect of adding corn germ to a diet containing DDGS have not been reported. Additional research is needed to determine how much corn germ may be included in diets fed to growing-finishing pigs, but results of this experiment indicate that as much as 15% corn germ may be included in corn-soybean meal diets containing 30% DDGS without negatively affecting growth performance.

Growth performance of pigs fed corn-soybean meal diets with 5 or 10% tallow is not different from that of pigs fed diets with no tallow (Apple et al., 2009; Realini et al., 2010). Results of the current experiment indicate that adding 3% tallow to corn-soybean meal diets containing 30% DDGS does not affect growth performance of growing-finishing pigs, which agree with Apple et al. (2009) and Realini et al. (2010). However, ADG of pigs fed corn-soybean meal diets containing 40% sorghum DDGS was not affected by adding tallow to the diet, but G:F was improved (Feoli et al., 2008a). Data from this experiment also indicate that inclusion of 3% palm kernel oil in a corn-soybean meal-DDGS diet has no effect on growth performance of growing-finishing pigs. Likewise, adding 2.8% palm kernel oil to diets based on wheat, barley, and soybean meal did not affect pig growth performance (Teye et al., 2006). It is, therefore, evident that 3% tallow or palm kernel oil is not sufficient to improve G:F of pigs fed corn-soybean meal-DDGS diets.

Inclusion of 8% glycerol in corn-soybean meal diets may improve ADG, ADFI, and G:F (Schieck et al., 2010), but we were not able to repeat this effect. It is possible that the reason for this difference is that in the present experiment, glycerol was included in a diet that also contained DDGS. Growth performance of pigs fed diets containing 5% glycerol and 20% DDGS was similar to that of pigs fed a control diet without glycerol (Duttlinger et al., 2011), and the present results indicate that inclusion of 5% glycerol in a diet that contains 30% DDGS has no impact on pig growth performance.

Carcass Characteristics

The fact that dressing percentage of pigs fed the DDGS-containing diets was not different from that of pigs fed the control diet is in agreement with results of some previous experiments (Drescher et al., 2008; Hill et al., 2008; Widmer et al., 2008). However, in a review of 18 experiments, it was reported that in 8 of these experiments, dressing percentage was reduced as DDGS was included in the diet (Stein and Shurson, 2009). It is not clear why dressing percentage is sometimes reduced when DDGS is included in the diet but not in other cases. The reduced LEA of pigs fed the DDGS diet compared with pigs fed the control diet is largely a result of the numerically reduced HCW for these pigs because lean percentage was not affected by DDGS. This observation is also in agreement with results of previous research (Stein and Shurson, 2009). The lack of an effect of feeding glycerol on carcass characteristics of finishing pigs is also consistent with other research (Kijora et al., 1997; Lammers et al., 2008; Schieck et al., 2010).

Muscle Quality

The lack of an effect of DDGS on LM marbling, firmness, drip loss, and color indicates that addition of DDGS to corn-soybean meal diets does not affect loin muscle quality. This observation is also in agreement with previous data (Whitney et al., 2006; Widmer et al., 2008). A reduction in a* and b* values of LM was reported when DDGS-containing diets were fed to pigs (Xu et al., 2010). Likewise, LM b* value was reduced by including DDGS to the diet (Widmer et al., 2008). There were, however, no changes in LM objective color scores in this experiment when DDGS was used. The fact that yellowness and redness of the LM of pigs fed diets containing DDGS is not changed when diets are supplemented with tallow, palm kernel oil, corn germ, or glycerol indicates that consumers would not be able to distinguish between loin chops from DDGS-fed pigs from those of pigs fed corn-soybean meal diets.

The L* value of backfat was reduced when DDGS was added to a corn-soybean meal diet (Xu et al., 2010), and results of this experiment are in agreement with those of Xu et al. (2010). Feeding DDGS to laying hens resulted in increased egg yolk color compared with eggs from hens fed a corn-soybean meal diet, which was explained by the greater concentration of xanthophylls in DDGS compared with corn and soybean meal (Masàdeh et al., 2011). It was also concluded that xanthophylls in DDGS are highly available. It is possible that backfat color in pigs fed DDGS-based diets were affected by the increased level of xanthophylls fed to pigs compared with those fed the control diet and that the xanthophylls in DDGS resulted in darker backfat color in pigs. The lack of an effect of including corn germ, tallow, palm kernel oil, or glycerol to the DDGS-containing diet on L* values of backfat indicate that the darker color caused by DDGS is not changed by including other lipid sources or glycerol to the diet.

Belly Quality

Belly firmness of pigs fed DDGS-containing diets is reduced compared with those fed corn-soybean meal diets with no DDGS (Whitney et al., 2006; Chromwell et al., 2011). The increased belly flop distance observed in this experiment is in agreement with this observation. As expected, the analyzed fatty acid composition of corn germ was similar to those in corn and DDGS, which may explain the lack of an effect of corn germ on belly flop distance when added to a diet containing DDGS. It is, however, surprising that the dietary inclusion of tallow and palm kernel oil did not ameliorate the negative effect of DDGS on belly flop distance. It was expected that addition of these fat sources to the diet would have resulted in deposition of more SFA in belly fat, which theoretically should have improved belly flop distance (Lizardo et al., 2002). However, the inclusion of either 5% tallow or 5% palm oil to a corn-soybean meal diet containing 40% sorghum DDGS also failed to improve belly firmness of finishing pigs (Feoli et al., 2008a), whereas pigs fed 5% coconut oil had firmer bellies similar to those fed diets without DDGS (Feoli et al., 2008b). Coconut oil contains about 90% SFA compared with 50% in both tallow and palm oil (Feoli et al., 2008b). Therefore, the inclusion rate or the fat source may influence the effects of dietary saturated fats in negating the effects of DDGS on belly firmness. It was also reported that pigs fed 8% glycerol tended to have firmer bellies compared with pigs that were not fed glycerol (Schieck et al., 2010), but results of this experiment indicate that 5% glycerol is not effective in improving belly firmness in diets containing 30% DDGS.

Carcass Fat Quality

In most experiments, IV was increased as DDGS is included in the diet (Stein and Shurson, 2009). Recent data also indicate that carcass fat IV of pigs fed diets containing DDGS is increased regardless of the fat depot analyzed (Benz et al., 2010; Xu et al., 2010). It is not clear why carcass fat IV is increased in some experiments when DDGS is included in the diet but not in others.

Belly fat IV was reduced in pigs fed a corn-soybean meal diet containing 10% corn germ compared with those fed corn-soybean meal diets or DDGS-containing diets (Widmer et al., 2008). Result of the present experiment was not in agreement with this earlier observation. It may be due to the fact that the analyzed IV of corn germ was similar to those in corn and DDGS. It was also hypothesized that adding tallow or palm kernel oil to the diet would reduce carcass fat IV. Feeding pigs a diet containing 5% tallow reduced backfat IV compared with those fed basal diets with no fat added (Averette Gatlin et al., 2002). However, jowl fat IV was unaffected when 5% tallow or 5% palm oil was added to a corn-soybean meal diet containing 40% sorghum DDGS (Feoli et al., 2008a). Results of the present experiment were in agreement with Feoli et al. (2008a). The reason we did not observe an improvement in fat IV in this experiment may be that inclusion of 30% DDGS in the diet results in addition of approximately 3% corn oil to the diets. This may have negated the potential positive effects of tallow or palm kernel oil on the fatty acid composition of carcass fat. When 5% stearic acid or 5% coconut oil was added to DDGS-containing diets, only coconut oil reduced jowl fat IV (Feoli et al., 2008b). Both stearic acid and coconut oil contain twice as much SFA as tallow and palm oil (Feoli et al., 2008a,b); however, stearic acid mostly contains C18:0 and C16:0 whereas coconut oil is mostly composed of C12:0 and C14:0. This suggests that the fatty acid composition of saturated fats may play a role in affecting the degree of unsaturation of the diet.

Inclusion of glycerol in diets was reported to reduce the degree of unsaturation in backfat (Mourot et al., 1994) because lipogenic substrates that are synthesized during glycerol metabolism may be increased by inclusion of glycerol in the diets. However, this effect does not appear to impact fat deposition in pigs fed diets containing DDGS. The negative effects of DDGS on pork fat quality were also not ameliorated by the inclusion of 5% glycerol in a diet containing 20% DDGS (Duttlinger et al., 2011).

Gender Effects

Typical growth and carcass trait differences between barrows and gilts were observed in this study as barrows had greater ADFI, poorer G:F, and fatter carcasses than gilts. The softer bellies and greater carcass fat IV in gilts compared with barrows is also consistent with previous research (Averette-Gatlin et al., 2002; Correa et al., 2008; Benz et al., 2010), and gilts had less backfat and had greater fat free lean percentage compared with barrows. Greater fat deposition increases the degree of saturation of carcass fat (Wood and Enser, 1982; Lo Fiego, 1996; De Smet et al., 2004). As a result, IV increases as fat depth decreases (Barton-Gade, 1984). This may explain the observed differences in carcass fat IV between gilts and barrows.

In conclusion, the negative effect of DDGS on carcass fat quality was not ameliorated by the inclusion of corn germ, tallow, palm kernel oil, or glycerol in diets fed to finishing pigs. Further research is needed to identify alternative feed ingredients or fat sources that may be added to DDGS-containing diets to negate the effects of DDGS on carcass fat quality.

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Table 3.1. Analyzed composition in corn, soybean meal, dried distillers grains with solubles (DDGS), and corn germ (as-fed basis)

Item	Corn	Soybean meal	DDGS	Corn germ
DM, %	85.97	86.48	84.79	89.69
GE, kcal/kg	3,769	4,146	4,697	4,579
Ash, %	1.11	7.11	4.27	5.01
Ether extract, %	2.64	1.10	8.58	14.40
CP (N × 6.25), %	6.67	46.07	26.28	13.99
Indispensable AA, %				
Arg	0.29	3.24	1.12	0.88
His	0.19	1.13	0.75	0.39
Ile	0.21	2.06	1.00	0.43
Leu	0.66	3.42	2.76	1.02
Lys	0.22	2.81	0.94	0.70
Met	0.12	0.62	0.48	0.20
Phe	0.27	2.21	1.11	0.52
Thr	0.22	1.63	0.99	0.47
Trp	0.06	0.58	0.18	0.10
Val	0.29	2.22	1.34	0.64
Dispensable AA, %				
Ala	0.42	1.98	1.66	0.81

Table 3.1 (cont.)

Asp	0.39	4.94	1.60	0.99
Cys	0.14	0.66	0.48	0.25
Glu	0.99	7.56	3.24	1.70
Gly	0.25	1.86	0.98	0.63
Pro	0.48	2.18	1.61	0.80
Ser	0.25	1.79	1.02	0.47
Tyr	0.18	1.58	0.82	0.36

Table 3.2. Analyzed fatty acid composition (% of total fatty acids) in corn, soybean meal, distillers dried grains with solubles (DDGS), corn germ, tallow, and palm kernel oil (as-fed basis)

Item	Corn	Soybean meal	DDGS	Corn germ	Tallow	Palm kernel oil
Caproic acid, C6:0	0.11	0.05	0.21	-	0.31	0.15
Capric acid, C10:0	0.02	0.09	-	-	0.09	0.06
Lauric acid, C12:0	0.01	-	0.06	-	0.21	0.18
Myristic acid, C14:0	0.08	0.14	0.24	-	3.67	1.32
Palmitic acid, C16:0	11.25	13.06	12.06	10.61	23.32	45.69
Palmitoleic acid, C16:1	0.14	0.13	0.11	-	3.08	0.17
Margaric acid, 17:0	0.04	0.13	0.03	-	1.32	0.10
Stearic acid, C18:0	2.07	4.08	2.14	1.38	17.92	4.04
Oleic acid, 18:1	23.74	16.19	23.32	25.25	42.52	36.34
Linoleic acid, C18:2	59.41	55.20	58.85	59.89	3.43	10.99
Linolenic acid, C18:3	1.62	10.09	1.66	1.36	0.58	0.43
Arachidic acid, C20:0	0.29	0.29	0.26	0.54	0.53	0.33
Gadoleic acid, C20:1	0.14	0.10	0.15	0.09	0.17	0.13
Eicosadienoic acid, C20:2	-	-	-	-	0.07	-
Eicosatrienoic acid, C20:3	0.10	0.28	-	-	-	-
Arachidonic acid, C20:4	-	-	0.02	-	-	-
Total SFA,[1] %	13.88	17.83	15.00	12.53	47.37	51.87

Table 3.2 (cont.)

Total MUFA,[2] %	24.17	16.54	22.59	25.33	45.77	36.64
Total PUFA,[3] %	61.13	65.56	60.52	61.24	4.08	11.42
UFA:SFA ratio[4]	6.15	4.61	5.54	6.91	1.05	0.93
PUFA:SFA ratio[5]	4.41	3.68	4.03	4.89	0.09	0.31
Iodine value,[6] g/100 g	127.8	136.1	125.7	129.0	47.1	51.7

[1]Total SFA = ([C6:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0]); brackets represent concentration.

[2]Total MUFA = ([C16:1] + [C17:1] + [C18:1] + [C20:1]); brackets represent concentration.

[3]Total PUFA = ([C18:2] + [C18:3] + [C20:2] + [C20:3] + [C20:4]); brackets represent concentration.

[4]UFA:SFA ratio = [total PUFA + total MUFA]/total SFA.

[5]PUFA:SFA ratio = total PUFA/total SFA.

[6]Iodine value (IV) = ([16:1] × 0.95) + ([C18:1] × 0.86) + ([C18:2] × 1.732) + ([C18:3] × 2.616) + ([C20:1] × 0.785) + ([C22:1] × 0.723); brackets represent concentration (AOCS, 1998).

Table 3.3. Composition of early finisher diets (as-fed basis)

	Diet					
Item	Control	DDGS[1]	Corn germ	Tallow	Palm kernel oil	Glycerol
Ingredient, %						
Ground corn	72.65	55.45	41.70	52.40	52.40	50.38
Soybean meal, 48% CP	25.00	12.25	11.00	12.25	12.25	12.25
DDGS	-	30.00	30.00	30.00	30.00	30.00
Corn germ	-	-	15.00	-	-	-
Tallow	-	-	-	3.00	-	-
Palm kernel oil	-	-	-	-	3.00	-
Glycerol	-	-	-	-	-	5.00
Ground limestone	0.85	1.20	1.30	1.20	1.20	1.20
Dicalcium phosphate	0.80	0.10	-	0.13	0.13	0.15
L-Lys HCL	-	0.30	0.30	0.32	0.32	0.32
NaCl	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30
Analyzed composition, %						
DM	87.33	87.33	88.25	87.85	87.36	82.39
GE, kcal/kg	3,768	4,091	4,185	4,326	4,302	4,191
CP (N × 6.25)	15.36	16.67	15.32	17.26	17.46	17.37
Ether extract	2.35	4.85	6.08	7.48	7.39	4.13

Table 3.3 (cont.)

Ash	2.85	4.10	4.37	4.58	4.77	4.35
ADF	2.73	5.00	4.42	4.68	4.70	4.70
NDF	9.21	18.40	18.58	14.58	14.34	14.99
Dietary IV,[3] g/100 g	126.7	126.4	127.1	105.2	101.8	127.8
Indispensable AA, %						
Arg	1.00	0.91	0.83	0.87	0.92	0.90
His	0.44	0.50	0.45	0.47	0.49	0.44
Ile	0.66	0.69	0.60	0.65	0.68	0.66
Leu	1.36	1.73	1.54	1.63	1.65	1.64
Lys	0.85	1.04	1.04	0.98	1.04	0.96
Met	0.23	0.31	0.28	0.28	0.30	0.29
Phe	0.76	0.80	0.71	0.75	0.79	0.77
Thr	0.58	0.66	0.60	0.63	0.65	0.61
Trp	0.18	0.17	0.16	0.16	0.18	0.18
Val	0.77	0.87	0.79	0.83	0.85	0.83

[1]DDGS = distillers dried grains with solubles.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid,

44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]Iodine value (IV) = ([16:1] × 0.95) + ([C18:1] × 0.86) + ([C18:2] × 1.732) + ([C18:3] × 2.616) + ([C20:1] × 0.785) + ([C22:1] × 0.723); brackets represent concentration (AOCS, 1998).

Table 3.4. Composition of late finisher diets (as-fed basis)

Item	Diet					
	Control	DDGS[1]	Corn germ	Tallow	Palm kernel oil	Glycerol
Ingredient, %						
Ground corn	79.65	62.40	43.43	59.37	59.37	57.37
Soybean meal, 48% CP	18.25	5.50	4.25	5.50	5.50	5.50
DDGS	-	30.00	30.00	30.00	30.00	30.00
Corn germ	-	-	15.00	-	-	-
Tallow	-	-	-	3.00	-	-
Palm kernel oil	-	-	-	-	3.00	-
Glycerol	-	-	-	-	-	5.00
Ground limestone	0.80	1.09	1.30	1.09	1.09	1.09
Dicalcium phosphate	0.60	-	-	-	-	-
L-Lys HCL	-	0.30	0.30	0.32	0.32	0.32
L-Trp	-	0.01	0.02	0.02	0.02	0.02
NaCl	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30
Analyzed composition, %						
DM	86.70	86.46	86.61	88.15	88.30	85.68
GE, kcal/kg	3,891	4,119	4,200	4,361	4,346	4,206
CP (N × 6.25)	14.46	15.73	15.92	13.55	13.58	13.64

Table 3.4 (cont.)

Ether extract	3.02	4.60	5.68	8.38	8.21	4.92
Ash	3.52	3.84	4.11	3.49	3.39	3.39
ADF	2.32	4.48	3.99	4.57	4.64	4.97
NDF	7.54	14.55	16.47	14.99	14.71	16.52
Dietary IV,[3] g/100 g	129.1	126.3	126.3	95.3	97.1	122.4
Indispensable AA, %						
Arg	0.85	0.73	0.72	0.68	0.62	0.73
His	0.39	0.43	0.38	0.42	0.39	0.45
Ile	0.57	0.57	0.54	0.55	0.50	0.56
Leu	1.24	1.52	1.48	1.52	1.40	1.58
Lys	0.72	0.81	0.80	0.83	0.79	0.89
Met	0.22	0.26	0.27	0.26	0.24	0.29
Phe	0.66	0.67	0.65	0.65	0.60	0.66
Thr	0.50	0.57	0.58	0.53	0.49	0.61
Trp	0.16	0.15	0.16	0.14	0.16	0.16
Val	0.67	0.73	0.71	0.72	0.66	0.75

[1]DDGS = distillers dried grains with solubles.

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-

pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]Iodine value (IV) = ([16:1] × 0.95) + ([C18:1] × 0.86) + ([C18:2] × 1.732) + ([C18:3] × 2.616) + ([C20:1] × 0.785) + ([C22:1] × 0.723); brackets represent concentration (AOCS, 1998).

Table 3.5. Effect of adding corn germ, beef tallow, palm kernel oil, and crude glycerol to DDGS-containing diets on growth performance of finishing pigs[1,2]

	Diet								Sex			
Item	Control	DDGS[3]	Corn germ	Tallow	PKO[4]	Glycerol	SEM	*P*-value	Barrows	Gilts	SEM	*P*-value
Early finisher (d 0 to 42)												
Initial BW, kg	43.5	43.3	43.8	43.8	43.5	44.1	1.0	0.90	44.3	43.1	1.0	0.01
ADG, kg	1.03	0.98	1.02	1.03	1.03	1.01	0.03	0.85	1.08	0.95	0.02	<0.001
ADFI, kg	2.73	2.64	2.68	2.61	2.55	2.77	0.07	0.28	2.89	2.44	0.04	<0.001
G:F	0.38	0.37	0.39	0.40	0.40	0.37	0.01	0.08	0.38	0.39	0.01	0.07
Final BW, kg	86.9	84.3	86.8	87.1	86.7	86.5	1.6	0.85	89.8	83.0	0.9	<0.001
Late finisher (d 42 to 88)												
ADG, kg	0.95	0.93	0.93	0.93	0.94	0.90	0.04	0.96	0.93	0.93	0.02	0.84
ADFI, kg	2.97[a]	2.70[ab]	2.79[ab]	2.77[ab]	2.54[b]	2.69[ab]	0.09	0.04	2.89	2.59	0.05	<0.001
G:F	0.33	0.35	0.33	0.34	0.37	0.34	0.01	0.20	0.32	0.36	0.01	<0.001
Final BW, kg	130.6	127.0	129.5	129.8	129.9	128.0	2.5	0.92	132.4	125.9	1.4	0.002
Entire period (d 0 to 88)												

Table 3.5 (cont.)

ADG, kg	0.99	0.95	0.97	0.98	0.98	0.95	0.03	0.91	1.00	0.94	0.02	0.01
ADFI, kg	2.85	2.67	2.74	2.70	2.54	2.73	0.07	0.06	2.89	2.52	0.04	<0.001
G:F	0.35	0.36	0.36	0.37	0.39	0.35	0.01	0.10	0.35	0.38	0.01	0.001

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

[1]Data for diets are means of 12 observations per treatment (6 barrows and 6 gilts). Data for sex are means of 36 observations.

[2]Diet × sex interactions were not significant.

[3]DDGS = distillers dried grains with solubles.

[4]PKO = palm kernel oil.

Table 3.6. Effect of adding corn germ, tallow, palm kernel oil, and glycerol to DDGS-containing diets on carcass characteristics and loin muscle quality of finishing pigs[1,2]

	Diet								Sex			
Item	Control	DDGS[3]	Corn germ	Tallow	PKO[4]	Glycerol	SEM	*P*-value	Barrows	Gilts	SEM	*P*-value
Carcass characteristics												
Live wt, kg	127.1	122.7	126.1	126.1	125.9	124.4	2.32	0.80	128.7	122.1	1.34	<0.001
HCW, kg	99.4	95.1	98.4	98.5	98.0	96.1	1.85	0.56	100.4	94.7	1.07	<0.001
Dressing,[5] %	78.1	77.5	78.0	78.1	77.8	77.2	0.30	0.18	78.00	77.6	0.17	0.10
Backfat, cm	1.93	1.73	1.93	1.85	1.96	1.84	0.11	0.66	2.27	1.47	0.06	<0.001
Loin eye area, cm^2	54.7[a]	47.5[c]	54.4[a]	52.5[ab]	50.1[bc]	51.5[ab]	1.74	0.003	51.0	52.6	1.34	0.16
FFL,[6] %	54.5	54.2	54.6	54.5	53.6	54.5	0.59	0.84	52.3	56.3	0.34	<0.001
Loin muscle quality												
24-h LM pH	5.59	5.55	5.62	5.62	5.58	5.61	0.03	0.36	5.62	5.56	0.02	<0.001
48-h drip loss, %	8.41	7.47	6.74	12.72	8.61	6.90	3.05	0.75	6.76	10.19	1.76	0.17
Subjective evaluation[7]												
Color	2.67	2.67	2.58	2.75	2.33	2.58	0.25	0.73	2.64	2.56	0.20	0.60
Marbling	2.00	1.50	1.67	1.42	1.50	1.58	0.16	0.14	1.78	1.44	0.09	0.01
Firmness	2.50	2.58	2.33	2.42	1.83	2.42	0.37	0.13	2.42	2.28	0.33	0.39

Table 3.6 (cont.)

LM color[8]														
L*	54.4	51.9	50.9	50.5	53.9	51.5	1.62	0.18	51.8	52.5	1.23	0.51
a*	7.79	8.55	7.69	8.28	8.29	8.05	0.71	0.86	8.13	8.09	0.57	0.93
b*	4.74	4.31	3.16	3.40	4.39	3.51	0.68	0.29	3.89	3.95	0.49	0.89
Backfat color												
L*	76.4[a]	73.7[b]	73.3[b]	73.8[b]	73.7[b]	74.0[b]	0.88	<0.001	74.3	74.1	0.81	0.48
a*	3.81	4.58	4.19	3.74	4.26	3.97	0.39	0.65	3.55	4.64	0.22	0.001
b*	4.87	5.10	4.71	4.77	4.85	4.57	0.26	0.61	4.39	5.23	0.19	<0.001

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

[1]Data for diets are means of 12 observations per treatment (6 barrows and 6 gilts). Data for sex are means of 36 observations.

[2]Diet × sex interactions were not significant.

[3]DDGS = distillers dried grains with solubles.

[4]PKO = palm kernel oil.

[5]Dressing, % = HCW/ live wt × 100.

[6]Fat free lean (FFL), % = as calculated from NPPC (1999): lbs FFL = 8.588 – (21.896 × 10th rib fat depth, in.) + (0.465 × HCW, lb.) + (3.005 × 10th rib loin muscle area, sq. in.); (lbs FFL/HCW) × 100 = % FFL.

[7]Subjective evaluations based on National Pork Producers Council (Des Moines, IA) standards.

[8]L* = lightness; a* = redness; b* = yellowness.

Table 3.7. Effect of adding corn germ, tallow, palm kernel oil, and glycerol to DDGS-containing diets on belly quality of finishing pigs[1,2]

	Diet								Sex			
Item	Control	DDGS[3]	Corn germ	Tallow	PKO[4]	Glycerol	SEM	*P*-value	Barrows	Gilts	SEM	*P*-value
Belly length, cm	63.6	61.9	61.7	62.1	60.4	62.0	1.6	0.52	62.2	61.6	1.4	0.45
Belly width, cm	23.7	24.3	24.6	24.6	24.6	24.5	0.5	0.81	24.7	24.1	0.3	0.16
Belly wt, kg	8.1	8.2	8.5	8.3	8.2	8.2	2.8	0.83	8.6	7.9	2.8	<0.001
Flop distance, cm	18.1[a]	9.7[b]	9.6[b]	10.0[b]	8.8[b]	10.3[b]	0.8	<0.001	13.2	9.0	0.5	<0.001

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

[1]Data for diets are means of 12 observations per treatment (6 barrows and 6 gilts). Data for sex are means of 36 observations.

[2]Diet × sex interactions were not significant.

[3]DDGS = distillers dried grains with solubles.

[4]PKO = palm kernel oil.

Table 3.8. Effect of adding corn germ, tallow, palm kernel oil, and glycerol to DDGS-containing diets on backfat quality of finishing pigs[1,2]

	Diet								Sex			
Item	Control	DDGS[3]	Corn germ	Tallow	PKO[4]	Glycerol	SEM	*P*-value	Barrows	Gilts	SEM	*P*-value
Myristic acid (14:0), %	1.61	1.77	1.93	1.76	1.79	1.82	0.21	0.56	1.83	1.73	0.19	0.33
Palmitic acid (16:0), %	22.60	21.36	21.10	21.52	22.73	22.48	0.70	0.40	22.70	21.23	0.41	0.01
Palmitoleic acid (16:1), %	2.04	2.07	1.96	1.96	2.02	2.03	0.15	0.99	2.13	1.89	0.10	0.02
Margaric acid (17:0), %	0.30	0.40	0.40	0.35	0.28	0.30	0.05	0.16	0.32	0.36	0.04	0.17
Stearic acid (18:0), %	11.12	9.75	9.62	10.16	9.39	10.40	0.64	0.44	10.40	9.87	0.37	0.43
Oleic acid (18:1 *cis*-9), %	38.24	35.37	35.34	37.10	36.49	36.21	0.93	0.24	36.75	36.17	0.54	0.45
Linoleic acid (18:2n-6), %	20.40	24.96	24.89	23.08	23.38	22.76	1.84	0.54	21.92	24.56	1.06	0.09
α-Linolenic acid (18:3n-3), %	0.71	0.79	0.83	0.77	0.76	0.69	0.06	0.61	0.74	0.78	0.04	0.48
Arachidic acid (20:0), %	0.26	0.36	0.34	0.29	0.25	0.26	0.05	0.57	0.28	0.31	0.03	0.52
Gadoleic acid (20:1), %	0.57	0.62	0.81	0.57	0.63	0.61	0.08	0.06	0.62	0.64	0.06	0.70
Arachidonic acid (20:4n-6), %	0.34	0.40	0.45	0.35	0.38	0.37	0.06	0.60	0.37	0.39	0.05	0.46
Total SFA,[5] %	36.37	34.33	34.12	34.71	35.08	35.90	1.28	0.79	36.05	34.12	0.74	0.07
Total MUFA,[6] %	41.13	38.46	38.47	40.01	39.45	39.22	0.99	0.40	39.86	39.06	0.57	0.33
Total PUFA,[7] %	22.34	27.16	27.36	25.24	25.45	24.80	1.94	0.50	24.00	26.78	1.12	0.09

Table 3.8 (cont.)

UFA:SFA ratio[8]	1.83	1.94	1.95	1.91	1.90	1.81	0.10	0.89	1.82	1.96	0.06	0.11
PUFA:SFA ratio[9]	0.67	0.81	0.82	0.75	0.76	0.71	0.08	0.74	0.70	0.80	0.04	0.11
Iodine value,[10] g/100 g	72.7	78.6	78.6	76.6	76.6	75.2	2.6	0.61	74.4	78.4	1.5	0.07

[1]Data for diets are means of 12 observations per treatment (6 barrows and 6 gilts). Data for sex are means of 36 observations.

[2]Diet × sex interactions were not significant.

[3]DDGS = distillers dried grains with solubles.

[4]PKO = palm kernel oil.

[5]Total SFA = ([C6:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0]); brackets represent concentration.

[6]Total MUFA = ([C16:1] + [C17:1] + [C18:1] + [C20:1]); brackets represent concentration.

[7]Total PUFA = ([C18:2] + [C18:3] + [C20:2] + [C20:3] + [C20:4]); brackets represent concentration.

[8]UFA:SFA ratio = [total PUFA + total MUFA]/total SFA.

[9]PUFA:SFA ratio = total PUFA/total SFA.

[10]Iodine value (IV) = ([16:1] × 0.95) + ([C18:1] × 0.86) + ([C18:2] × 1.732) + ([C18:3] × 2.616) + ([C20:1] × 0.785) + ([C22:1] × 0.723); brackets represent concentration (AOCS, 1998).

Table 3.9. Effect of adding corn germ, tallow, palm kernel oil, and glycerol to DDGS-containing diets on belly fat quality of finishing pigs[1,2]

	Diet								Sex			
Item	Control	DDGS[3]	Corn germ	Tallow	PKO[4]	Glycerol	SEM	*P*-value	Barrows	Gilts	SEM	*P*-value
Myristic acid (14:0), %	1.76	2.07	1.99	1.83	1.94	2.23	0.18	0.43	2.07	1.88	0.11	0.17
Palmitic acid (16:0), %	21.27	20.99	20.59	21.07	21.76	22.24	0.55	0.34	21.90	20.73	0.32	0.01
Palmitoleic acid (16:1), %	2.87	3.02	2.67	2.81	2.63	2.86	0.21	0.71	2.84	2.78	0.14	0.67
Margaric acid (17:0), %	0.24	0.27	0.28	0.32	0.23	0.25	0.03	0.29	0.27	0.26	0.02	0.68
Stearic acid (18:0), %	8.45	7.29	7.63	8.28	8.30	7.56	0.46	0.33	8.12	7.72	0.29	0.27
Oleic acid (18:1 *cis*-9), %	42.95[a]	39.56[c]	39.89[c]	42.23[ab]	40.50[bc]	39.58[c]	0.82	0.01	40.78	40.79	0.48	0.98
Linoleic acid (18:2n-6), %	18.69	22.83	22.53	19.22	20.31	21.53	1.39	0.19	20.07	21.63	0.80	0.17
α-Linolenic acid (18:3n-3), %	0.74	0.91	0.89	0.82	0.85	0.86	0.04	0.06	0.81	0.88	0.02	0.03
Arachidic acid (20:0), %	0.17	0.22	0.21	0.20	0.14	0.18	0.04	0.74	0.18	0.19	0.02	0.64
Gadoleic acid (20:1), %	0.63	0.56	0.66	0.72	0.75	0.60	0.08	0.30	0.66	0.65	0.05	0.79
Arachidonic acid (20:4n-6), %	0.36	0.36	0.40	0.36	0.32	0.32	0.03	0.50	0.34	0.37	0.02	0.35
Total SFA,[5] %	32.94	31.89	31.83	32.72	33.64	33.47	0.92	0.63	33.37	32.12	0.53	0.10
Total MUFA,[6] %	46.76[a]	43.48[c]	43.51[bc]	46.17[ab]	44.15[abc]	43.36[c]	0.99	0.04	44.61	44.54	0.63	0.93
Total PUFA,[7] %	20.75	25.11	24.97	21.36	22.44	23.55	1.45	0.18	22.11	23.95	0.84	0.13

Table 3.9 (cont.)

UFA:SFA ratio[8]	2.09	2.16	2.17	2.09	2.01	2.02	0.08	0.65	2.03	2.15	0.05	0.07
PUFA:SFA ratio[9]	0.66	0.79	0.80	0.67	0.69	0.72	0.06	0.37	0.68	0.76	0.03	0.13
Iodine value,[10] g/100 g	74.9	79.4	79.1	75.4	75.7	77.0	1.9	0.38	75.4	78.4	1.07	0.05

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

[1]Data for diets are means of 12 observations per treatment (6 barrows and 6 gilts). Data for sex are means of 36 observations.

[2]Diet × sex interactions were not significant.

[3]DDGS = distillers dried grains with solubles.

[4]PKO = palm kernel oil.

[5]Total SFA = ([C6:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0]); brackets represent concentration.

[6]Total MUFA = ([C16:1] + [C17:1] + [C18:1] + [C20:1]); brackets represent concentration.

[7]Total PUFA = ([C18:2] + [C18:3] + [C20:2] + [C20:3] + [C20:4]); brackets represent concentration.

[8]UFA:SFA ratio = [total PUFA + total MUFA]/total SFA.

[9]PUFA:SFA ratio = total PUFA/total SFA.

[10]Iodine value (IV) = ([16:1] × 0.95) + ([C18:1] × 0.86) + ([C18:2] × 1.732) + ([C18:3] × 2.616) + ([C20:1] × 0.785) + ([C22:1] × 0.723); brackets represent concentration (AOCS, 1998).

CHAPTER 4

UP TO 30% CORN GERM MAY BE INCLUDED IN DIETS FED TO GROWING-FINISHING PIGS WITHOUT AFFECTING PIG GROWTH PERFORMANCE, CARCASS COMPOSITION OR PORK FAT QUALITY

ABSTRACT: A total of 280 pigs (initial BW: 42.5 ± 4.6 kg) were used to determine effects of adding corn germ (15.6% CP; 16.6% crude fat) to diets fed to growing-finishing pigs. Pigs were randomly allotted to 1 of 8 dietary treatments in a 2 × 4 factorial design with 2 levels of distillers dried grains with solubles (DDGS; 0 or 30%) and 4 levels of corn germ (0, 10, 20, or 30%). Each diet was fed to 10 pens with either 3 or 4 pigs per pen. Pigs were fed phase 1, 2, and 3 diets for 28, 28, and 27 d, respectively. At the conclusion of the experiment, the pig in each pen that had a BW that was closest to the average BW for the pen was harvested. Results indicated that for the overall experimental period, there were no effects on pig growth performance of including corn germ in the diet regardless of the level of DDGS, but inclusion of 30% DDGS in the diet reduced ($P < 0.001$) ADG, ADFI, and final BW. There were no effects of corn germ on carcass composition, muscle quality, or fat quality, but LM marbling and firmness were reduced ($P < 0.05$) by inclusion of DDGS in the diet. The L* value of LM decreased (linear and quadratic, $P < 0.05$) as corn germ was included in diets containing no DDGS, but that was not the case when corn germ was added to diets containing 30% DDGS (corn germ × DDGS interaction, $P < 0.01$). Inclusion of DDGS in the diet reduced ($P < 0.001$) the L* value for back fat, but there were no effects of corn germ on back fat color measures. Inclusion of corn germ in diets containing no

DDGS increased belly length (quadratic, $P < 0.05$), but that was not the case if corn germ was added to diets containing 30% DDGS. There was also a decrease in belly flop distance as corn germ was added to diets containing no DDGS (linear, $P< 0.001$), but no effects of corn germ were observed in diets containing 30% DDGS. However, inclusion of DDGS in the diet reduced ($P < 0.001$) the belly flop distance. In conclusion, addition of up to 30% corn germ in diets containing 0 or 30% DDGS did not negatively affect pig growth performance, carcass composition, or muscle quality, but belly firmness was reduced by inclusion of corn germ in the diets.

Key words: corn germ, distillers dried grains with solubles, growth performance, fat quality, pigs

INTRODUCTION

Corm germ is produced by fractionation of corn into germ and endosperm, and the endosperm may then be used in the biofuels industry to produce ethanol, whereas the corn germ may be used in diets fed to pigs (Rausch et al., 2006). Digestibility of energy, P, AA, and CP in corn germ fed to growing-finishing pigs was reported (Widmer et al., 2007), and growth performance of pigs fed diets containing up to 10% corn germ is not negatively affected by corn germ (Widmer et al., 2008). Up to 30% distillers dried grains with solubles (**DDGS**) may also be included in diets fed to growing-finishing pigs if sufficient quantities of digestible Lys are included in the diets (Stein and Shurson, 2009). However, belly fat firmness is reduced in pigs fed DDGS because fatty acid composition of the adipose tissues is altered by the high concentration of unsaturated fatty acids in DDGS (Whitney et al., 2006; Benz et al., 2010; Xu et al., 2010b). Recently, it was reported that there are no negative effects on pig growth performance and fat quality of adding 15% corn germ to a diet containing 30% DDGS (Lee et al., 2011). However, it is possible that greater inclusion rates of corn germ can be used in diets fed to growing-finishing pigs, but research to investigate this hypothesis has not been reported. It is also not known if the presence of DDGS in the diets influences the responses to inclusion of corn germ in the diet.

It was hypothesized that corn germ may be included in diets fed to growing-finishing pigs in greater quantities than previously used regardless of the level of DDGS in the diet without negatively affecting pig growth performance and pork fat quality. The objective of this experiment, therefore, was to determine the optimal inclusion rate of corn germ in growing-finishing pig diets containing 0 or 30% DDGS.

MATERIALS AND METHODS

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Pigs used in this experiment were the offspring of G-performer boars mated to F-25 females (Genetiporc, Alexandria, MN).

Animals, Housing, Experimental Design, and Diets

A total of 280 pigs (Genetiporc, Alexandria, MN) with an initial BW of 42.5 ± 4.6 kg were used. Pigs were housed in pens equipped with a feeder, a nipple drinker, and partly slatted concrete floors in an environmentally controlled building. Ad libitum access to feed and water was allowed throughout the experiment. Pigs were randomly allotted to 1 of 8 dietary treatments in a 2 × 4 factorial design with 2 levels of DDGS (0 or 30%) and 4 levels of corn germ (0, 10, 20, or 30%). There were 10 pen replicates of each diet. There were 5 replicates with 4 pigs per pen and 5 replicates with 3 pigs per pen, and there was the same number of gilts and barrows on each treatment. Corn, soybean meal, DDGS, and corn germ were the main ingredients in the diets (Table 4.1). A 3-phase feeding program was used and grower diets (Table 4.2) were provided for 28 d, early finisher diets (Table 4.3) were also provided for 28 d, and late finisher diets (Table 4.4) were provided for 27 d. Current estimates for nutrient requirements (NRC, 1998) were met or exceeded in all diets..

Feeding and Growth Performance

Individual pig BW was recorded at the initiation of the experiment and at the conclusion of each of the 3 phases. Daily allotments of feed and the weight of feed left in the feeders were recorded at the conclusion of each of the 3 phases. At the conclusion of the experiment, data for ADG, ADFI, and average G:F were summarized and calculated for each pen and diet. One pig from each pen was transported to the Meat Science Laboratory at the University of Illinois on the last day of the experiment. Before selecting this pig, 5 pens per treatment were randomly chosen to deliver a gilt to the Meat Science Laboratory and barrows were selected from the other 5 pens. Within each pen, the pig of the determined gender that had a BW closest to the average for the pen was selected. Pigs were harvested after an overnight fast, but free access to water was allowed during this time.

Slaughter and Carcass Evaluation

Prior to slaughter, the live BW was recorded of each pig. After electrical stunning, pigs were lifted off the floor and exsanguinated, and pigs were scalded after reflex action had ended. Carcasses were dehaired and eviscerated, and the HCW was recorded for each pig. Carcasses were stored at 4°C for 24 h. A pH-STAR (SFK Technologies Inc., Cedar Rapids, IA) was used to determine the pH of the LM at the 10th rib of each pig 24 hr post-mortem. The loin muscle from each carcass was collected and sampled from the edge of the loin muscle to the outer edge of and perpendicular to the skin at the 10th rib and used to determine the fat depth at 3/4 distances. Tracings were cut off of the LM and then traced using a Super PLANIX α Polar Planimeter (Tamaya Technics Inc., Tokyo, Japan). An average of 2 tracings per LM was determined to calculate the Loin Eye Area (Boler et al., 2011). On a scale from 1 to 6 (1 = pale pinkish gray to white and 6 = dark purplish red), subjective LM color scores were determined. On a scale from 1 to 10 (1 = devoid and 10 = abundant), LM marbling scores were also determined (NPPC, 1999). Subjective LM firmness scores were determined using a scale from 1 to 5 (1 = very soft and watery and 5 = very firm and dry; NPPC, 1991). A Minolta Chromameter was used to measure objective color values (L*, a*, b*) of the loin muscle (CR-300; Minolta Camera Co., Osaka, Japan). The loin muscle and the fat were collected at the second layer, and objective color values (L*, a*, b*) of both the loin muscle and the fat were determined using the Minolta Chromameter. The loin muscle from the left side of each carcass was removed and a 2.5-cm chop from the loin muscle was collected at the 10th rib. The loin chop was stored and placed in a Whirlpak™ bag and it was suspended from a steel rod using a fish hook for 24 h. The initial weights of the loin chop were recorded and compared with the final weights to determine drip loss (Boler et al., 2011). The belly of each pig was removed from the left side of each carcass, and laid flat on a stainless steel table and chilled for 24 h at 2°C. The belly length was determined from the cranial to the caudal end. The distance from the dorsal to the ventral edge was measured to determine belly width. Each belly was then draped over a suspended, stainless steel rod with the skin side down to perform a flop test. At a standardized point, which was 10 cm down from the stainless steel rod, the distance from skin surface to skin surface was measured (Leick et al., 2010).

Chemical Analysis

All diets and the main ingredients (corn, soybean meal, DDGS, and corn germ) were analyzed for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as a calibration standard. Ingredients and diets were also analyzed for DM by oven drying at 135°C for 2 h (method 930.15; AOAC Int., 2007), and dry ash (method 942.05; AOAC Int., 2007). A combustion procedure (method 990.03; AOAC Int., 2007) on an Elemental Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ) was used to determine CP concentration in diets and ingredients. Aspartic acid was used as the standard for calibration and CP was calculated as N × 6.25. Acid hydrolyzed ether extract analysis was performed to determine the concentration of fat in the ingredients and diets (method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). A Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc; Pleasanton, CA) was used to analyze the concentration of AA in all diets and ingredients using ninhydrin for postcolumn derivatization and norleucine as the internal standard. All samples were hydrolyzed with 6*N* HCl for 24 h at 110°C (method 982.30 E(a); AOAC Int., 2007) prior to analysis. Methionine and Cys were determined as Met sulfone and cysteic acid after an overnight cold performic acid oxidation before acid hydrolysis (method 982.30 E(b); AOAC Int., 2007). The concentration of Trp was determined after NaOH hydrolysis for 22 h at 110°C (method 982.30 E(c); AOAC Int., 2007). Analysis for ADF (method 973.18; AOAC Int., 2007) and NDF (Holst, 1973) was performed in all diets and ingredients and Ca and P were analyzed by using coupled plasma (ICP) spectroscopy (method 985.01; AOAC Int., 2007).

Statistical Analysis

Data were analyzed using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC) as a 2 × 4 factorial design with DDGS and corn germ as the 2 factors. The pen was the experimental unit for all analyses. The model included corn germ, DDGS, and the interaction between DDGS and corn germ as fixed effects and block as the random effect. Least squares means were calculated for each independent variable. When treatment effect was a significant source of variation, the PDIFF option of SAS was used to separate means. Linear and quadratic effects of inclusion of corn germ in diets without or with DDGS were determined using orthogonal polynomial contrasts. Significance was determined at $P \leq 0.05$ for all statistical analyses and tendencies were determined at $P > 0.05 \leq 0.10$.

RESULTS

Growth Performance

Initial BW of pigs did not differ among the 8 dietary treatments (Table 4.5). There were no linear or quadratic effects of including graded levels of corn germ in diets without or with DDGS on ADG, ADFI, G:F, or final BW during the growing, early finishing, late finishing, or the entire experimental period. However, there was a tendency for ADG to increase in the growing period with increasing levels of corn germ if no DDGS was included in the diet (linear, $P = 0.07$), but there was a trend for ADG to decrease as corn germ was added to diets that contained no DDGS in the late finishing period (quadratic, $P = 0.06$).

Average daily gain, and ADFI for pigs fed diets containing no DDGS were greater ($P < 0.01$) than for pigs fed diets containing 30% DDGS during the growing, the late finishing, and the entire experimental period, and ADG for pigs fed diets that contained no DDGS was also greater ($P < 0.01$) than for pigs fed diets that contained 30% DDGS during the early finishing period. Average G:F values were, however, not influenced by DDGS in the diet. The BW of pigs fed no DDGS was greater ($P < 0.001$) than for pigs fed diets containing 30% DDGS at the end of each phase and at the conclusion of the experiment.

Carcass Composition and Muscle and Backfat Quality

There were no effects on live weight, hot carcass weight, dressing percentage, backfat, LM area, or fat free lean percentage of including corn germ in diets that contained 0 or 30% DDGS (Table 4.6). However, live weight and hot carcass weight were greater ($P < 0.01$) for pigs fed no DDGS than for pigs fed 30% DDGS. Backfat was also greater ($P = 0.05$) for pigs fed diets without DDGS than for pigs fed diets with DDGS, but dressing percentage, LM area, and fat free lean percentage were not affected by including DDGS in the diets. Interactions between DDGS and corn germ were not significant for any of the carcass composition parameters that were measured.

No linear or quadratic effects of inclusion of corn germ on LM subjective color, marbling, firmness, pH, drip loss, or LM a* value were observed regardless of the level of DDGS in the diets. However, the LM L* value decreased as corn germ was included in diets containing 0% DDGS (linear and quadratic, $P < 0.05$), but that was not the case as corn germ was included in the diet containing 30% DDGS (corn germ × DDGS interaction, $P < 0.01$). A trend for decreased LM b* values was also observed as graded levels of corn germ was added to the diet without DDGS (linear, $P = 0.06$). Pigs fed diets containing no DDGS had greater ($P < 0.05$) marbling than pigs fed diets containing 30% DDGS, and LM firmness was greater ($P < 0.01$) for pigs fed diets containing 0% DDGS than for pigs fed diets containing 30% DDGS. There was a tendency ($P = 0.06$) for an interaction between corn germ and DDGS in 24 h pH with values increasing as corn germ was added to diets without DDGS, but decreasing as corn germ was added to diets containing 30% DDGS.

There were no linear or quadratic effects of corn germ on backfat a* and b* values regardless of the level of DDGS in the diet. However, there was a tendency (linear, $P = 0.06$) for decreased backfat L* values as corn germ was added to diets containing no DDGS. Backfat L* value for pigs fed 0% DDGS also was greater ($P < 0.001$) than the backfat L* value of pigs diets containing 30% DDGS.

There were no linear or quadratic effects on belly length of including corn germ in diets containing 30% DDGS, but belly length increased (quadratic, $P < 0.05$) as corn germ was included in the diet containing no DDGS (Table 4.7). However, belly width and belly weight were not affected by inclusion of corn germ to the diets regardless of the level of DDGS in the diets. In contrast, there was a decrease in belly flop distance with inclusion of corn germ in diets containing no DDGS (linear, $P < 0.001$), whereas belly flop distance was not affected of corn germ in diets containing 30% DDGS. There were no effects of DDGS on belly length or belly width, but there was a tendency ($P = 0.06$) for reduced belly weight in pigs fed diets containing 30% DDGS compared with pigs fed no DDGS. Belly flop distance also was reduced ($P < 0.001$) as DDGS was included in the diet.

DISCUSSION

Distillers dried grains with solubles (DDGS) used in this experiment contained a greater concentration of Lys than the average concentration of Lys in DDGS (Stein and Shurson, 2009). The Lys:CP ratio was 3.48%, which is above the average Lys:CP ratio for DDGS that has been reported previously (Stein et al., 2009). This indicates that the DDGS used in this experiment was not heat damaged. The Lys:CP ratio in DDGS used in this experiment was greater than the Lys:CP ratio in corn, which is most likely because yeast is added to the corn during fermentation, which may result in synthesis of microbial protein that has a greater Lys:CP ratio than corn (Han and Keshun, 2010). The crude fat level of 16.64% in the corn germ used in this experiment is close to previous values (Widmer et al. 2007; 2008), and the concentration of other nutrients in corn germ were also in agreement with previous values. If corn germ is defatted, corn germ meal is produced and the concentration of crude fat in corn germ meal is only around 2% (Weber et al., 2009). Corn germ and corn germ meal, therefore, are different feed ingredients, and results obtained with one of these ingredients should not be extrapolated to the other without experimental verification.

Growth Performance

Growth performance of growing-finishing pigs was not affected by inclusion of 10% corn germ to a corn soybean meal based diet (Widmer et al., 2008) or by addition of 15% corn germ to corn-soybean meal diets containing 30% DDGS (Lee et al., 2011). Results of this experiment are in agreement with the previous results, and indicate that up to 30% corn germ may be included in growing-finishing pig diets containing up to 30% DDGS without negatively affecting pig growth performance.

Inclusion of up to 30% DDGS in diets fed to growing-finishing pigs has been reported not to affect pig growth performance (Linneen et al., 2008; Drescher et al., 2009; Lammers et al., 2009; Xu et al., 2010b) and only minor negative effects on ADG, but not ADFI and G:F of inclusion of up to 45% DDGS in corn soybean meal diets fed to growing-finishing pigs were reported (Cromwell et al., 2011). However, reduced growth performance of growing-finishing pigs fed corn soybean based diets containing 30% DDGS has also been reported (Whitney et al., 2006; Xu et al., 2010a). It is not clear why growth performance is reduced by the inclusion of 30% DDGS in some experiments, but not in others. The fact that ADF, ADFI, and final BW but not G:F were reduced for pigs fed diets containing 30% DDGS indicates that the main reason for the reduced growth of pigs fed DDGS containing diets is reduced ADFI of these diets compared with pigs fed corn-soybean meal diets. The palatability of diets is reduced if DDGS is included (Seabolt et al., 2010) and the current data indicate that reduced palatability results in reduced ADFI and ADG. Results of the present experiment also indicate that the negative effects of DDGS on palatability are not ameliorated by inclusion of corn germ in the diet.

Carcass Composition and Quality

Carcass composition and carcass quality were not negatively affected by inclusion of up to 10% corn germ to corn soybean meal based diets (Widmer et al., 2008) and there were very few effects on carcass composition and carcass quality of adding 15% corn germ to a diet containing 30% DDGS (Lee et al., 2011). Results of this experiment are in close agreement with these observations and also indicate that carcass composition and quality will not be affected by inclusion of up to 30% corn germ in the diets. The fact that very few interactions between corn germ and DDGS were observed indicates that the effects of adding corn germ to the diets are independent of the level of DDGS in the diet. There are also very limited effects on carcass composition and carcass quality of including DDGS in diets fed to growing-finishing pigs (Whitney et al., 2006; Widmer et al., 2008; Benz et al., 2011)and results of the present experiment are in agreement with the previous data. A reduction in belly firmness of pigs fed diets containing DDGS has been reported (Whitney et al., 2006; Benz et al., 2010; Xu et al., 2010a; Cromwell et al., 2011) and results of this experiment confirm these observations. However, the reduced belly firmness for pigs fed diets containing corn germ is not in agreement with Widmer et al. (2008) who reported that there were no effects of adding 10% corn germ to corn soybean meal diets on belly firmness. The reason for the differences between the 2 experiments may be that a greater inclusion rate of corn germ was used in this experiment than in the experiment by Widmer et al. (2008), which increased the total amount of corn oil in the diet compared with the level of corn oil in diets containing 10% corn germ. The present results indicate that feeding increasing levels of corn oil from DDGS or from corn germ will result in soft bellies of growing-finishing pigs.

The negative effects of DDGS on fat quality may be ameliorated by removal of DDGS from the growing-finishing diets prior to slaughter (Gaines et al., 2007; Hill et al., 2008; Xu et al., 2010a). Dressing percentage of pigs fed 30% DDGS was improved by withdrawal of DDGS for a period of 3 or 6 weeks prior to slaughter and withdrawal of DDGS for 2 to 4 weeks prior to slaughter reduced the IV of belly fat to a value that is in an acceptable range (Gaines et al., 2007; Hill et al., 2008). Withdrawal of DDGS from the diets for a period of 3 to 9 weeks also resulted in a linear reduction in linoleic acid (C18:2) concentration in belly fat (Xu et al., 2010a). To our knowledge, no experiments have been reported in which effects of withdrawing corn germ from diets fed to finishing pigs was investigated, but it is likely that negative effects of corn germ on belly firmness may be reduced if the concentration of corn germ in the diets is reduced during the final 2 to 4 weeks prior to slaughter.

In conclusion, corn germ has no detrimental effects on pig growth performance, carcass composition, or carcass quality. However, feeding corn germ to finishing pigs may result in reduced belly firmness of the pigs even if no DDGS is included in the diet. It is possible that reducing the inclusion rate of corn germ in the late finishing diets fed to pigs may ameliorate the negative effects of corn germ on belly quality but research to confirm this hypothesis has not been conducted.

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Table 4.1. Analyzed nutrient composition of corn, soybean meal, distillers dried grains with solubles (DDGS), and corn germ (as-fed basis)

Item	Corn	Soybean meal	DDGS	Corn germ
GE, kcal/kg	3,926	4,203	4,724	4,585
DM, %	86.03	88.28	87.33	87.61
Ash, %	1.25	6.82	5.06	6.25
CP, %	8.35	48.29	26.47	15.60
AEE[1], %	3.68	2.13	11.11	16.64
ADF, %	2.23	4.81	7.68	5.55
NDF, %	8.18	9.74	27.58	21.72
Ca, %	0.01	0.46	0.06	0.06
P, %	0.23	0.67	0.91	1.34
Indispensable AA, %				
Arg	0.38	3.56	1.19	1.10
His	0.22	1.30	0.73	0.45
Ile	0.26	2.23	0.99	0.47
Leu	0.87	3.80	2.78	1.15
Lys	0.26	3.07	0.92	0.81
Met	0.16	0.66	0.52	0.24
Phe	0.35	2.48	1.23	0.60
Thr	0.27	1.87	0.99	0.54
Trp	0.06	0.70	0.19	0.11
Val	0.35	2.37	1.28	0.74

Table 4.1 (cont.)

Dispensable AA, %				
Ala	0.54	2.10	1.71	0.92
Asp	0.48	5.34	1.60	1.16
Cys	0.17	0.65	0.52	0.27
Glu	1.32	8.62	3.40	2.00
Gly	0.30	2.06	1.00	0.75
Pro	0.63	2.29	1.92	0.99
Ser	0.34	2.10	1.03	0.56
Tyr	0.24	1.81	1.00	0.44

[1]AEE = acid hydrolyzed ether extract.

Table 4.2. Composition of diets for growing pigs containing graded levels of corn germ and either 0 or 30% distillers dried grains with solubles (DDGS), as-fed basis[1]

	Diet							
	0% DDGS				30% DDGS			
Corn germ, %:	0	10	20	30	0	10	20	30
Ingredient								
Ground corn	70.55	61.50	52.46	43.42	50.65	41.55	32.32	22.69
Soybean meal, 48% CP	27.00	26.10	25.20	24.30	17.10	16.10	15.20	14.60
DDGS	-	-	-	-	30.00	30.00	30.00	30.00
Corn germ	-	10.00	20.00	30.00	-	10.00	20.00	30.00
Ground limestone	0.75	0.86	0.97	1.08	1.07	1.24	1.36	1.58
Dicalcium phosphate	0.76	0.58	0.40	0.22	0.08	-	-	-
L-Lysine HCL	0.15	0.15	0.15	0.15	0.37	0.37	0.37	0.37
L-Tryptophan	-	-	-	-	0.01	0.01	0.01	0.01
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Energy and nutrients								
GE, kcal/kg	3,883	3,957	4,005	4,157	4,148	4,215	4,360	4,411
DM, %	88.73	88.79	89.24	89.64	89.39	89.70	89.87	90.39
Ash, %	4.08	4.38	4.99	5.06	4.76	5.60	5.56	5.93
CP, %	19.97	18.71	19.13	20.25	20.78	21.60	21.95	21.48
AEE[3], %	3.38	4.63	6.15	7.56	5.80	7.34	8.22	10.03

Table 4.2 (cont.)

ADF, %	3.02	3.49	3.62	4.34	4.10	4.72	4.86	5.39
NDF, %	9.01	11.96	10.94	13.94	14.90	21.52	16.26	17.16
Ca, %	0.52	0.57	0.60	0.46	0.55	0.59	0.61	0.59
P, %	0.49	0.57	0.66	0.77	0.55	0.65	0.74	0.88
Indispensable AA, %								
Arg	1.19	1.29	1.19	1.28	1.13	1.26	1.25	1.33
His	0.50	0.53	0.49	0.52	0.54	0.60	0.59	0.60
Ile	0.75	0.74	0.71	0.72	0.75	0.81	0.80	0.81
Leu	1.56	1.63	1.45	1.51	1.84	2.03	1.99	1.93
Lys	1.10	1.18	1.09	1.15	1.18	1.30	1.24	1.41
Met	0.32	0.35	0.32	0.31	0.33	0.37	0.36	0.36
Phe	0.91	0.95	0.86	0.89	0.95	1.05	1.02	1.02
Thr	0.71	0.79	0.70	0.76	0.76	0.85	0.84	0.88
Trp	0.20	0.23	0.21	0.22	0.21	0.21	0.21	0.21
Val	0.86	0.86	0.83	0.87	0.90	1.00	1.00	1.03

[1]All diets were formulated to contain all nutrients in quantities sufficient to meet the requirement of growing pigs (NRC, 1998).

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-

pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and niacotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]AEE = acid hydrolyzed ether extract.

Table 4.3. Composition of diets for early finishing pigs containing graded levels of corn germ and either 0 or 30% distillers dried grains with solubles (DDGS), as-fed basis[1]

	Diet							
	0% DDGS				30% DDGS			
Corn germ, %:	0	10	20	30	0	10	20	30
Ingredient								
Ground corn	77.38	68.34	59.30	50.23	55.49	46.17	36.87	27.62
Soybean meal, 48% CP	20.50	19.60	18.70	17.80	12.50	11.60	10.70	9.80
DDGS	-	-	-	-	30.00	30.00	30.00	30.00
Corn germ	-	10.00	20.00	30.00	-	10.00	20.00	30.00
Ground limestone	0.67	0.78	0.89	1.05	1.00	1.22	1.42	1.57
Dicalcium phosphate	0.56	0.38	0.20	-	-	-	-	-
L-Lysine HCL	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30
L-Tryptophan	-	-	-	-	0.01	0.01	0.01	0.01
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Energy and nutrients								
GE, kcal/kg	3,838	3,939	4,045	4,137	4,182	4,227	4,286	4,297
DM, %	87.61	87.66	88.73	88.74	88.44	88.80	89.22	89.43
Ash, %	3.85	3.91	4.69	4.93	4.43	4.88	5.60	6.25
CP, %	15.95	15.93	16.92	17.70	18.81	18.58	19.65	19.67
AEE[3], %	2.97	4.74	6.11	7.27	6.51	7.62	8.65	10.51

Table 4.3 (cont.)

ADF, %	2.89	3.34	3.83	4.41	4.36	4.80	5.22	5.45
NDF, %	9.18	10.67	12.05	12.51	13.75	17.32	17.44	19.31
Ca, %	0.49	0.44	0.51	0.47	0.54	0.52	0.65	0.69
P, %	0.45	0.52	0.59	0.66	0.50	0.61	0.72	0.84
Indispensable AA, %								
Arg	0.87	1.05	1.02	1.11	0.98	1.05	1.06	1.11
His	0.38	0.46	0.44	0.47	0.50	0.53	0.52	0.54
Ile	0.55	0.66	0.62	0.66	0.71	0.73	0.70	0.71
Leu	1.22	1.43	1.33	1.38	1.72	1.79	1.75	1.72
Lys	0.81	0.97	0.95	1.02	1.03	1.06	1.06	1.10
Met	0.23	0.27	0.25	0.26	0.32	0.34	0.33	0.34
Phe	0.68	0.80	0.75	0.79	0.86	0.89	0.87	0.87
Thr	0.54	0.63	0.62	0.65	0.65	0.70	0.70	0.68
Trp	0.19	0.19	0.19	0.19	0.18	0.19	0.19	0.18
Val	0.63	0.78	0.74	0.81	0.88	0.91	0.90	0.94

[1]All diets were formulated to contain all nutrients in quantities sufficient to meet the requirement of early finishing pigs (NRC, 1998).

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-

pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and niacotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]AEE = acid hydrolyzed ether extract.

Table 4.4. Composition of diets for late finishing pigs containing graded levels of corn germ and either 0 or 30% distillers dried grains with solubles (DDGS), as-fed basis[1]

	Diet							
	0% DDGS				30% DDGS			
Corn germ, %:	0	10	20	30	0	10	20	30
Ingredient								
Ground corn	84.24	75.19	66.14	56.85	61.97	52.70	43.40	34.13
Soybean meal, 48% CP	14.00	13.10	12.20	11.30	6.00	5.10	4.20	3.30
DDGS	-	-	-	-	30.00	30.00	30.00	30.00
Corn germ	-	10.00	20.00	30.00	-	10.00	20.00	30.00
Ground limestone	0.56	0.68	0.79	0.97	1.02	1.19	1.38	1.55
Dicalcium phosphate	0.35	0.17	-	-	-	-	-	-
L-Lysine HCL	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30
L-Tryptophan	-	-	-	-	0.01	0.01	0.01	0.01
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Energy and nutrients								
GE, kcal/kg	3,850	3,962	4,052	4,128	4,182	4,274	4,354	4,408
DM, %	88.04	88.11	88.57	89.12	88.46	89.19	89.22	88.72
Ash, %	3.60	3.79	4.27	4.75	4.13	4.86	4.91	5.82
CP, %	15.24	15.44	15.56	16.27	17.26	17.54	17.98	18.67
AEE[3], %	2.21	4.34	5.02	6.42	5.79	6.31	7.85	8.37

Table 4.4 (cont.)

ADF, %	2.73	3.16	3.37	3.49	4.07	4.41	4.71	4.99
NDF, %	9.79	10.56	10.45	12.64	14.66	16.36	16.10	15.23
Ca, %	0.42	0.48	0.41	0.46	0.47	0.56	0.45	0.59
P, %	0.39	0.48	0.56	0.66	0.49	0.60	0.70	0.84
Indispensable AA, %								
Arg	0.90	0.91	0.98	1.00	0.86	0.91	0.92	1.01
His	0.41	0.40	0.42	0.43	0.44	0.47	0.46	0.50
Ile	0.61	0.56	0.58	0.59	0.57	0.60	0.58	0.64
Leu	1.34	1.27	1.31	1.31	1.59	1.65	1.61	1.68
Lys	0.86	0.87	0.89	0.95	0.90	0.92	0.90	1.00
Met	0.24	0.23	0.24	0.25	0.30	0.31	0.31	0.32
Phe	0.72	0.70	0.72	0.70	0.76	0.79	0.77	0.81
Thr	0.55	0.56	0.60	0.61	0.62	0.64	0.64	0.66
Trp	0.16	0.16	0.16	0.16	0.18	0.18	0.19	0.18
Val	0.71	0.67	0.72	0.73	0.71	0.78	0.76	0.85

[1]All diets were formulated to contain all nutrients in quantities sufficient to meet the requirement of late finishing pigs (NRC, 1998).

[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-

pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and niacotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]AEE = acid hydrolyzed ether extract.

Table 4.5. Growth performance of pigs fed diets containing graded levels of corn germ (CG) and either 0 or 30% distillers dried grains with solubles (DDGS)[1]

	Diet								*P*-value								
	0% DDGS				30% DDGS								0% DDGS		30% DDGS		
Item Corn germ, %:	0	10	20	30	0	10	20	30	SEM	DDGS	CG[2]	DDGS× CG	L[2]	Q[2]	L	Q
Growing period																
Initial BW, kg	40.97	40.99	40.80	41.21	41.42	40.86	40.93	41.11	0.75	0.87	0.96	0.98	0.88	0.80	0.80	0.63
ADG, kg	0.97	1.00	1.04	1.02	0.91	0.93	0.92	0.91	0.02	<0.001	0.46	0.47	0.07	0.31	0.95	0.70
ADFI, kg	2.07	2.22	2.18	2.05	1.87	2.00	1.89	1.95	0.10	<0.01	0.49	0.81	0.82	0.15	0.75	0.67
G:F, kg/kg	0.48	0.46	0.48	0.51	0.51	0.47	0.49	0.47	0.02	0.91	0.65	0.57	0.37	0.33	0.38	0.78
Final BW, kg	68.26	68.97	69.90	69.76	66.94	66.79	66.57	66.67	0.97	<0.001	0.90	0.72	0.21	0.66	0.81	0.89
Early finishing period																
ADG, kg	1.03	1.00	1.04	0.97	0.96	0.95	0.96	0.94	0.03	<0.01	0.42	0.75	0.24	0.48	0.85	0.95
ADFI, kg	2.65	2.73	2.63	2.64	2.56	2.48	2.52	2.50	0.14	0.14	1.00	0.93	0.80	0.80	0.82	0.83
G:F, kg/kg	0.39	0.38	0.41	0.38	0.38	0.39	0.39	0.39	0.02	0.90	0.95	0.89	0.84	0.80	0.81	0.85
Final BW, kg	97.06	96.96	98.90	96.87	93.70	93.26	93.37	93.10	1.28	<0.001	0.81	0.83	0.81	0.45	0.77	0.95
Late finishing period																

Table 4.5 (cont.)

ADG, kg	1.09	1.00	1.02	1.02	0.96	0.94	0.99	0.97	0.03	<0.001	0.18	0.30	0.14	0.06	0.65	0.98
ADFI, kg	3.39	3.39	3.32	3.33	3.09	3.14	3.19	3.10	0.08	<0.001	0.94	0.76	0.51	0.94	0.82	0.38
G:F, kg/kg	0.32	0.30	0.31	0.31	0.31	0.30	0.31	0.31	0.01	0.91	0.22	0.91	0.59	0.14	0.76	0.37
Final BW, kg	126.43	123.88	126.36	124.51	119.74	118.70	120.10	119.19	1.52	<0.001	0.51	0.95	0.63	0.82	0.97	0.97
Entire period																
ADG, kg	1.03	1.00	1.03	1.00	0.94	0.94	0.95	0.94	0.02	<0.001	0.42	0.86	0.54	0.91	0.92	0.83
ADFI, kg	2.82	2.90	2.83	2.79	2.62	2.65	2.65	2.62	0.06	<0.001	0.66	0.89	0.53	0.32	1.00	0.62
G:F, kg/kg	0.36	0.35	0.36	0.37	0.36	0.35	0.36	0.36	0.01	0.71	0.22	0.75	0.43	0.16	0.99	0.73

[1] Data are means of 10 observations per treatment.

[2]L = linear effect; Q = quadratic effect.

Table 4.6. Carcass composition, muscle quality, and backfat quality of pigs fed diets containing graded levels of corn germ (CG) and either 0 or 30% distillers dried grains with solubles (DDGS)[1]

	Diet								*P*-value								
	0% DDGS				30% DDGS								0% DDGS		30% DDGS	
Item Corn germ, %	0	10	20	30	0	10	20	30	SEM	DDGS	CG[2]	DDGS×CG	L[2]	Q[2]	L	Q
Carcass composition																
Live wt, kg	121.6	118.4	122.5	118.25	116.4	114.6	114.1	115.6	2.36	<0.01	0.69	0.65	0.58	0.81	0.78	0.49
Hot carcass wt, kg	96.1	93.7	96.8	93.4	92.0	91.0	89.8	91.4	1.91	<0.01	0.78	0.56	0.55	0.78	0.74	0.49
Dressing, %	79.1	79.2	79.0	78.9	79.0	79.4	78.7	79.1	0.30	0.90	0.63	0.76	0.69	0.85	0.78	0.96
Backfat, cm	2.02	1.86	2.06	2.07	1.64	2.04	1.77	1.68	0.15	0.05	0.88	0.19	0.61	0.56	0.81	0.11
LM area, cm^2	56.1	53.2	53.0	54.9	53.1	53.2	51.1	53.8	1.57	0.18	0.34	0.81	0.58	0.13	1.00	0.40
FFL,[3] %	54.7	55.1	53.8	54.8	56.1	54.4	55.1	56.1	0.92	0.16	0.72	0.58	0.63	0.87	0.83	0.16
Muscle quality																
Subjective color[4]	2.1	2.3	2.4	2.2	2.5	2.1	2.2	2.2	0.14	1.00	0.79	0.11	0.52	0.15	0.20	0.15
Marbling[5]	1.3	1.3	1.4	1.4	1.1	1.0	1.1	1.2	0.15	0.02	0.78	0.97	0.56	1.00	0.56	0.51
Firmness[6]	2.8	2.9	3.1	3.0	2.5	2.7	2.4	2.1	0.20	<0.01	0.61	0.27	0.38	0.62	0.10	0.22
24-h pH, LM	5.5	5.6	5.6	5.6	5.7	5.6	5.6	5.6	0.03	0.31	0.84	0.06	0.12	0.27	0.30	0.15

Table 4.6 (cont.)

48-h drip loss, %	5.9	3.8	4.0	3.6	4.6	5.0	4.5	5.6	0.92	0.40	0.71	0.32	0.11	0.35	0.52	0.68
LM color, L*	51.3	47.0	47.6	47.9	46.6	48.4	48.3	47.8	0.92	0.29	0.50	<0.01	0.02	0.01	0.38	0.24
LM color, a*	7.9	8.2	7.9	7.2	8.1	7.9	8.1	8.0	0.56	0.60	0.81	0.79	0.29	0.37	0.97	0.95
LM color, b*	3.7	2.7	2.6	2.3	3.0	3.2	3.2	2.9	0.49	0.53	0.53	0.52	0.06	0.52	0.89	0.61
Backfat color																
Fat color, L*	75.0	73.9	74.4	73.7	73.1	73.2	72.1	72.9	0.41	<0.001	0.16	0.12	0.06	0.54	0.35	0.36
Fat color, a*	4.0	4.3	3.5	3.8	4.2	3.5	4.2	3.8	0.34	0.90	0.84	0.18	0.37	0.91	0.79	0.65
Fat color, b*	4.0	3.9	3.8	3.8	4.3	4.2	3.9	4.0	0.27	0.19	0.63	0.97	0.56	0.97	0.28	0.67

[1] Data are means of 10 observations per treatment.

[2]L = linear effect; Q = quadratic effect.

[3]FFL, % = as calculated from NPPC (1999): pounds fat free lean = 8.588 – (21.896 × 10th rib fat depth, in.) + (0.465 × HCW, lb.) + (3.005 × 10th rib loin muscle area, sq. in.), (pounds FFL / HCW) × 100 = %FFL.

[4]National Pork Producers Council (NPPC) color scale (1 to 6): 1 = pale pinkish gray to white; 6 = dark purplish red.

[5]NPPC marbling scale (1 to 10): 1 = devoid; 10 = abundant.

[6]NPPC firmness scale (1 to 5): 1 = very soft; 5 = very firm and dry.

Table 4.7. Belly quality of pigs fed diets containing graded levels of corn germ (CG) and either 0 or 30% distillers dried grains with solubles (DDGS)[1]

	Diet								*P*-value								
	0% DDGS				30% DDGS								0% DDGS		30% DDGS	
Item Corn germ, %:	0	10	20	30	0	10	20	30	SEM	DDGS	CG[2]	DDGS× CG	L[2]	Q[2]	L	Q
Belly length, cm	57.05	59.21	58.75	56.51	57.23	56.69	56.44	56.67	1.00	0.12	0.56	0.36	0.65	0.03	0.67	0.71
Belly width, cm	22.91	23.70	23.93	23.44	24.18	24.39	24.13	23.50	0.76	0.31	0.81	0.85	0.59	0.40	0.50	0.58
Belly wt, kg	5.10	5.36	5.51	5.16	5.11	5.22	4.92	4.88	0.19	0.06	0.51	0.44	0.71	0.11	0.24	0.70
Flop distance,[3] cm	17.37	14.28	11.66	9.98	8.10	9.45	7.37	6.22	1.53	<0.001	0.01	0.26	<0.001	0.64	0.26	0.42

[1] Data are means of 10 observations per treatment.

[2]L = linear effect; Q = quadratic effect.

[3]A flop test was performed by draping a centered belly lengthwise over a suspended, stainless steel rod with the skin side down. The distance from skin surface to skin surface was measured at a standardized point, 10 cm down from the stainless steel rod.

CHAPTER 5

CONCLUSION

The two experiments included in this thesis evaluated effects of inclusion of co-products from the ethanol industry on pig growth performance, carcass composition and pork fat quality. In the first experiment, a hypothesis that negative impacts of DDGS on carcass fat quality may be ameliorated by inclusion of corn germ, glycerol, or dietary saturated fatty acids in growing-finishing diets was investigated. It was concluded that dietary treatments had minor impacts on pig growth performance, carcass characteristics, and fat quality. Belly firmness and the IV of back fat and belly fat of pigs fed corn germ, glycerol, or dietary sources of saturated fatty acids were not improved. It is necessary to further evaluate effects of greater inclusion rates of these dietary saturated fatty acid sources in grower-finisher pig diets on pig growth performance. Furthermore, other possible dietary sources of saturated fatty acids need to be investigated to improve IV values of back fat and belly fat of pigs fed diets containing DDGS. If fat sources or other additives that improve belly fat quality of pigs can be identified, it may be possible that greater quantities of DDGS in growing-finishing pig diets can be used and negative effects of DDGS on pork fat quality may be ameliorated.

In the second experiment, effects of inclusion of graded levels of corn germ to grower-finisher pig diets containing 0 or 30% DDGS on pig growth performance, carcass composition, and pork fat quality were studied. It was hypothesized that greater quantities of corn germ than previously used may be used regardless of the inclusion rate of DDGS in corn-soybean meal based diets without negatively influencing pig growth performance and pork fat quality. It was concluded that there were no negative effects of inclusion of up to 30% corn germ in diets containing 0 or 30% DDGS on pig growth performance, carcass composition, and muscle quality, but belly firmness was reduced by inclusion of corn germ to grower-finisher pig diets.