UTILIZATION OF DISTILLER'S DRIED GRAINS WITH SOLUBLES IN SWINE DIETS

by

SCOTT MATTHEW WILLIAMS

B.S., Kansas State University, 2008

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2010

Approved by:

Major Professor
Dr. Joe D. Hancock

Abstract

Six experiments were completed to determine factors influencing the use of distillers dried grains with solubles (DDGS) in diets for nursery and finishing pigs. In Exp. 1, 105 nursery pigs were fed corn-soybean meal (SBM) based diets with CP concentrations of 22.5, 25, and 27.5%. Overall ADG, ADFI, and G:F were not affected by increasing CP ($P > 0.19$). In Exp. 2, 105 nursery pigs were fed excess CP from SBM and DDGS. Overall ADG, ADFI, and G:F for pigs fed the control diet were not different from those fed the high CP treatments ($P > 0.12$). However, pigs fed the DDGS treatment had lower G:F than pigs fed the corn-soy diet with similar CP content ($P < 0.04$). For Exp. 3, 176 finishing pigs were fed diets with CP concentrations increasing from 12 to 18%. Increasing CP had no effect ($P > 0.20$) on ADG, ADFI, G:F, and hot carcass weight (HCW). For Exp. 4, 180 finishing pigs were fed excess dietary CP from SBM and DDGS. Pigs fed diets with high CP had lower ADG, ADFI, and HCW, but these results were caused by the diet with 40% DDGS (SBM vs DDGS, $P < 0.001$). For Exp. 5, 224 nursery pigs were used to determine the effects of extrusion processing on the nutritional value of DDGS. Overall ADG and ADFI were greater for pigs fed the corn-soy control compared to the DDGS treatments ($P < 0.02$). Extruding the DDGS did not improve ADG or G:F ($P > 0.11$), but DM and GE digestibility were greater for diets with extruded DDGS vs. unprocessed DDGS ($P < 0.04$). In Exp. 6, 200 finishing pigs were fed DDGS-based diets formulated for ME, NE, and digestible amino acids. Feeding DDGS lowered ADG ($P < 0.09$) and ADFI ($P < 0.05$). Formulating for ME, NE, and digestible amino acids needs improved ADG and G:F ($P < 0.002$) to that of the corn-soy control diet. In conclusion, moderate excesses of dietary CP does not impact growth performance. Also, extruding DDGS can improve the nutritional value of diets for nursery pig and formulating for ME, NE and digestible amino acid needs can improve growth performance of finishing pigs fed diets with high levels of DDGS.

(Key words: Excess dietary crude protein, DDGS, Extrusion, digestible amino acids, nursery and finishing pigs

Table of Contents

List of Tables vi

Acknowledgements viii

Dedication ix

Chapter 1 - Distillers dried grains with solubles in swine diets: a review article 1

- INTRODUCTION 2
- AVAILABILITY OF DDGS 2
- INCLUSION LEVEL OF DDGS IN DIETS OF GROWING SWINE 3
- NUTRIENT CONTENT OF DDGS 5
- PROTEIN IN DDGS 7
- EXTRUSION PROCESSING 10
- FORMULATION STRATEGIES FOR DIETS WITH 13
- HIGH INCLUSION OF DDGS 13
- CONCLUSIONS 16
- LITERATURE CITED 17

Chapter 2 - Effects of Feeding Excess Dietary Crude Protein from Soybean Meal and Distillers Dried Grains with Solubles in Diets for Nursery and Finishing Pigs 22

- ABSTRACT 23
- INTRODUCTION 24
- MATERIALS AND METHODS 25
  - Experiment 1 25
  - Experiment 2 25
  - Experiment 3 26
  - Experiment 4 27
- RESULTS AND DISCUSSION 28
  - Experiment 1 28
  - Experiment 2 28
  - Experiment 3 29
  - Experiment 4 30

LITERATURE CITED 31
Chapter 3 - Effects of Extrusion Processing on the Nutritional Value of Distillers Dried Grains with Solubles in Diets for Nursery Pigs 41
ABSTRACT 42
INTRODUCTION 43
MATERIALS AND METHODS 43
RESULTS AND DISCUSSION 44
LITERATURE CITED 46
Chapter 4 - Effect of Formulation Strategy on the Nutritional Value of Distillers Grains with Solubles 54
ABSTRACT 55
INTRODUCTION 56
MATERIALS AND METHODS 56
RESULTS AND DISCUSSION 57
LITERATURE CITED 59

List of Tables

Table 1.1 Effects of DDGS inclusion level on growth performance in nursery pigs.......................... 3

Table 1.2 Effects of DDGS inclusion level on growth performance in finishing pigs 4

Table 1.3 Effects of fat addition to diets with DDGS and carcass characteristics 6

Table 1.4 Effects of excess CP from soybean meal on growth performance on nursery pigs[1] 8

Table 1.5 Effects of excess CP from SBM and DDGS on growth performance on nursery pigs[1] 8

Table 1.6 Effects of excess CP from SBM on growth performance of finishing pigs[1] 9

Table 1.7 Effects of excess dietary CP from SBM and DDGS in diets for finishing pigs[1] 10

Table 1.8 Chemical characteristics of distillers dried grains with solubles (DDGS)........................ 12

Table 1.9 Effects of extrusion processing on the nutritional value of distillers dried grains with solubles (DDGS) in diets for nursery pigs[1, 2] 13

Table 1.10 Concentration and digestibility of amino acids in DDGS as used for diet formulation.. 14

Table 1.11 Composition of diets (as-fed basis) 15

Table 1.12 Effects of formulation strategy on the nutritional value of diets with 40% DDGS 16

Table 2.1 Composition of diets (Exp. 1 and 2; as-fed basis)[1] 35

Table 2.2 Composition of diets (Exp. 3; as-fed basis)[1] 36

Table 2.3 Composition of diets (Exp. 4; as-fed basis)[1] 37

Table 2.4 Effects of excess CP from sbm[1] on growth performance on nursery pigs (Exp. 1) [2] 38

Table 2.5 Effects of excess CP from soybean meal (SBM) and distillers dried grains with soluble (DDGS) on growth performance on nursery pigs (Exp. 2)[1] 38

Table 2.6 Effects of excess CP from SBM on growth performance of finishing pigs (Exp. 3)[1] 39

Table 2.7 Effects of excess dietary CP from soybean meal and distillers dried grains with solubles (DDGS) in diets for finishing pigs (Exp. 4)[1] 40

Table 3.1 Composition of diets[1] 51

Table 3.2 Chemical characteristics of distillers dried grains with solubles (DDGS)........................ 52

Table 3.3 Effects of extrusion processing on the nutritional value of distillers dried grains with solubles (DDGS) in diets for nursery pigs[1] 53

Table 4.1 Composition of diets (as-fed basis).. 61

Table 4.2 Chemical analysis[1] 62

Table 4.3 Concentration and digestibility of amino acids in distillers dried grains with solubles as used for diet formulations 63
Table 4.4 Effects of formulation strategy on the nutritional value of diets with 40% DDGS 64

Acknowledgements

I would like to sincerely thank everyone who, through their extra efforts and tireless support, assisted me with my research. First and foremost, I want to give a special thank you to Dr. Hancock. Thank you for your guidance, your encouragement, and for your financial support, not just for the 2-plus years of my Master's research, but also my undergraduate years. To the members of my committee, Drs. Behnke, Beyer, and Valdes, thank you to each of you for your time and your contributions to my education.

To Carolina, thank you for the help and guidance you gave me, both as an undergraduate worker during your Ph.D. research and as a graduate student beginning my own research projects. You showed me the ropes and taught me a lot of what I know- for better or for worse. Salissou, Chad, and the rest of the graduate students I had the pleasure of working with through my time here: thank you all for your assistance in weighing, feeding, and checking my pigs not to mention collecting fecals. Without your undying enthusiasm and energy this would not have been possible.

Thank you to Mark, Lyle, Frank, and the rest of the farm crew. Thank you Terry and your ASI feedmill student workers. Thank you Dr. McKinney, Adam, Erin, Johnny, and Scott from Grain Science for your help on our collaborative projects. Thank you Cheryl, Dave, and Theresa for your help and support in the lab.

Special thanks to Farmland at Crete, NE. Your willingness to support my research is very appreciated. Especially Cory, who always went above and beyond to ensure every one of my research pigs was accounted for on every trip.

Finally, to my friends: Abby, Brad, Brian, Eric, Katie, Mark, Mike, and Tom. Each of you supported me with your friendship and love and for that, thank you.

Dedication

To my family: Mom, Dad, Michael, Mark, Cheryl, and my incredible wife Kristen- You were all there with me, every step of the way. You guided me, you supported me, and you loved me. Without you, none of this would be possible. So this is for you. I love you all.

Chapter 1 - **Distillers dried grains with solubles in swine diets: a review article**

INTRODUCTION

"Distillers grains" is a common term used for a group of co-products from the ethanol industry. These grains can be sold wet or dry and with or without solubles. Distillers dried grains with solubles (DDGS) is the co-product more often used in diets for nonruminants and is defined by the American Association of Feed Control Officials (AAFCO, 2005) as the product obtained after removal of ethyl alcohol by distillation from the yeast fermentation of grain and by condensing and drying at least ¾ of the solids of the resultant whole stillage by methods employed in the grain distilling industry. These DDGS are a reasonably good source of protein and energy and often can be used in place of higher cost corn and soybean meal. Yet, many questions remain about the nutritional value of DDGS and how to best use them in diet formulations. Thus, this review will be focused on research, especially from our laboratory at Kansas State University, on the nutritional value of DDGS and the use of DDGS in swine diets.

AVAILABILITY OF DDGS

According to the Energy Information Administration (2009), the average cost of a gallon of gasoline will continue to increase through the year 2035. Because of this increasing trend in fuel costs and to reduce dependence on foreign oil, the United States Congress enacted the Energy Independence and Security Act of 2007 (Public Law 110-140). Section 202 of this law stipulates that use of renewable fuels, as a component of transportation fuel sold in the United States, must increase from 15 billion liters (4 billion gallons) in 2006 to 136 billion liters (36 billion gallons) by 2022. It would take an estimated 323 million metric tons (12.7 billion bushels) of corn to produce 136 billion liters of fuel ethanol with approximately 1/3 of that tonnage yielded as DDGS. However, major factors limiting utilization of DDGS are lack of knowledge related to the nutrient content, nutrient availability, and animal acceptance of DDGS.

INCLUSION LEVEL OF DDGS IN DIETS OF GROWING SWINE

Because of the widespread availability of DDGS, researchers have worked to maximize their inclusion in diet formulation without negatively impacting growth performance. Research from our laboratory showed that 20% DDGS in diets for nursery pigs and 30% DDGS in diets for finishing pigs can be fed without decreases in ADG or G:F (Senne, 1995). However, increasing the level of DDGS in the diet from 15 to 60% decreased (Linear, Quadratic, $P < 0.001$) ADG as well as G:F (Linear, $P < 0.001$) in nursery pigs. Additionally, increasing DDGS from 20 to 60% in diets for finishing pigs tended to decrease ADG (Quadratic, $P < 0.10$) while significantly reducing G:F (Linear, $P < 0.001$). In more recent research, Feoli et al. (2008) and Williams (2010) showed that feeding 30% DDGS in diets for nursery pigs, ADG decreased, while G:F remained unaffected ($P < 0.05$). While feeding finishing pigs 40% DDGS Feoli et al. (2007b, 2007c) and Williams (2010) saw consistently reduced ADG while G:F was not affected to the same degree.

Table 1.1 Effects of DDGS inclusion level on growth performance in nursery pigs

	Inclusion level of DDGS, %								
Item	0	10	15	20	30	40	60	No. Pigs	Reference
ADG, g	463	463		458				72	Senne et al. (1995)
G:F, g/kg	621	621		575					
ADG, g	485		499		463	399	322	180	Senne et al. (1996)
G:F, g/kg	621		680		719	613	552		
ADG, g	606					574		126	Feoli et al. (2007c)
G:F, g/kg	667					661			
ADG, g	576					534		180	Feoli et al. (2008d)
G:F, g/kg	669					695			
ADG, g	585					545		105	Williams (2010)
G:F, g/kg	679					653			
ADG, g	526					506		224	Williams (2010)
G:F, g/kg	671					683			

Table 1.2 Effects of DDGS inclusion level on growth performance in finishing pigs

	Inclusion level of DDGS, %							
Item	0	10	20	30	40	60	No. Pigs	Reference
ADG, g	894	898	875	875			192	Senne et al. (1995)
G:F, g/kg	379	382	388	380				
ADG, g	948		1,007		1,007	993	80	Senne et al. (1996)
G:F, g/kg	299		329		333	344		
ADG, g	943				913		132	Feoli et al. (2007b)
G:F, g/kg	300				287			
ADG, g	1,115				897		70	Feoli et al. (2007c)
G:F, g/kg	331				307			
ADG, g	963				890		56	Feoli et al. (2007d)
G:F, g/kg	289				281			
ADG, g	970				876		330	Feoli et al. (2008d)
G:F, g/kg	319				281			
ADG, g	1,029				926		56	Feoli et al. (2008a)
G:F, g/kg	308				296			
ADG, g	840				789		56	Feoli et al. (2008b)
G:F, g/kg	294				287			
ADG, g	960				854		180	Williams (2010)
G:F, g/kg	320				328			
ADG, g	1,117				1,039			Williams (2010)
G:F, g/kg	319				318			

NUTRIENT CONTENT OF DDGS

The Renewable Fuels Association (2010) reported that 201 ethanol refineries are in operation with another 12 under construction. With so many facilities producing DDGS via miscellaneous methods as well as numerous grain sources being fermented, the nutrient variability among DDGS is a concern. The nutrient variability of DDGS can be caused by many factors, but particularly the nutrient content of the grain being distilled, the proportion of solubles added back to the distillers dried grains, as well as the efficiency of the fermentation conversion of the grain starch (Shurson, 2004). According to Cromwell et al. (1993), these variables can impact lysine, acid detergent fiber, and acid detergent insoluble nitrogen content of the DDGS. Other researchers have suggested that DDGS from “new generation” ethanol plants- those plants built since the mid-1990s (Spiehs et al., 2002)- have higher metabolizable energy (Spiehs et al., 1999), apparent digestible amino acids (Whitney et al., 2000), and available phosphorus (Whiteny et al., 2001) than DDGS from older facilities. The Swine NRC (1998) states that corn DDGS has 3,200 kcal/kg DE, 27.7% CP, and 0.62% lysine with a digestibility of 47% at the terminal ileum. The Feedstuffs Reference Issue (Miller Publishing, 1999) is slightly more generous stating that DDGS contain 29% CP and 0.65% lysine. In contrast, Shurson et al. (2004) reported DDGS from modern plants to have 3,990 kcal/kg DE, 30.5% CP, and 0.85% lysine. Additionally, researchers at the University of Illinois reported that DDGS from modern production facilities have 4,088 kcal/kg DE, 27.5% crude protein, and 0.78% lysine that has 62.3% standardized ileal digestibility (Stein, 2007). Lysine may be damaged if excessive heating is used during the drying process, which can lead to low digestibility of lysine (Stein, 2007). The increased concentration of CP as well as amino acids and other proximate components in DDGS from new generation ethanol plants is most likely the result of more complete fermentation processes utilized by modern facilities.

In addition to the increase in CP, other proximate components of cereal grains are increased through the fermentation process, including fat. Because animals tend to deposit fat similar to that which they consume. Data suggests that because DDGS contain unsaturated fat (vegetable oil), feeding of DDGS can cause negative effects on carcass firmness (Xu et al., 2007; Benz, 2008; White et al., 2008; Whitney et al., 2006). Additionally, Averette-Gatlin et al. (2003) found that hydrogenation of choice white grease increased the level of carcass firmness in pigs. Because of this, Feoli et al. (2007….) designed a series of three experiments to determine the effects of adding saturated fat sources (beef tallow, palm oil, stearic acid, and coconut oil) into diets of sorghum-based DDGS. Degree of fat saturation is measured as iodine value- the grams of iodine absorbed per 100 g of fat (AOCS, 1998). Saturated fat sources traditionally used in animal feeding are beef tallow and palm oil (particularly in Asia). However, these fat sources are approximately 50% saturated. The results of Feoli (2007d, 2008a, 2008b) showed that these fat sources were unable to improve carcass firmness in pigs fed diets containing 40% DDGS. Feeding coconut oil, a less traditional ingredient that is more than 90% saturated fatty acids, was able to correct carcass firmness.

Table 1.3 Effects of fat addition to diets with DDGS and carcass characteristics

		Iodine value			
Fat source	Fat,%	Control	40% DDGS	DDGS + Fat	Fat Effect
Beef tallow[1]	2.5	67.8	72.4	73.3	+0.9
Beef tallow[1]	5			74.2	+1.8
Beef tallow[2]	5	67.0	72.5	73.5	+1.0
Palm oil[2]	5			73.4	+0.9
Stearic acid[3]	5	67.1	71.9	70.7	-1.2
Coconut oil[3]	5			66.6	-5.3

[1] From Feoli et al. (2007d).
[2] From Feoli et al. (2008a).
[3] From Feoli et al. (2008b).

Additional work by Feoli et al. (2007a, 2007b) done in our laboratory, investigated the nutritional value of corn and sorghum-based distillers grains. Exp. 1 utilized 120 finishing pigs in a 19-d determination of the digestible energy (DE) value by substituting 50% corn or sorghum DDGS. The results indicated that DE was lower for sorghum-based DDGS than corn-based DDGS ($P < 0.02$). Furthermore, DDGS source also had a significant effect on DE ($P < 0.001$, for corn; $P < 0.03$, for sorghum). This would indicated that plan of origin can impact the DE of DDGS fed to swine. In a second experiment, pigs were fed diets with 40% corn and sorghum DDGS in a 72-d growth assay. The DDGS were classified as either high or moderate energy, based on Exp 1. The results indicated that pigs fed the corn-soy diet had greater ADG ($P < 0.003$) and digestibility of DM ($P < 0.001$), N ($P < 0.02$), and GE ($P < 0.001$) compared to the DDGS treatments. Additionally, pigs fed the high energy DDGS had lower ADG ($P < 0.06$), ADFI ($P < 0.02$), and diestiblity of DM ($P < 0.03$), while tending to increase G:F ($P < 0.06$) than pigs fed the moderate energy DDGS.

PROTEIN IN DDGS

Work done by Hansen and Lewis (1993) demonstrated that as CP in the diet of growing pigs was increased from a very low 11%, ADG, ADFI, and G:F improved. Furthermore, growth performance suffered with CP in excess 23%. A rule of thumb is that with conversion of cereal starch to ethanol the other proximate components (e.g., protein, fiber, and fat) are concentrated by about three times in DDGS. Thus, diets with containing moderate to high levels of DDGS will have CP concentrations higher than corn-soy formulations. Therefore, we (Williams et al., 2010) designed four experiments to determine the impact of excess CP from both soybean meal and DDGS in the diets for nursery and finishing pigs.

In Exp. 1, 105 nursery pigs were fed increasing concentration of CP from soybean meal (SBM) with treatments being corn-SBM-based diets formulated to 22.5, 25, and 27.5% CP. We chose our CP values based on the NRC (1998) requirement of 23.7% CP for nursery age pigs, ensuring our treatments were just below and surpassed this requirement. For the 28-d experiment, ADG, ADFI, and G:F were not affected by increasing dietary CP.

Table 1.4 Effects of excess CP from soybean meal on growth performance on nursery pigs[1]

	Crude Protein %				P value	
Item	22.5%	25%	27.5%	SE	Linear	Quadratic
ADG, g	592	570	576	23	—[2]	—
ADFI, g	876	849	843	35	—	—
G:F, g/kg	676	671	683	6	—	—

[1] A total of 105 pigs (avg. initial BW of 10.4 kg) with 7 pigs/pen and 5 pens/treatment.
[2] Dashes indicate P > 0.15.

In Exp. 2, 105 pigs were used to determine the effects of feeding excess CP from both SBM and DDGS. We formulated a diet with 30% DDGS and it had 25% CP. We then formulated corn-soy diets with 22.9 and 25% CP. For the 28-d experiment, ADG, ADFI, and G:F for pigs fed the diet with 22.9% CP were not different from those fed the higher CP treatments. However, pigs fed the DDGS treatment had lower G:F compared to pigs fed the corn-soy diet with similar CP content.

Table 1.5 Effects of excess CP from SBM and DDGS on growth performance on nursery pigs[1]

	Treatments				P value	
Item	22.9% CP control	25% CP 30% DDGS	25% CP SBM	SE	Control vs High CP	SBM vs DDGS
ADG, g	585	545	587	18	—[2]	0.12
ADFI, g	861	834	858	29	—	—
G:F, g/kg	679	653	684	9	—	0.04

[1]A total of 105 pigs (avg initial BW of 10.0 kg) with 7 pigs/pen and 5 pens/trt.
[2]Dashes indicate P > 0.15.

For Exp. 3, a total of 176 finishing pigs were fed corn-soy-based diets formulated to 12, 14, 16, and 18% CP. Increasing CP concentration had no effect on ADG, ADFI, G:F, and hot carcass weight (HCW). However, with HCW used as a covariate, dressing percentage decreased from 73.6 to 73.2% (linear effect) and loin depth at the last rib decreased from 6.4 to 6.1cm (linear effect) as CP concentration in the diet was increased from 12 to 18%.

Table 1.6 Effects of excess CP from SBM on growth performance of finishing pigs[1]

	Crude Protein %					P value		
Item	12 %	14%	16%	18%	SE	Linear	Quad	Cubic
ADG, g	944	927	921	936	20	—[4]	—	—
ADFI, kg	2.86	2.85	2.83	2.79	0.08	—	—	—
G:F, g/kg	330	325	325	335	9	—	—	—
Hot carcass weight, kg	92.6	91.6	91.0	91.7	2.0	—	—	—
Dress, %[2]	73.6	73.3	73.1	73.2	0.2	0.01	—	—
Backfat thickness, mm[2]	18.9	19.4	19.3	19.4	1.1	—	—	—
Loin depth, cm[2]	6.4	6.2	6.2	6.1	0.1	0.04	—	—
FFLI, %[2,3]	55.0	54.5	54.5	54.4	0.7	—	—	—

[1] A total of 176 pigs (avg. initial BW of 94 kg) with 11 pigs/pen and 4 pens/treatment.
[2] Hot carcass weight used as a covariate.
[3] Fat-free lean index (NPPC, 2001).
[4] Dashes indicate P > 0.15.

For Exp. 4, a total of 180 finishing pigs were fed diets with dietary CP from SBM and DDGS. Treatments were corn-soy diets formulated to 15.3 and 18.3% CP and a diet with 40% DDGS having 18.3% CP. Pigs fed diets with high CP had lower ADG, ADFI, and HCW, but these results were caused by the diet with 40% DDGS. Indeed, the corn-soy diet with 18.3% CP supported growth performance very similar to that of the diet with 15.3% CP and pigs fed the diet with greater CP actually had the lowest backfat thickness of any treatment group.

Table 1.7 Effects of excess dietary CP from SBM and DDGS in diets for finishing pigs[1]

Item	Control	High CP corn-soy	High CP DDGS	SE	P value: Control vs others	P value: SBM vs DDGS
ADG, g	960	957	854	13	0.001	0.001
ADFI, kg	2.97	2.91	2.64	0.04	0.001	0.001
G:F, g/kg	323	329	324	3	—[4]	0.09
Hot carcass weight, kg	97.6	97.0	91.1	1.6	0.001	0.001
Dressing, %[2]	73.8	73.6	74.0	0.4	—	—
Backfat, mm[2]	19.3	17.4	19.1	0.6	0.09	0.03
Loin depth, cm[2]	6.1	6.2	6.1	0.1	—	—
FFLI, %[2,3]	55.2	55.7	54.8	0.4	—	0.11

[1]A total of 180 pigs (90 barrows and 90 gilts, initial wt 67 kg) with 12 pigs/pen and 5 pens/treatment.
[2]Hot carcass weight used as a covariate.
[3]Fat-free lean index (NPPC, 2001).
[4]Dashes indicate P > 0.15.

Our results indicate that feeding nursery pigs diets ranging from 22 to 27% and finishing pigs diets ranging from 12 to 18% CP had no negative effects on growth performance with small negative effects on dressing percentage and loin depth in finishing pigs. In contrast, diets with high inclusion of DDGS (30% in nursery and 40% in finishing) decreased key measurements of growth performance and carcass value in finishing pigs. Our research demonstrated that any negative effect from high inclusion of DDGS in diets for nursery and finishing pigs does not seem to result from the moderate excess of CP in those diets because corn-soy diets formulated to the same CP content failed to show the same negative effects as were observed by feeding DDGS.

EXTRUSION PROCESSING

Traditionally, the extrusion of complete diets has been limited to use in the human and pet food industry (Hancock and Behnke, 2001). Work done by Hancock et al. (1992) suggested that extruding corn-, sorghum-, wheat-, and barley-based diets improved G:F as well as DM and N digestibility. Additionally, work done by Feoli et al. (2008) demonstrated that for diets with high concentrations of DDGS, thermal processing (expanding) improved both efficiency of growth and nutrient digestibility in nursery and finishing pigs. Because of this improved nutrient utilization with thermal processing of complete diets, Williams et al. (2010) designed an experiment to investigate the impact of extruded DDGS as an ingredient in diets for nursery pigs.

A total of 224 pigs (112 barrows and 112 gilts with an average initial BW of 8.4 kg) were used. All pigs were fed a common diet for 11 d post weaning and the experimental treatments for the next 21 d. Treatments were a corn-soybean meal-based control and three diets formulated with 30% DDGS. For the DDGS treatments, the DDGS were not treated, extruded with the barrel configured for processing cereal grain (to generate less shear and temperature rise), and extruded with the barrel configured for processing soybeans (to generate more shear and temperature rise). Orthogonal contrasts were used to separate treatment means with comparisons of: 1) the control vs DDGS treatments; 2) untreated DDGS vs extruded DDGS; and 3) low shear vs high shear extrusion. Extruder barrel temperatures were collected by probes located 20cm from the end of the extruder. The low shear DDGS had a final temperature of 109^{o}C while the higher shear DDGS had a final temperature of 112^{o}C.

Table 1.8 Chemical characteristics of distillers dried grains with solubles (DDGS)

Item: as-fed	Dry Matter, %[1]	Crude Protein, %[2]	Gross Energy, Mcal/kg[3]	Ether Extract, %[4]	NDF, %[5]	ADF, %[5]
DDGS	87.1	24.3	4.8	9.0	26.5	11.1
Low shear DDGS	91.8	28.2	5.0	11.5	25.1	10.3
High shear DDGS	91.8	27.5	5.0	10.4	23.7	8.1
Item: dry matter						
DDGS		27.9	5.5	10.3	30.4	12.7
Low shear DDGS		30.7	5.4	12.5	23.7	11.2
High shear DDGS		30.0	5.4	10.4	25.1	8.8

[1]NFTA Method 2.1.2.
[2]AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO.
[3]Adiabatic bomb calorimetry; Parr Instruments, Moline, IL.
[4]AOAC 920.39.
[5]ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

Overall, ADG and ADFI were greater ($P < 0.02$) for pigs fed the corn-soy control compared to the DDGS treatments but G:F tended ($P < 0.06$) to be greater when DDGS were added to the diets. Extruding the DDGS did not affect ADG or G:F and there were no differences in growth performance among pigs fed the DDGS extruded with low- vs high shear configurations. Pigs fed the corn-soy control diet had greater ($P < 0.02$) digestibility of DM, N, and GE compared to pigs fed diets containing DDGS. There was a general tendency ($P < 0.04$) for extrusion to improve digestibility of nutrients for diets with DDGS, but the improvement was not sufficient to completely restore digestibility values to those of the corn-soy control.

Table 1.9 Effects of extrusion processing on the nutritional value of distillers dried grains with solubles (DDGS) in diets for nursery pigs[1, 2]

	Treatments					P value		
Item	Corn-Soy control	DDGS	DDGS Low Shear	DDGS High Shear	SE	Control vs DDGS	Treated vs Untreated DDGS	Low vs High Shear
ADG, g	526	506	472	493	20	0.02	0.11	—[4]
ADFI, g	784	741	682	707	31	0.001	0.02	—
G:F, g/kg	671	683	692	697	9	0.06	—	—
Apparent digestibilities, %[3]								
DM, %	78.6	72.8	75.2	74.2	0.8	0.001	0.04	—
N, %	75.6	72.2	74.3	71.9	1.0	0.02	—	0.05
GE, %	77.9	71.9	75.1	73.9	0.9	0.001	0.02	—

[1]A total of 224 pigs (avg initial BW of 8.4 kg) with 7 pigs/pen and 8pens/treatment.
[2]Chemical analysis: CP, % corn-soy, 21.67; DDGS, 24.71; DDGS low shear, 24.85; DDGS high shear, 24.18.
[3]Fecal samples for digestibility determinations were collected on d 32 post-weaning with chromic oxide used as an indigestible marker.
[4] Dashes indicate P > 0.15.

Our results indicate that feeding nursery pigs diets with 30% DDGS decreased ADG and ADFI with no affect on G:F. Extruding DDGS improved GE and DM utilization. However, extruding the DDGS did not ameliorate the loss in growth performance for nursery pigs. The extrusion conditions also had no impact on growth performance.

FORMULATION STRATEGIES FOR DIETS WITH HIGH INCLUSION OF DDGS

There is considerable disagreement about the level of energy and the availability of amino acids in DDGS. These differences are often the result of the grain used for fermentation, the distillation process utilized, as well as the amount of solubles added back to the distillers grains. Work by Senne (1996) and Feoli (2008) at our laboratory showed success in improving G:F in pigs fed diets containing high levels (> 35%) DDGS when fat was added to the diet. Furthermore, Stein (2007) suggested that diets with DDGS should be formulated using standardized ileal digestible (SID) amino acids and digestible phosphorus to most accurately meet the pigs nutrient needs. Thus, we designed a pilot study, to determine the effects of various formulation strategies on growth performance of pigs fed diets with high inclusion of DDGS.

A total of 200 pigs (100 barrows and 100 gilts, average initial BW of 73.1 kg) were used in the 49-d experiment. Treatments were a corn-soybean meal-based control and 4 diets formulated with 40% DDGS. The DDGS treatments were formulated with: no energy adjustment and total amino acids as found in the NRC for Swine (1998); ME and true-ileal digestible amino acids to be equal or greater to that in the corn-soy control (using NRC values); NE and true-ileal digestible amino acids to be equal or greater than that in the corn-soy control (using NRC values); and ME and standardized ileal amino acids as suggested by Stein (2007) to be equal to or greater than that of the corn-soy control.

Table 1.10 Concentration and digestibility of amino acids in DDGS as used for diet formulation

	True Ileal Digestible[1]		Standardized Ileal Digestible[2]	
Amino Acid	Amount, %	Digestibility, %	Amount, %	Digestibility, %
Arginine	1.13	77.0	1.16	81.1
Histidine	0.69	61.0	0.72	77.4
Isoleucine	1.03	73.0	1.01	75.2
Leucine	2.57	79.0	3.17	83.4
Lysine	0.62	59.0	0.78	62.3
Methionine	0.50	75.0	0.55	81.9
Cysteine	0.52	60.0	0.53	73.6
Phenylalanine	1.34	79.0	1.34	80.9
Tyrosine	0.83	90.0	1.01	80.9
Threonine	0.94	85.0	1.06	70.6
Tryptophan	0.25	87.0	0.21	69.9
Valine	1.30	86.0	1.35	74.5

[1]Swine NRC (1998).

[2]Swine Focus #001 Distillers dried grains with soluble (DDGS) in diets fed to swine. (Stein, 2007).

Table 1.11 Composition of diets (as-fed basis)

Ingredient, %	Corn- Soy Control	DDGS	DDGS ME TID	DDGS NE TID	DDGS SID
Corn	88.52	57.85	52.78	54.44	57.83
DDGS[1]	—	40.00	40.00	40.00	40.00
Soybean meal (47.5% CP)	8.84	—	—	—	—
Choice white grease	—	—	4.83	3.18	—
Limestone	1.10	1.26	1.27	1.26	1.26
Monocalcium phosphate (21% P)	0.59	—	—	—	—
Salt	0.23	0.23	0.23	0.23	0.23
L-lysine HCl	0.39	0.51	0.56	0.56	0.49
DL- methionine	0.02	—	—	—	—
L-threonine	0.13	0.002	0.08	0.08	0.02
L-tryptophan	0.03	0.009	0.11	0.11	0.05
Vitamin premix[2]	0.04	0.04	0.04	0.04	0.04
Mineral premix[3]	0.04	0.04	0.05	0.05	0.05
Supplemental premix[4]	0.02	—	—	—	—
Antibiotic [5]	0.05	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Crude protein, %	12.1	16.4	16.1	16.3	16.4
Metabolizeable energy, kcal/kg	3,351	3,131	3,351	3,276	3,370
Net energy, kcal/kg	2,318	2,230	2,362	2,318	2,230
Total lysine, %	0.80[6]	0.80[6]	0.69[7]	0.69[7]	0.69[7]
Available P, %	0.17	0.26	0.26	0.26	0.26

[1] Distillers dried grains with solubles. Chemical analysis,%: CP, 26.01; EE, 10.76; ADF, 11.52; NDF, 28.44 (CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), EE (AOAC 920.39), ADF and NDF were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

[2]Supplied per kilogram of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 mg vitamin E; 1,764 mg vitamin K (as menadione dimethylpyrimidinol bisulfate); 19,841 mg niacin; 11,023 mg pantothenic acid (as calcium pantothenate); 3,307 mg riboflavin, 15,432 µg vitamin B_{12}.

[3]Supplied per kilogram premix: 11,000 mg Cu, 200 mg I, 110,000 mg Fe; 26,400 mg Mn, 200 mg Se, 110,000 mg Zn.

[4]Supplied per kilogram of premix: 8,818 mg vitamin E; 88 mg biotin; 220,460 mg choline; 661 mg Folacin; 1,984 mg vitamin B_6.

[5] To provide 44 g/ton of tylosin.

[6] Formulated on total amino acid basis (NRC, 1998).

[7] Formulated on true ileal digestible amino acid basis (NRC, 1998) .

[8] Formulated on standardized ileal digestible amio acid basis (Stein, 2007).

All dietary treatments were compared to the corn-soy control diet using Bonferroni's t-tests to ensure control of the type-one error rates. Feeding the diet with 40% DDGS and no adjustments for energy or digestible amino acid content tended to decrease ADG and ADFI. Adding fat and formulating the DDGS diets to digestible amino acids significantly reduced both ADFI and G:F ($P < 0.002$). Finally, adjusting the energy and amino acids in the 40% DDGS diets improved ADG to a level similar to that of the corn-soy control diet ($P > 0.5$).

Table 1.12 Effects of formulation strategy on the nutritional value of diets with 40% DDGS

							Bonferroni adjusted P value-Control vs.			
Item	Control	DDGS	ME TID	NE TID	SID	SE	DDGS	ME TID	NE TID	SID
ADG, g	1,117	1,039	1,136	1,135	1,061	30	0.09	—[4]	—	—
ADFI, kg	3.50	3.27	3.16	3.14	3.35	0.09	0.05	0.002	0.001	—
G:F, g/kg	319	318	359	361	317	9	—	0.002	0.001	—
HCW, kg	94.0	89.8	94.0	92.5	90.7	1.5	0.001	—	—	0.008
Dressing, %	73.6	72.5	73.0	71.9	72.6	0.4	—	—	0.03	—
Backfat, mm	24.8	22.6	23.4	23.9	22.4	1.3	—	—	—	0.19
Loin depth, cm	6.2	6.1	6.3	6.3	6.1	0.1	—	—	—	—
FFLI[3], %	51.4	52.3	52.2	51.7	52.5	0.9	—	—	—	—

[1] A total of 176 pigs (avg initial BW of 94 kg) with 11 pigs/pen and 4 pens/treatment.
[2] Hot carcass weight used as a covariate.
[3] Fat-free lean index (NPPC, 2001).
[4]Dashes indicate $P > 0.15$.

In conclusion, feeding high levels of DDGS reduced growth performance while formulating diets on a basis of ME and TID, NE and TID improved growth performance to a level similar to the corn-soy control.

CONCLUSIONS

From our series of experiments as reported herein, it can be concluded that when formulating diets for nursery and finishing pigs, a range of CP concentrations can be fed without negative effects on growth performance. This is especially important because diets formulated with feed ingredients, such as DDGS, can have excess CP. Our data suggests that nursery pigs can be fed up to 27.5% CP and finishing pigs up to 18% CP without negative effects on growth performance. However, reductions in feed intake and growth performance often are still observed when including high levels of DDGS into swine diets. Extruding the DDGS before inclusion in nursery diets improved nutrient digestibility but did not improve growth performance. Addition of fat to the diet, to increase its energy content is beneficial in finishing pigs. Because of the financial benefits from the feeding of DDGS, it is important that research be done to continue to improve the utilization of high levels of DDGS in swine diets.

LITERATURE CITED

AOCS. 1998. Official Methods and Recommmended Practices. 5th ed. American Oil Chemists' Society. Champaign, IL.

Association of American Feed Control Officials. 2005. Official Publication. AAFCO.

Averette Gatlin, L., M. T. See, J. A. Hansen, and J. Odle. 2003. Hydrogenated dietary fat improves pork quality of pigs from two lean genotypes. J. Anim. Sci. 81:1989-1997.

Benz, J. 2008. Influence of dietary ingredients on pork fat quality. M. Sc. Thesis. Kansas State Univ., Manhattan.

Cromwell, G. L., K. L. Herkelman, and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with soluble for chicks and pigs. J. Anim. Sci. 71:679-686.

Feedstuffs Reference Issue. Ingredient analysis table. Miller Publishing Co., Minnetonka, Minnesota, USA 71: (1999) 24-31.

Feoli, C., J. D. Hancock, C. Monge, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007a. Digestible energy content of corn- vs sorghum-based distillers dried grains with soluble in finishing pigs. J. Anim. Sci. 85(Suppl. 2): 95 (Abstr.).

Feoli, C., J. D. Hancock, C. Monge, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007b. Effects of corn- and sorghum-based distillers dried grains with soluble on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 85(Suppl. 2):95 (Abstr).

Feoli, C., J. D. Hancock, S. M. Williams, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007c. Effects of dietary electrolyte balance and molasses in diets with corn-based distillers dried grains with soluble on growth performance in nursery and finishing pigs. J. Anim. Sci. 85(Suppl. 1): 648 (Abstr.).

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007d. Effects of adding saturated fat to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008a. Effects of adding beef tallow and palm oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., J. D. Hancock, D. H. Kropf, S. Issa, T. L. Gugle, and S. D. Carter. 2008b. Effects of adding stearic acid and coconut oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):87 (Abstr.).

Feoli, C., J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008c. Effects of expander conditioning on the nutritional value of diets with corn- and sorghum-based distillers dried grains with soluble in nursery and finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):84 (Abstr.).

Feoli, C., J. D. Hancock, T. L. Gugle, S. D. Carter, and N. A. Cole. 2008d. Effects of enzyme additions to diets with corn- and sorghum-based distillers dried grains with soluble on growth performance and nutrient digestibility in nursery and finishing pigs. J. Anim. Sci. 86(E-Suppl. 2):572 (Abstr.).

Feoli, C. 2008e. Use of corn- and sorghum-based distillers dried grains with soluble in diets for nursery and finishing pigs. PhD Diss. Kansas State Univ., Manhattan.

Hancock, J. D., and K. C. Behnke. 2001. Use of ingredient and diet processing technologies (grinding, mixing, pelleting, and extruding) to produce quality feeds for pigs. Page 469 in Swine Nutrition, 2nd ed. A. J. Lewis and L. L. Southern, ed. CRC Press, Boca Raton, FL.

Hancock, J. D., R. H. Hines, B. T. Richert, and T. L. Gugle. 1992. Extruded corn, sorghum, wheat, and barley for finishing pigs, Kansas State University Swine Day, Agric. Exp. Sta. Rep. Prog. No. 667, p. 130.

Hansen, B. C. and A. J. Lewis. 1993. Effects of dietary protein concentration (corn:soybean meal ratio) on the performance and carcass characteristics of growing boars, barrows, and gilts; mathmatical descriptions. J.Anim. Sci. 71:2122-2132.

NPPC. 2001. Procedures for estimating pork carcass composition. National Pork Producers Council and American Meat Science Association. Des Moines, IA.

NRC. 1998. Nutrient Requirement of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Renewable Fuels Association. 2010. Biorefinery Locations. http://www.ethanolrfa.org/bio-refinery-locations/ Accessed April 23, 2010.

Senne, B. W., J. D. Hancock, I. Mavromichalis, S. L. Johnston, P. S. Sorrell, I. H. Kim, and R. H. Hines. 1996. Use of sorghum-based distillers grains in diets for nursery and finishing pigs. Kansas Agri. Exp. Sta. Rep. Prog. SRP 772. pp. 140-145.

Shurson, G., M. Spiehs, and M. Whitney. 2004. The use of maize distiller's dried grains with solubles in pig diets. Pig News and Informtaion 25 (2), 75N-83N.

Spiehs, M. J., G. C. Shurson, and M. H. Whitney. 1999. Energy, nitrogen, and phosphorus digestibility of growing and finishing swine diets containing distiller’s dried grains with solubles. J. Anim. Sci. 77(Suppl. 1):188. (Abstr.).

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller’s dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Schi. 80:2639-2645.

Stein, H. H. 2007. Swine Focus #001- Distillers dried grains with solubles (DDGS) in diets fed to swine. http://www.distillersgrains.org/files/feedsource/swine_brochure.pdf Accessed Feb. 2, 2009.

U. S. Energy Information Administration. Annual Energy Outlook 2010 Early Release Overview with Projections to 2035. http://www.eia.doe.gov/oiaf/aeo/pdf/overview.pdf Accessed April 22, 2010.

White, H. M., B. T. Richert, J. S. Radcliffe, A. P. Schinckel, J. R. Burgess, S. L. Koser, S. S. Donkin, and M. A. Latour. 2008. Feeding CLA partially recovers carcass quality in pigs fed dried corn distillers grains with solubles. J. Anim. Sci. doi:10.2527/jas.2007-0734.

Whitney, M. H., G. C. Shurson, L. J. Johnson, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grains with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Whitney, M. H., M. J. Spiehs, and G. C. Shurson. 2001. Availiability of phosphorus in distiller’s dried grains with solubles for growing swine. J. Anim. Sci. 79(Suppl. 1):108. (Abstr.).

Whitney, M. H., M. J. Spiehs, G. C. Shurson, and S. K. Baidoo. 2000. Apparent ileal amino acid digestibilities of corn distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 78:185 (Suppl. 1).

Williams, S. M. 2010. Utilization of distillers dried grains with solubles in swine deits. M. Sc. Thesis. Kansas State Univ., Manhattan.

Xu, G., G. C. Shurson, E. Hubly, B. Miller, and B. de Rodas. 2007. Effects of feeding corn-soybean meal diets containing 10% corn dried distillers grains with solublres (DDGS) on pork fat quality of growing-finishing pigs under commercial production conditions. J. Anim. Sci. 85(Suppl. 2):113(Abstr.).

Chapter 2 - **Effects of Feeding Excess Dietary Crude Protein from Soybean Meal and Distillers Dried Grains with Solubles in Diets for Nursery and Finishing Pigs**

ABSTRACT

Four experiments were conducted to determine the effects of feeding excess dietary CP to nursery and finishing pigs. In Exp. 1, 105 pigs were fed increasing concentration of CP from a corn-soybean meal (SBM) mixture. Treatments were diets with 22.5, 25, and 27.5% CP. For the 28-d ADG, ADFI, and G:F were not affected by increasing CP from 22.5 to 27.5% ($P > 0.19$). In Exp. 2, 105 pigs were used to determine the effects of feeding excess CP from SBM vs. distillers dried grains with solubles (DDGS). Treatments were corn-SBM diets formulated to 22.9% and 25% CP and a diet with 30% DDGS (also having 25% CP). For the 28-d experiment ADG, ADFI, and G:F for pigs fed the control diet were not different from that of pigs fed the high CP treatments ($P > 0.12$). However, pigs fed the DDGS treatment had lower G:F compared to pigs fed the corn-soy diet with similar CP content ($P < 0.04$). For Exp. 3, 176 finishing pigs were used in a 33-d growth assay. Treatments were corn-SBM-based and formulated to 12, 14, 16, and 18% CP. Increasing CP concentration had no effect ($P > 0.20$) on ADG, ADFI, G:F, and hot carcass weight (HCW). However, with HCW used as a covariate, dressing percentage decreased from 73.6 to 73.2% (linear effect, $P < 0.01$) and loin depth at the last rib decreased from 6.4 to 6.1cm (linear effect, $P < 0.04$) as CP concentration in the diet was increased from 12 to 18%. For Exp. 4, a total of 180 finishing pigs were used in a 67-d growth assay. Treatments were corn-SBM-based diets formulated to 15.3 and 18.3% CP and a diet with 40% DDGS (also having 18.3% CP). Pigs fed diets with high CP had lower ADG, ADFI, and HCW, but these results were caused by the diet with 40% DDGS (SBM vs DDGS, $P < 0.001$).

Our results indicate that feeding nursery pigs diets ranging from 22.5 to 27.5% CP and finishing pigs diets ranging from 12 to 18% CP had no negative effects on growth performance with small negative effects on dressing percentage and loin depth in the finishing pigs. In contrast, diets with high concentrations of DDGS (30% in nursery and 40% in finishing) decreased key

measurements of growth performance and carcass value in finishing pigs. Any negative effects from high inclusion of DDGS in diets for nursery and finishing pigs does not seem to result from the excess CP in those diets.

(Key Words: Swine, DDGS, Crude Protein, Growth, Carcass)

INTRODUCTION

According to the Energy Information Administration (2009), the retail price of gasoline will steadily increase through 2035. To combat rising fuel costs and to reduce dependence on foreign oil, the United States Congress enacted the Energy Indepenence and Securtiy Act of 2007 (US Public Law 110-140). Section 202 of this law stipulates the use of renewable components in transportation fuel sold in the United States must increase from 15.1 billion liters in 2006 to 136.3 billion liters by 2022.

Distillers dried grains with solubles (DDGS) are defined by the American Association of Feed Control Officials (AAFCO, 2005) as the product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of grain and by condensing and drying at least ¾ of the solids of the resultant whole stillage.

A rule of thumb is that with conversion of cereal starch to ethanol the other proximate components (such as protein, fiber, and fat) are concentrated by about three times in DDGS. Researchers have suggested that DDGS from “new generation” ethanol plants- those plants built since the mid-1990s (Spiehs et al., 2002)- have higher metabolizable energy (Spiehs et al., 1999), apparent digestible amino acids (Whitney et al., 2000), and available phosphorus (Whiteny et al., 2001) than DDGS from older facilities. Thus, Distillers grains are a reasonably good source of protein and energy. In many diet formulations, lower cost DDGS can be used in the place of higher cost corn and soybean meal. However, diets with moderate to high levels of DDGS will have CP concentrations higher than corn-soy formulations. Work by Hansen and Lewis (1993) demonstrated that as CP in the diet of swine was increased from a low level of only 11% ADG, ADFI, and G:F were improved, until at 23% CP, growth performance suffered because of CP excess. Therefore, the objective of the experiments reported herein was to determine the impact of excess CP from both soybean meal and DDGS in diets for nursery and finishing pigs.

MATERIALS AND METHODS

Experiment 1

A total of 105 nursery pigs (56 barrows and 49 gilts, PIC line TR4 × 1050), with an average initial BW of 10.4 kg were used in a 28-d growth assay. The pigs were weaned, sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 7 pigs/pen and 5 pens/treatment. The pigs were housed in an environmentally-controlled nursery having 1.22-m x 1.22-m pens with woven-wire flooring. Temperature at animal level initially was 32°C and was lowered by 1.5°C each week. Pens had a self-feeder and nipple waterers to allow ad libitum consumption of feed and water. The pigs were fed a pelleted commercial starter diet (Rapid Start N/T; Suther Feeds Inc., Frankfort, KS) for the first 14 d post-weaning and the experimental treatments were fed for the next 21 d. Treatments were corn-soybean meal-based and formulated to 22.5, 25, and 27.5% CP (Table 2.1). Pigs and feeders were weighed on d 14 and 35 to allow calculation of ADG, ADFI, and G:F. All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Polynomial regression was used to describe the shape of the response to increasing concentrations of CP.

Experiment 2

A total of 105 nursery pigs (49 barrows and 56 gilts, PIC line TR4 × 1050), with an average initial BW of 10.0 kg were used in a 28-d growth assay. The pigs were weaned, sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 7 pigs/pen and 5 pens/treatment. The pigs were housed and managed as in Exp. 1 with the commercial starter diet consumed for the first 14 d post-weaning and the experimental treatments for the next 21 d. Treatments (Table 2.1) were corn-SBM diets formulated to 22.9% and 25% CP and a diet with 30% DDGS (also having 25% CP). We chose to formulated to 30% DDGS based on the work of Feoli et al. (2007c, 2008d) who showed feeding 30% DDGS reduced ADG in nursery pigs. Pigs and feeders were weighed on d 14 and 35 to allow calculation of ADG, ADFI, and G:F. The feed and DDGS were analyzed for concentrations of N (AOAC 990.03; Leco Corp., St. Joseph, MO), with the DDGS also being analyzed for ether extract (AOAC 920.39), GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL), and ADF and NDF (ANKOM 200 Fiber analyzer, ANKOM Technology Corp., Fairport, NY). All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Orthogonal contrasts were used to compare the corn-soy control vs the mean of the two higher CP treatments, and the 25% CP diet with 30% DDGS vs corn-soy diet formulated to the same CP concentration.

Experiment 3

A total of 176 pigs (88 barrows and 88 gilts, PIC line TR4 × 1050) with an average initial BW of 94 kg were used in a 33-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 11 pigs/pen and 4 pens/treatment. The pigs were housed in a finishing facility having 1.8-m × 4.9-m pens with half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow *ad libitum* consumption of feed and water until slaughtered at an avg. BW of 125kg at a commercial abattoir (Farmland, Crete, NE). All diets were formulated to a minimum 0.8% lysine with 12, 14, 16, and 18% total CP (Table 2.2). The diets were corn-soybean meal-based with the soybean meal fraction of the diet increased (largely at the expense of corn and synthetic amino acids) to supply greater CP to the diet. Pigs and feeders were weighed at d 0 and 33 to allow calculation of ADG, ADFI, and G:F. Hot carcass weight (HCW), loin depth, and tenth rib fat thickness (SFK Technology A/S model S 82; Herlev, Denmark) were measured immediately after slaughter. Dressing percentage was calculated with HCW as a percentage of preshipping live weight. Fat-free lean index (FFLI) was calculated according to the equation suggested by the National Pork Producers Council (NPPC, 2001). All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Polynomial regression was used to describe the shape of the response to increasing concentrations of CP in the diet. Because differences in HCW are known to affect other carcass measurements, it was used as a covariate for the analysis of dressing percentage, fat depth, loin depth, and fat free lean index.

Experiment 4

A total of 180 pigs (90 barrows and 90 gilts, PIC line TR4 × 1050) with an average BW of 67 kg were used in a 67-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 12 pigs/pen and 5 pens/treatment. The pigs were housed and managed as in Exp. 3 until slaughter at an average BW of 129 kg. Treatments (Table 2.3) were a control diet formulated with corn and SBM to supply 15.3% CP, a corn-SBM diet formulated to 18.5% CP, and a diet with 40% DDGS (Souix River Ethanol, Hudson, SD) which also had 18.5% CP. Pigs and feeders were weighed at d 0, 34, and 67 to allow calculation of ADG, ADFI, and G:F. The pigs were killed on d 67 (average BW of 129 kg) and carcass data was collected as in Exp 3. The feed and DDGS were analyzed for concentrations of N (AOAC 990.03; Leco Corp., St. Joseph, MO), with the DDGS also analyzed for ether extract (AOAC 920.39), GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL), and ADF and NDF (ANKOM 200 fiber analyzer, ANKOM Technology Corp., Fairport, NY). All data was analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Orthogonal contrasts were used to separate treatment means with comparisons being the control vs high protein treatments and high protein from SBM vs high protein from DDGS. As in Exp. 3, HCW was used as a covariate for analysis of dressing percentage, fat depth, loin depth, and fat free lean index.

RESULTS AND DISCUSSION

Experiment 1

Overall ADG, ADFI, and G:F were not affected ($P > 0.19$) by increasing CP concentration in the diet from 22.5 to 27.5 (Table 2.4). Dietary A corn-soy diet that meets the amino acid requirements for nursery pigs was predicted to have 23.7% for 5 to 10 kg BW and 20.9% for 10 to 20 kg BW (NRC, 1999). The diets in our experiment were, therefore, well in excess of the pigs' requirements for growth. In contrast, Hansen and Lewis (1993) fed diets with CP concentrations from 11 to 23% and reported poor growth performance at the highest CP levels. However, their data resulted from feeding a single CP concentration from 19 to 105kg BW, so the impact of their treatments on nursery aged pigs was limited. Other researchers have reported that pigs can tolerate considerable excesses of DL-methionine, L-tryptophan, L-threonine, and L-leucine (Edmonds and Baker, 1987). This would support our data that nursery-aged pigs are able to tolerate diets containing CP concentration in moderate excess of NRC requirements.

Experiment 2

There was no difference ($P > 0.12$) in ADG, ADFI and G:F when comparing the control diet with 22.9% CP versus the mean of the two higher CP diets (Table 2.5). However, within the 25% CP treatments, pigs fed the diet with DDGS had numerically lower ADG and ADFI and lower ($P < 0.04$) G:F. Work by Whitey and Shurson (2004), Senne et al. (1995, 1996) as well as by Feoli et al, (2008c,d) found a decrease in feed intake when DDGS was increased from 0 to 25%, 0 to 20%, 0 to 60% or included at 30% of the diet, respectively. The losses in G:F are in contrast to the results of other authors who reported feeding DDGS to nursery pigs showed no negative effects in feed efficiency (Whitney and Shurson, 2004, Feoli et al., 2008c,d).

Our results indicate that feeding nursery pigs diets with 22.5 to 27.5% CP had no negative effects on growth performance. Additionally, the inclusion of 30% DDGS had no negative impact on ADG or ADFI, but did decrease G:F for the 28 d feeding period.

Experiment 3

In finishing pigs, increasing CP concentration in the diet from 12 to 18% had no effect ($P > 0.20$) on ADG, ADFI, G:F, and HCW (Table 2.6). Hansen and Lewis (1993) reported that once CP of a corn-soy diet was adequate to meet amino acid requirements (13% CP) growth performance plateaued to 19% CP. Chen et al. (1999) saw a reduced ADG and ADFI (linear effects, $P < 0.1$) in finishing pigs when CP was increased from 13 to 25%. In our experiment, diets with up to 18% CP did not negatively affect growth performance. In addition to Chen et al (1999) other researchers have observed reductions in ADFI as CP concentrations were fed at levels in excess of requirements (Sugahara et al., 1969; Benevenga et al., 1971). Yet the present study would suggest that pigs are tolerant of CP concentrations in excess of requirement with no observed decrease in ADFI. However, there were slight decreases in dressing percentage (linear effect, $P < 0.01$) and loin depth at the last rib (linear effect, $P < 0.04$) as CP concentration in the diet was increased. Some researchers have reported that increasing CP can lead to increased organ weights, particularly the liver and kidneys (Chen et al., 1999). This could help explain the decreased dressing percent in the present study; however organ weights were not recorded. Fat thickness at the last rib and fat free carcass lean were not affected (P > 0.34) as CP concentration in the diet was increased. This is in contrast to Chen et al. (1999) who saw linear decreases in backfat depths with increased CP concentration in the diet. In conclusion, increasing CP from 12 to 18% did not affect growth performance, carcass weight, or carcass leanness with small decreases in dressing percentage and loin depth as CP was increased from 12 to 18%.

Experiment 4

Pigs fed the corn-soybean meal control diet with 15.3% CP had greater (P < 0.03) ADG, ADFI, HCW, and dressing percentage than pigs fed the 18.3% CP treatments (Table 2.7). These results would seem to support the work of others suggesting that feeding high levels of CP negatively affects growth performance in pigs. However, the negative effects of the high CP treatments were caused entirely by the significantly (P < 0.001) reduced ADG, ADFI, and HCW for pigs fed the DDGS diet compared with pigs fed the high CP corn-soybean meal diet. Thus, the DDGS, and not the excess CP in the diet are causing the negative effects. Other authors (Whitney et al., 2006; Linneen et al., 2008) also observed similar decreases in growth performance with the inclusion of DDGS. More specifically, feeding diets with 40% DDGS impaired growth performance in other research from our laboratory (Feoli et al., 2007a,b,c,d; 2008a,b,d). Although some have found no negative effects from feeding 30 to 60% DDGS when fat was added to the diets (Senne, 1996).

As for carcass measurements, when HCW was used as a covariate there were no treatment effects (P > 0.1) on dressing percentage and FFLI. However, pigs fed the control diet had greater (P < 0.09) fat thickness than pigs fed the high CP treatments. Hansen and Lewis (1993) reported a similar response to increasing CP, where backfat decreased as CP was increased from 11 to 23%.

Also, pigs fed the 18.3% CP from SBM treatment had less ($P < 0.04$) backfat than those fed the 18.3% CP from DDGS diet.

In conclusion, our experiments indicated that both nursery and finishing pigs are tolerant to a wide range of CP concentrations in their diets. Including up to 40% DDGS in the finishing phase did impact performance, but our data would suggest that the increased CP in these diets was not to blame.

LITERATURE CITED

AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Association of American Feed Control Officials Inc. 2005. Official Publication. Atlanta, Georgia, USA.

Benevernga, N. J., A. J. Nielsen, J. W. Jones, and R. H. Grummer. 1971. Adaptation of pigs to diets high in protein. J. Anim. Sci. 33:226 (Abstr.).

Chen, H. Y., A. J. Lewis, P. S. Miller, and J. T. Yen. 1999. The effects of excess protein on grwoth performance and protein metabolism of finishing barrows and gilts. J. Anim. Sci. 77: 3238-3247.

Edmonds, M. S., and D. H. Baker. 1987. Amino acid excesses for young pigs: effects of excess methionine, tryptophan, threonine, or leucine. J. Anim. Sci. 64: 1664-1671.

Feoli, C., J. D. Hancock, C. Monge, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007b. Effects of corn- and sorghum-based distillers dried grains with soluble on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 85(Suppl. 2):95 (Abstr).

Feoli, C., J. D. Hancock, S. M. Williams, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007c. Effects of dietary electrolyte balance and molasses in diets with corn-based distillers dried grains with soluble on growth performance in nursery and finishing pigs. J. Anim. Sci. 85(Suppl. 1): 648 (Abstr.).

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007d. Effects of adding saturated fat to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008a. Effects of adding beef tallow and palm oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., J. D. Hancock, D. H. Kropf, S. Issa, T. L. Gugle, and S. D. Carter. 2008b. Effects of adding stearic acid and coconut oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):87 (Abstr.).

Feoli, C., J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008c. Effects of expander conditioning on the nutritional value of diets with corn- and sorghum-based distillers dried grains with soluble in nursery and finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):84 (Abstr.).

Feoli, C. 2008d. Use of corn- and sorghum-based distillers dried grains with soluble in diets for nursery and finishing pigs. PhD Diss. Kansas State Univ., Manhattan.

Hansen, B. C., and A. J. Lewis. 1993. Effects of dietary protein concentration (corn:soybean meal ratio) on the performance and carcass characteristics of growing boars, barrows, and gilts; mathmatical descriptions. J.Anim. Sci. 71:2122-2132.

Linneen, S. K., J. M. DeRouchey, S. S. Dritz, R. D. Goodband, M. D. Tokach, and J. L. Nelssen. 2008. Effects of dried distillers grains with solubles on growing and finishing pig performance in a commercial environment. J. Anim. Sci. 86:1579-1587.

NPPC. 2001. Procedures for estimating pork carcass composition. National Pork Producers Council and American Meat Science Association. Des Moines, IA.

Senne, B. W., J. D. Hancock, I. Mavromichalis, S. L. Johnston, P. S. Sorrell, I. H. Kim, and R. H. Hines. 1996. Use of sorghum-based distillers grains in diets for nursery and finishing pigs. Kansas Agri. Exp. Sta. Rep. Prog. SRP 772. pp. 140-145.

Senne, B. W., J. D. Hancock, P. S. Sorrell, I. H. Kim, S. L. Traylor, R. H. Hines, and K. C. Behnke. 1995. Effects of distillers grains on growth performance in nursery and finishing pigs. Kansas Agri. Exp. Sta. Rep. Prog. SRP 746. pp. 68-70.

Spiehs, M. J., G. C. Shurson, and M. H. Whitney. 1999. Energy, nitrogen, and phosphorus digestibility of growing and finishing swine diets containing distiller's dried grains with solubles. J. Anim. Sci. 77(Suppl. 1):188. (Abstr.).

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Schi. 80:2639-2645.

Sugahara, M., D. H. Baker, B. G. Harmon, and A. H. Jensen. 1969. Effects of excess levels of dietary crude protein on carcass development in swine. J. Animl. Sci. 29:598.

Whitney, M. H., and G. C. Shurson. 2004. Growth performance of nursery pigs fed diets containing increasing levles of corn distiller's dried grains with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 82:122-128

Whitney, M. H., M. J. Spiehs, and G. C. Shurson. 2001. Availiability of phosphorus in distiller's dried grains with solubles for growing swine. J. Anim. Sci. 79(Suppl. 1):108. (Abstr.).

Whiteny, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth perforamnce and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grains with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356-3363.

Whitney, M. H., M. J. Spiehs, G. C. Shurson, and S. K. Baidoo. 2000. Apparent ileal amino acid digestibilities of corn distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 78:185 (Suppl. 1).

U. S. Energy Information Administration. 2009. Annual Energy Outlook 2010 Early Release Overview with Projections to 2035. http://www.eia.doe.gov/oiaf/aeo/pdf/overview.pdf Accessed April 22, 2010.

Table 2.1 Composition of diets (Exp. 1 and 2; as-fed basis)[1]

	Experiment 1			Experiment 2		
Ingredient, %	22.5% CP	25% CP	27.5% CP	22.9% CP control	25% CP 30% DDGS	25% CP SBM
Corn	48.32	41.71	35.44	47.30	27.30	41.67
Corn DDGS[2,3]	—	—	—	—	30.00	—
Soybean meal (47.5% CP)	30.23	37.44	43.95	31.35	21.65	37.51
Spray-dried whey	15.00	15.00	15.00	15.00	15.00	15.00
Menhaden fishmeal	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate (21% P)	0.74	0.60	0.46	0.72	0.21	0.60
Limestone	0.80	0.81	0.81	0.80	0.99	0.81
L-lysine HCl	0.30	0.04	—	0.26	0.46	0.04
DL- methionine	0.14	0.06	—	0.13	0.03	0.06
L-threonine	0.11	—	—	0.09	0.04	—
L-tryptophan	0.01	—	—	—	—	—
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[4]	0.09	0.09	0.09	0.09	0.09	0.09
Mineral premix[5]	0.07	0.06	0.05	0.07	0.03	0.03
Zinc oxide[6]	0.19	0.19	0.20	0.19	0.20	0.19
Antibiotic[7]	0.70	0.70	0.70	0.70	0.70	0.70
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis, %						
Crude protein	22.5	25.0	27.5	22.9	25.0	25.0
Lysine	1.55	1.55	1.70	1.55	1.55	1.55
Chemical analysis, %[8]						
Crude Protein	21.9	24.4	26.0	21.3	24.2	22.6

[1]The diets were formulated to 0.80% Ca and 0.70% total P.

[2]Distillers dried grains with soluble.

3Chemical analysis, %: CP, 27.05; EE, 10.27; ADF, 7.16; NDF, 24.33; GE,Mcal/kg, 4.82.

[4]Supplied per kilogram of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 mg vitamin E; 1,764 mg vitamin K (as menadione dimethylpyrimidinol bisulfate); 19,841 mg niacin; 11,023 mg pantothenic acid (as calcium pantothenate); 3,307 mg riboflavin, 15,432 µg vitamin B_{12}.

[5]Supplied per kilogram premix: 11,000 mg Cu, 200 mg I, 110,000 mg Fe; 26,400 mg Mn, 200 mg Se, 110,000 mg Zn.

[6]To supply 1500 mg/kg Zn.

[7]To provide 154 g/ton oxytetracycline and 154 g/ton neomycin.

[8]CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO).

Table 2.2 Composition of diets (Exp. 3; as-fed basis)[1]

	Crude protein,%			
Ingredient, %	12	14	16	18
Corn	88.51	83.28	78.01	72.98
Soybean meal (47.5% CP)	8.80	14.50	20.06	25.15
Limestone	1.06	1.07	1.04	1.01
Monocalcium phosphate (21% P)	0.66	0.55	0.51	0.48
Salt	0.23	0.23	0.23	0.23
L-lysine HCl	0.39	0.19	—	—
L-threonine	0.11	0.02	—	—
L-tryptophan	0.05	0.01	—	—
DL- methionine	0.04	—	—	—
Vitamin premix[2]	0.06	0.06	0.06	0.06
Mineral premix[3]	0.04	0.04	0.04	0.04
Antibiotic [4]	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00
Calculated analysis, %				
Lysine	0.80	0.80	0.81	0.95
Chemical analysis, %				
Crude protein[5]	12.2	13.7	16.4	17.7

[1]Diets formulated to 0.55% Ca and 0.45% total P.

[2]Supplied per kilogram of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 mg vitamin E; 1,764 mg vitamin K (as menadione dimethylpyrimidinol bisulfate); 19,841 mg niacin; 11,023 mg pantothenic acid (as calcium pantothenate); 3,307 mg riboflavin, 15,432 µg vitamin B_{12}.

[3]Supplied per kilogram premix: 11,000 mg Cu, 200 mg I, 110,000 mg Fe; 26,400 mg Mn, 200 mg Se, 110,000 mg Zn.

[4]To provide 44g/ton of tylosin.

[5]AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO.

Table 2.3 Composition of diets (Exp. 4; as-fed basis)[1]

	d 0 to 34			d 34 to 67		
Ingredient, %	15.3% CP control	18.5% CP SBM[2]	18.5% CP DDGS	14.6% CP control	17.6% CP SBM	17.6% CP DDGS
Corn	79.78	72.06	52.82	81.70	74.13	54.74
Corn DDGS[3,4]	—	—	40.00	—	—	40.00
Soybean meal (47.5% CP)	17.80	25.85	4.95	16.20	24.00	3.25
Limestone	1.09	1.05	1.34	1.06	1.01	1.24
Monocalcium phosphate (21% P)	0.73	0.67	0.05	0.54	0.49	—
Salt	0.23	0.23	0.23	0.23	0.23	0.23
L-lysine HCl	0.20	—	0.47	0.13	—	0.40
L-threonine	0.03	—	—	—	—	—
Vitamin premix[5]	0.04	0.04	0.04	0.04	0.04	0.04
Mineral premix[6]	0.05	0.05	0.05	0.05	0.05	0.05
Antibiotic[7]	0.05	0.05	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis, %						
Lysine	0.90	0.97	0.90	0.80	0.92	0.80
Crude protein	15.3	18.3	18.3	14.6	17.6	17.6
Chemical analysis,%[8]						
Crude protein	14.2	17.3	16.5	13.6	17.4	16.7

[1]Diets formulated to 0.6% Ca (d 0 to 34) and 0.55% Ca (d 34-67) and 0.50% total P (d 0 to 34) and 0.45% total P (d 34 to 67).

[2]Soybean meal.

[3]Distillers dried grains with soluble.

[4]Chemical analysis,%: CP, 27.05; EE, 10.27; ADF, 7.16; NDF, 24.33; GE,Mcal/kg, 4.82.

[5]Supplied per kilogram of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 mg vitamin E; 1,764 mg vitamin K (as menadione dimethylpyrimidinol bisulfate); 19,841 mg niacin; 11,023 mg pantothenic acid (as calcium pantothenate); 3,307 mg riboflavin, 15,432 μg vitamin B_{12}.

[6]Supplied per kilogram premix: 11,000 mg Cu, 200 mg I, 110,000 mg Fe; 26,400 mg Mn, 200 mg Se, 110,000 mg Zn.

[7]To provide 44g/ton of tylosin.

[8]CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), ADF and NDF were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY), GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL).

Table 2.4 Effects of excess CP from sbm[1] on growth performance on nursery pigs (Exp. 1) [2]

	Crude Protein %				P value	
Item	22.5%	25%	27.5%	SE	Linear	Quadratic
ADG, g	592	570	576	23	—[3]	—
ADFI, g	876	849	843	35	—	—
G:F, g/kg	676	671	683	6	—	—

[1]Soybean meal.

[2]A total of 105 pigs (avg. initial BW of 10.4 kg) with 7 pigs/pen and 5 pens/treatment.

[3]Dashes indicate P > 0.15.

Table 2.5 Effects of excess CP from soybean meal (SBM) and distillers dried grains with soluble (DDGS) on growth performance on nursery pigs (Exp. 2)[1]

	Treatments				P value	
	22.9% CP	25% CP	25% CP		Control vs	SBM vs
Item	control	SBM	30% DDGS	SE	High CP	DDGS
ADG, g	585	587	545	18	—[2]	0.12
ADFI, g	861	858	834	29	—	—
G:F, g/kg	679	684	653	9	—	0.04

[1]A total of 105 pigs (avg. initial BW of 10.0 kg) with 7 pigs/pen and 5 pens/trt.

[2]Dashes indicate P > 0.15.

Table 2.6 Effects of excess CP from SBM on growth performance of finishing pigs (Exp. 3)[1]

	Crude Protein, %					P value		
Item	12 %	14%	16%	18%	SE	Linear	Quad	Cubic
ADG, g	944	927	921	936	20	—[4]	—	—
ADFI, kg	2.86	2.85	2.83	2.79	0.08	—	—	—
G:F, g/kg	330	325	325	335	9	—	—	—
Hot carcass weight, kg	92.6	91.6	91.0	91.7	2.0	—	—	—
Dress, %	73.7	73.3	73.0	73.1	0.2	0.01	0.08	—
Backfat thickness, mm	19.1	19.4	19.2	19.4	1.2	—	—	—
Loin depth, cm	6.4	6.2	6.2	6.1	0.1	0.03	—	—
FFLI, % [3]	55.2	54.5	54.6	54.4	0.7	0.14	—	—
Dress, %	73.6	73.3	73.1	73.2	0.2	0.01	—	—
Backfat thickness, mm [2]	18.9	19.4	19.3	19.4	1.1	—	—	—
Loin depth, cm [2]	6.4	6.2	6.2	6.1	0.1	0.04	—	—
FFLI, % [2,3]	55.0	54.5	54.5	54.4	0.7	—	—	—

[1] A total of 176 pigs (avg. initial BW of 94 kg) with 11 pigs/pen and 4 pens/treatment.

[2] Hot carcass weight used as a covariate.

[3] Fat-free lean index (NPPC, 2001).

[4] Dashes indicate P > 0.15.

Table 2.7 Effects of excess dietary CP from soybean meal and distillers dried grains with solubles (DDGS) in diets for finishing pigs (Exp. 4)[1]

Item	15.3% CP control	18.5% CP SBM	18.5% CP DDGS	SE	P value: Control vs others	P value: SBM vs DDGS
ADG, g	960	957	854	0.01	0.001	0.001
ADFI, kg	3.0	2.9	2.6	0.04	0.001	0.001
G:F, g/kg	320	330	328	3	—[4]	0.09
Hot carcass weight, kg	97.6	97.0	91.1	1.6	0.001	0.001
Dressing, %	74.2	74.1	73.3	0.3	—	0.08
Backfat, mm	19.6	17.7	18.4	0.5	0.03	—
Loin depth, cm	6.1	6.2	6.0	0.1	—	0.11
FFLI, %[3]	54.3	55.6	54.8	0.4	0.06	0.15
Dressing, %[2]	73.8	73.6	74.0	0.4	—	—
Backfat, mm[2]	19.3	17.4	19.1	0.6	0.09	0.03
Loin depth, cm[2]	6.1	6.2	6.1	0.1	—	—
FFLI, %[2,3]	55.2	55.7	54.8	0.4	—	0.11

[1]A total of 180 pigs (90 barrows and 90 gilts, avg. initial BW of 67 kg) with 12 pigs/pen and 5 pens/treatment.

[2]Hot carcass weight used as a covariate.

[3]Fat-free lean index (NPPC, 2001).

[4]Dashes indicate $P > 0.15$.

Chapter 3 - **Effects of Extrusion Processing on the Nutritional Value of Distillers Dried Grains with Solubles in Diets for Nursery Pigs**

ABSTRACT

A total of 224 pigs (112 barrows and 112 gilts with an average initial BW of 8.4 kg) were used in a 21-d experiment to determine the effects of extrusion processing on the nutritional value of DDGS in diets for nursery pigs. The pigs were weaned, sorted by sex and ancestry, and blocked by BW with 7 pigs/pen and 8 pens/treatment. All pigs were fed a common diet for 11 d post weaning and the experimental treatments for the next 21 d. Treatments were a corn-soybean meal-based control and three diets formulated with 30% DDGS. The DDGS were not treated, extruded with the barrel configured for processing cereal grain (to generate less shear and temperature rise), and extruded with the barrel configured for processing soybeans (to generate more shear and temperature rise). Orthogonal contrasts were used to separate treatment means with comparisons of: 1) the control vs DDGS treatments; 2) untreated DDGS vs extruded DDGS; and 3) low shear vs high shear extrusion. Overall, ADG and ADFI were greater for pigs fed the corn-soy control compared to the DDGS treatments ($P < 0.02$), but the opposite was true for G:F ratio ($P < 0.06$). Extruding the DDGS did not affect ADG or G:F ($P > 0.11$) but did reduce ADFI ($P < 0.02$). There were no differences in growth performance among pigs fed the DDGS extruded with low- vs high shear ($P > 0.2$). Pigs fed the corn-soy control diet had greater digestibility of DM, N, and GE ($P < 0.02$) when compared to pigs fed the diets with DDGS. Among the DDGS treatments, extrusion improved digestibilties of DM and GE ($P < 0.04$), but improved digestibility of N only with high-shear conditions ($P < 0.05$).

(Key Words: Pigs, DDGS, Extrusion)

INTRODUCTION

Traditionally, the extrusion of complete diets has been limited to use in the human and pet food industries (Hancock and Behnke, 2001). However, Hancock et al. (1992) reported that extruding corn-, sorghum-, wheat-, and barley-based diets improved G:F as well as DM and N digestibility in finishing pigs. Previous research from our laboratory by Feoli et al. (et al., 2007a,b,c,d; 2008a,b,d) as well as Williams et al. (2008, 2010) found feeding high (>30%) DDGS to nursery and finishing pigs decreased both growth performance as well as nutrient digestibility. Additionally, Feoli et al. (2008c) reported that thermal processing (expanding) diets for nursery and finishing pigs containing high levels of DDGS, improved both efficiency of growth and nutrient digestibility over an unexpanded control. Because of the improved nutrient utilization with thermally processed complete diets, we designed an experiment to investigate the impact of extruded DDGS on growth performance and nutrient digestibility in nursery pigs.

MATERIALS AND METHODS

A total of 224 pigs (112 barrows and 112 gilts, PIC line TR4 × 1050) with an average initial BW of 8.4 kg were used in the 21-d growth assay. The pigs were weaned and allotted to by sex and ancestry, blocked by weight, and assigned to pens. There were 7 pigs/pen and 8 pens/treatment. Each pen had a self-feeder and nipple waterers to allow ad libitum consumption of feed and water. The pigs were fed a common, early weaning diet (Rapid Start N/T; Suther Feeds Inc., Frankfort, KS) for the first 11 d post-weaning and the experimental treatments were fed for the next 21 d.

Treatments (Table 3.1) were a corn-soybean meal-based control and three diets formulated with 30% DDGS. The DDGS treatments were no additional process, extruding with the barrel configured for processing cereal grain (to generate less shear and temperature rise), and extruding with the barrel configured for processing soybeans (to generate more shear and temperature rise).

To create the low-shear conditions we used an Insta-pro 2000 Dry Extruder (Des Moines, IA) fitted with a #6 steam lock, single flight screw, #6 steam lock, single flight screw, 11-R steam lock, and 15.9 mm cone opening sequence. For the high-shear conditions we used an 11-R steam lock, single flight screw, a blank spacer, single flight screw, 11-R steam lock, and 15.9 mm cone opening. Extruder barrel temperatures were collected by probes located 20cm from the end of the extruder. The low shear DDGS had a final temperature of 109^{o}C and a production rate of 599 kg/h while the higher shear DDGS had a final temperature of 112^{o}C and a production rate of 555 kg/h.

Pigs and feeders were weighed at d 11 and 32 post weaning to allow calculation of ADG, ADFI, and G:F. Feces were collected on d 32 post weaning from no less than 4 randomly selected pigs/pen. The fecal samples were combined within pen and kept frozen at -15^{o}C until dried at 50^{o}C. Feed and feces were analyzed for concentrations of DM (NFTA Method 2.1.2), N (AOAC 990.03; Leco Corp., St. Joseph, MO), and GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). Chromium concentrations in the feed and feces were determined using atomic absorption (Williams et al., 1962) to allow calculation of apparent digestibilities using the indirect ratio method. All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). Orthogonal contrasts were used to separate treatment means with comparisons of: 1) the control diet vs DDGS treatments; 2) untreated vs extruded DDGS; and 3) low shear vs high shear extrusion.

RESULTS AND DISCUSSION

With extrusion processing (Table 3.2), we observed that the degree of processing (none vs. low and high shear) cause an increase in the CP concentration of the DDGS. GE and ether extract both increase as the degree of processing was increased. Both NDF and ADF decreased after extrusion processing. However, the high degree of processing did cause a slight increase in the NDF and ADF contents compared to the lower degree of processing.

Overall ADG and ADFI were greater for pigs fed the corn-soy control compared to the DDGS treatments ($P < 0.02$). Like in the present study, work by Whitey and Shurson (2004), Senne et al. (1995, 1996) as well as by Feoli et al, (2008c,d) found a decrease in feed intake when DDGS was increased from 0 to 25%, 0 to 20%, 0 to 60% or included at 30% of the diet, respectively. Moreover, Feoli et al. (2008c,d) also observed greater ADG when nursery pigs were fed a corn-soy control vs. diets with 30% DDGS. However, in the present study, there was a tendency for greater G:F ($P < 0.06$) with DDGS in the diet. Extruding the DDGS had no effect on ADG ($P > 0.11$) or G:F ($P > 0.6$).

Pigs fed the corn-soy control diet had greater digestibility of DM, N, and GE ($P < 0.02$) compared to pigs fed the diets with DDGS. These results are consistent with the results of Feoli et al. (2008) who reported that feeding nursery and finishing pigs diets with both corn- and sorghum-based DDGS reduced apparent nutrient digestibility. Both DM and GE digestibility were improved by extrusion of the DDGS ($P < 0.04$) but N digestibility was improved only with the high-shear conditions ($P < 0.05$). These improvements in digestibility of DM, N, and GE agree with the work done by Feoli et al. (2008c) where expander conditioning of diets with 30% DDGS improved nutrient digestibility. Additionally Traylor (1999) found expanding high fiber diets (from wheat midds) prior to pelleting also improved nutrient digestibility in finishing pigs. These results are similar to work done by Noland et al. (1976) who found feeding extruded sorghums improved energy and nitrogen digestibility when fed to nursery pigs but did not affect growth performance. Herkelman et al. (1990) reported that extrusion of corn did not affect utilization of N.

Because feeding, as well as extruding DDGS reduced ADFI in the present study, some would wonder if this impacted nutrient digestibility. Past findings are inconsistent as to the impact of feed intake on energy digestibility in swine. Cunningham et al. (1962), Everts and Smits (1987) and Smits et al. (1994) reported decrased apparent energy digestibility with increased feeding level in growing pigs. However, Peers et al. (1977), Fernandez et al. (1986), and Morel et al. (2005) saw none or slight positive impacts on digestibility as intake increased.

Our results indicate that feeding nursery pigs diets with 30% DDGS decreased ADG and ADFI with no affect on G:F. Digestibility results showed that extruding DDGS can improve DM, N and GE digestibility, but extruding the DDGS did not ameliorate this loss in growth performance.

LITERATURE CITED

AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Cunningham, H. N., D. W. Friend, J. W. G. Nicholson. 1962. The effect of age, body weight, feed intake and adaptability of pigs on the digestibility and nutritive value of cellulose. Can. J. Anim. Scie. 42, 167-175.

Everts, H., B. Smits. 1987. Effect of crude fibre, feeding level, body weight and method of measuring on apparent digestibility of compound feeds by swine. Neth. J. Agric. Sci. 34, 501-503.

Feoli, C. J. D. Hancock, C. Monge, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007a. Digestbile energy content of corn- vs sorghum-based distillers dried grains with solubles in finishing pigs. J. Anim. Sci. 85(Suppl. 2):95(Abstr.).

Feoli, C., J. D. Hancock, C. Monge, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007b. Effects of corn- and sorghum-based distillers dried grains with soluble on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 85(Suppl. 2):95 (Abstr).

Feoli, C., J. D. Hancock, S. M. Williams, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007c. Effects of dietary electrolyte balance and molasses in diets with corn-based distillers dried grains with soluble on growth performance in nursery and finishing pigs. J. Anim. Sci. 85(Suppl. 1): 648 (Abstr.).

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007d. Effects of adding saturated fat to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008a. Effects of adding beef tallow and palm oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., J. D. Hancock, D. H. Kropf, S. Issa, T. L. Gugle, and S. D. Carter. 2008b. Effects of adding stearic acid and coconut oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):87 (Abstr.).

Feoli, C., J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008c. Effects of expander conditioning on the nutritional value of diets with corn- and sorghum-based distillers dried grains with soluble in nursery and finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):84 (Abstr.).

Feoli, C., J. D. Hancock, T. L. Gugle, S. D. Carter, and N. A. Cole. 2008d. Effects of enzyme additions to diets with corn- and sorghum-based distillers dried grains with soluble on growth performance and nutrient digestibility in nursery and finishing pigs. J. Anim. Sci. 86(E-Suppl. 2):572 (Abstr.).

Feoli, C. 2008e. Use of corn- and sorghum-based distillers dried grains with soluble in diets for nursery and finishing pigs. PhD Diss. Kansas State Univ., Manhattan.

Fernandez, J. A., H. Jorgensen, A. Just. 1986. Comparative digestibility experiemtns with growing pigs and adult sows. Anim. Prod. 43, 127-132.

Hancock, J. D., and K. C. Behnke. 2001. Use of ingredient and diet processing technologies (grinding, mixing, pelleting, and extruding) to produce quality feeds for pigs. Page 469 in Swine Nutrition, 2nd ed. A. J. Lewis and L. L. Southern, ed. CRC Press, Boca Raton, FL.

Hancock, J. D., R. H. Hines, B. T. Richert, and T. L. Gugle. 1992. Extruded corn, sorghum, wheat, and barley for finishing pigs, Kansas State University Swine Day, Agric. Exp. Sta. Rep. Prog. No. 667, p. 130.

Herkelman, K. L., S. L. Roadhouse, T. L. Veum, and M. R. Ellersieck. 1990. Effect of extrusion on the ileal and fecal digestibilities of lysine in yellow corn in diets for young pigs, J. Anim. Sci., 68:2414-2424.

Morel, P. C. H., T. S. Lee, P. J. Moughan. 2005. Effects of feeding level, live weight, and genotype on the apparent faecal digestibility of energy and organic matter in the growing pig. Anim. Feed Sci. Tech., 126: 63-74.

Noland, P. R., D. R. Campbell, R. K. Gage, Jr., R. N. Sharp, and Z. B. Johnson. 1976. Evaluation of processed soybeans and grians in diets for young pigs, J. Anim. Sci., 43:763-769.

Peers, D. G., A. G. Taylor, C. T. Whittemore. 1977. The influence of feeding level and level of dietary inclusion on digestibility fo barely meal in the pig. Anim. Feed Sci. Tech. 2, 41-47.

Senne, B. W., J. D. Hancock, I. Mavromichalis, S. L. Johnston, P. S. Sorrell, I. H. Kim, and R. H. Hines. 1996. Use of sorghum-based distillers grains in diets for nursery and finishing pigs. Kansas Agri. Exp. Sta. Rep. Prog. SRP 772. pp. 140-145.

Senne, B. W., J. D. Hancock, P. S. Sorrell, I. H. Kim, S. L. Traylor, R. H. Hines, and K. C. Behnke. 1995. Effects of distillers grains on growth performance in nursery and finishing pigs. Kansas Agri. Exp. Sta. Rep. Prog. SRP 746. pp. 68-70.

Smits, B., A. W. Jongbloed, L. B. J. Sebek. 1994. Effects of pelleting and feeding level on apparent digestibility and feeding value of diets for growing-finishing pigs. Jpn. J. Zootech. Sci. 56, 797-801.

Traylor, S. L., K. C. Behnke, J. D. Hancock, R. H. Hines, S. L. Johnston, B. J. Chae, and In K. Han. 1999. Effects of expander operating conditions on nutrient digestibility in finishing pigs. Asian-Aus. J. Anim. Sci. 12:400-410.

Whitney, M. H., and G. C. Shurson. 2004. Growth performance of nursery pigs fed diets containing increasing levles of corn distiller's dried grains with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 82:122-128.

Williams, S. M., J. D. Hancock, C. Feoil, S. Issa, and T. L. Gugle. 2008. Effects of feeding excess crude protein on growther performance and carcass traits in finishing pigs. J. Anim. Sci 86(Suppl. 1): 776 (Abstr.).

Williams, S. M., J. D. Hancock, S. Issa, and T. L. Gugle. 2010. Effects of excess dietary protein from soybean meal and dried distillers grains with solubles in nursery pigs. J. Anim. Sci. 88(E-Suppl.3):166 (Abstr.).

Williams, C. H., D. J. David, and O. Iismaa. 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. J. Agri. Sci., 59: 381-385.

Table 3.1 Composition of diets[1]

Ingredient, %	Corn-soy Control	30% DDGS
Corn	47.30	27.30
Corn DDGS[2]	—	30.00
Soybean meal (47.5% CP)	31.35	21.65
Spray dried whey	15.00	15.00
Menhaden fishmeal	3.00	3.00
Monocalcium Phosphate (21% P)	0.72	0.21
Limestone	0.80	0.99
L-lysine HCl	0.26	0.46
DL- methionine	0.13	0.03
L-threonine	0.09	0.04
Salt	0.30	0.30
Vitamin premix[2]	0.09	0.09
Mineral premix[3]	0.07	0.03
Zinc oxide[4]	0.19	0.20
Antibiotic[5]	0.70	0.70
Total	100.00	100.00
Calculated analysis, %		
Crude protein	22.9	25.0
Lysine	1.6	1.6

[1]The diets were formulated to 0.80%Ca, and 0.70% total P.
[2]Distillers dried grains with soluble.
[3]Supplied per kilogram of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 mg vitamin E; 1,764 mg vitamin K (as menadione dimethylpyrimidinol bisulfate); 19,841 mg niacin; 11,023 mg pantothenic acid (as calcium pantothenate); 3,307 mg riboflavin, 15,432 µg vitamin B_{12}.
[4]Supplied per kilogram premix: 11,000 mg Cu, 200 mg I, 110,000 mg Fe; 26,400 mg Mn, 200 mg Se, 110,000 mg Zn.
[5]To supply 1,500 mg/kg Zn.
[6]To provide 154 g/ton oxytetracycline and 154 g/ton neomycin.

Table 3.2 Chemical characteristics of distillers dried grains with solubles (DDGS)

Item: as-fed	Dry Matter, %[1]	Crude Protein, %[2]	Gross Energy, Mcal/kg[3]	Ether Extract, %[4]	NDF, %[5]	ADF, %[5]
DDGS	87.1	24.3	4.8	9.0	26.5	11.1
Low shear DDGS	91.8	28.2	5.0	11.5	25.1	10.3
High shear DDGS	91.8	27.5	5.0	10.4	23.7	8.1
Item: dry matter						
DDGS		27.9	5.5	10.3	30.4	12.7
Low shear DDGS		30.7	5.4	12.5	23.7	11.2
High shear DDGS		30.0	5.4	10.4	25.1	8.8

[1]NFTA Method 2.1.2.

[2]AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO.

[3]Adiabatic bomb calorimetry; Parr Instruments, Moline, IL.

[4]AOAC 920.39.

[5]ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

Table 3.3 Effects of extrusion processing on the nutritional value of distillers dried grains with solubles (DDGS) in diets for nursery pigs[1]

	Treatments[2]					P value		
Item	Corn-Soy control	DDGS	DDGS Low Shear	DDGS High Shear	SE	Control vs DDGS	Treated vs Untreated DDGS	Low vs High Shear
ADG, g	526	506	493	472	20	0.02	0.11	—[4]
ADFI, g	784	741	707	682	31	0.001	0.02	—
G:F, g/kg	671	683	697	692	9	0.06	—	—
Apparent digestibility, %[3]								
DM	78.6	72.8	74.2	75.2	0.8	0.001	0.04	—
N	75.6	72.2	71.9	74.3	1.0	0.02	—	0.05
GE	77.9	71.9	73.9	75.1	0.9	0.001	0.02	—

[1]A total of 224 pigs (avg. initial BW of 8.4 kg) with 7 pigs/pen and 8pens/treatment.

[2]Chemical analysis, %: CP; Corn-soy control, 21.67; DDGS, 24.71; DDGS low shear, 24.85; DDGS high shear, 24.18 (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO).

[3]Fecal samples for digestibility determinations were collected on d 32 post-weaning with chromic oxide used as an indigestible marker.

[4]Dashes indicate P > 0.15.

Chapter 4 - **Effect of Formulation Strategy on the Nutritional Value of Distillers Grains with Solubles**

ABSTRACT

A total of 200 pigs (100 barrows and 100 gilts, average initial BW of 73.1 kg) were used in a 49-d experiment to determine the effects of formulating diets with distillers dried grains with soluble (DDGS) using ME, NE and digestible amino acids. The pigs were allotted by sex and ancestry, blocked by weight, and assigned to pens with 5 pigs/pen and 8 pens/treatment. The energy and amino acid availability values used for diet formulation were those from the NRC (1998) except the last diet which was formulated using the standardized ileal digestible amino acids as proposed by Stein (2007). Treatments were a corn-soybean meal-based control and 4 diets formulated with 40% DDGS. DDGS treatments were formulated with no energy adjustment and total amino acids; fat added such that the ME is to the level of the corn-soy diet and a true-ileal digestible amino acids; fat added so that the NE is to the level of the corn-soy control diet and true-ileal digestible amino acids, and no energy adjustment and standardized ileal digestible amino acids.

All dietary treatments were compared to the corn-soy control with P-values adjusted using Bonferroni's t-test to ensure control of the type-one error rates. The unadjusted diet with 40% DDGS supported lower ADG ($P < 0.09$) and ADFI ($P < 0.05$). Adding fat and using TID supported numerically higher ADG and significantly ($P < 0.002$) increased G:F. Finally, Adjusting the energy and amiono acids in the 40% DDGS diets improved ADG to a level similar to that of the corn-soy control diet ($P > 0.5$). In conclusion, feeding high levels of DDGS reduced growth performance. But, formulating diets using NRC values for ME, NE and TID amino acids improved growth performance to a level similar to the corn-soy control.

(Key Words: Pigs, DDGS, metabolizable energy, net energy, true ileal digestible amino acids)

INTRODUCTION

There is notable disagreement about the level of energy and availability of amino acids in distillers dried grains with solubles (DDGS) resulting from the distillation process of the ethanol industry. From our previous research, we know that adding 40% DDGS to diets for finishing pigs reduces Senne (1996) and Feoli (2007 d; 2008 a,b) reported success in improving G:F in pigs fed diets with high levels (> 35%) of DDGS when fat was added to the diet. Stein (2007) went on to suggest that diets with DDGS should be formulated using standardized ileal digestible (SID) amino acids as well as digestible phosphorus. Because of this, we designed a pilot study, to determine the effects of formulating diets based on ME and NE as methods to improve pig performance. Also, we investigated weather adding crystalline amino acids to formulations for true ileal digestible (TID) amino acids rather than total amino acids would improve growth performance. We hoped this experiment would provide valuable information about which areas of research could have value in the near future to expand our effective utilization of DDGS.

MATERIALS AND METHODS

For this experiment, a total of 200 pigs (100 barrows and 100 gilts, PIC line TR4 × 1050) with an average initial BW of 73.1 kg were used in a 49-d growth assay. The pigs were allotted by sex and ancestry, blocked by weight, and assigned to pens. There were 5 pigs/pen and 8 pens/treatment. The pens had slotted flooring, with a single-hole self-feeder and nipple waterer to allow ad libitum consumption of feed and water. Treatments were a corn-soybean meal-based control and 4 diets formulated with 40% DDGS (Table 4.1). The ME, NE, and TID amino acid values were from the NRC for swine (1998). DDGS treatments were formulated with no energy adjustment and total amino acids; fat added such that the ME was at the level of the corn-soy diet and using TID amino acids; fat added so that NE was at the level of the corn-soy control diet and using TID amino acids; and no energy adjustment and SID amino acids (Stein, 2006, 2007).

Pigs and feeders were weighed at d 0 and 49 to allow calculation of ADG, ADFI, and G:F with the pigs killed (average BW of 127 kg) at a commercial slaughter facility (Farmland, Crete, NE). Hot carcass weight (HCW), loin depth, and tenth rib fat thickness (SFK Technology A/S model S 82; Herlev, Denmark) were measured immediately after slaughter. Dressing percentage was calculated with HCW as a percentage of preshipping live weight. Fat-free lean index (FFLI) was calculated according to the equation suggested by the National Pork Producers Council (NPPC, 2001). Feed and DDGS were analyzed for concentrations of N (AOAC 990.03; Leco Corp., St. Joseph, MO) and ether extract (AOAC 920.39), with DDGS additionally being analyzed for GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). The DDGS also were analyzed for ADF and NDF using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY). All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.2; SAS Inst. Inc., Cary, NC). The dietary treatments were compared to the corn-soy control diet to identify statistically significant differences with the formulations strategies. P-vales were adjusted using Bonferroni's t-tests to ensure control of type-one error rates.

RESULTS AND DISCUSSION

The diet with 40% DDGS tended to support lower ADG ($P < 0.09$) and ADFI ($P < 0.05$) compared to the corn-soy control diet (Table 4.4). However, G:F was unaffected by the additions of DDGS to the diet. These results agree with the work of Feoli et al. (2008d) and Williams et al (2008) where pigs fed diets with 40% DDGS had lower ADG and ADFI with G:F being unaffected. Adding fat to the DDGS diet to meet the ME and NE levels of the corn-soy control improved ADG to that of the control diet and actually increased G:F ($P < 0.002$). This was a 13% improvement in

G:F from the addition of fat to the DDGS diet. Senne et al. (1996) found that pigs fed isocaloric diets containing up to 60% DDGS had ADG similar to a corn-soy control diet.

Feeding the diet with 40% DDGS produced lower HCW than the corn-soy control ($P < 0.008$). Feoli et al. (2007d, 2008a,b,c), Williams et al. (2008) also found that pigs fed diets with 40% DDGS had significantly lower HCW. Weimer et al. (2008) also saw that feeding DDGS decreased HCW in finishing pigs. No treatment had a significant effect on back-fat depth, loin muscle depth, or FFLI ($P > 0.25$) which is in agreement with the results of Whitney et al. (2006) who also saw feeding DDGS decrease HCW with no effects on back-fat and carcass leanness. The addition of fat into the diets containing DDGS restored HCW to the level of the corn-soy control diet. These results were also observed by Feoli et al, (2007d, 2008a,b) when adding up to 5% saturated fatty acid source to diets with 40% DDGS.

In conclusion, our results indicate that formulating diets with 40% DDGS reduced ADG and ADFI as well as a tendency to decrease G:F in finishing pigs. Reformulating that diet with SID amino acid values (Stein, 2007) without adjusting energy values did not improve growth performance or efficiency of growth. However, adding fat to the DDGS diets so that had an ME and NE value equal to that of the corn-soy control alleviated the negative effects on growth rate and improved the efficiency of growth. Also, HCW was reduced for pigs fed the DDGS treatments without fat, while adjusting the energy in these diets seemed to alleviate these negative responses. Overall, formulating diets with 40% DDGS using ME and NE values found in the NRC for Swine (1998) while adding crystaline amino acids to meet the requirements of TID improved growth performance. Because of the successes of this study in restoring measures of growth performance and carcass quality, further research should be done to determine if these improvements are due to the fat addition or amino acid supplementation independently, or if ratios of dietary energy and digestible amino acids must be considered.

LITERATURE CITED

AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007d. Effects of adding saturated fat to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., S. Issa, J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008a. Effects of adding beef tallow and palm oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):86 (Abstr.).

Feoli, C., J. D. Hancock, D. H. Kropf, S. Issa, T. L. Gugle, and S. D. Carter. 2008b. Effects of adding stearic acid and coconut oil to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):87 (Abstr.).

Feoli, C., J. D. Hancock, T. L. Gugle, and S. D. Carter. 2008c. Effects of expander conditioning on the nutritional value of diets with corn- and sorghum-based distillers dried grains with soluble in nursery and finishing pigs. J. Anim. Sci. 86(E-Suppl. 3):84 (Abstr.).

Feoli, C. 2008d. Use of corn- and sorghum-based distillers dried grains with soluble in diets for nursery and finishing pigs. PhD Diss. Kansas State Univ., Manhattan.

NPPC. 2001. Procedures for estimating pork carcass composition. National Pork Producers Council and American Meat Science Association. Des Moines, IA.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, D.C.

Senne, B. W., J. D. Hancock, I. Mavromichalis, S. L. Johnston, P. S. Sorrell, I. H. Kim, and R. H. Hines. 1996. Use of sorghum-based distillers grains in diets for nursery and finishing pigs. Kansas Agri. Exp. Sta. Rep. Prog. SRP 772. pp. 140-145.

Stein, H. H. 2007. Swine Focus #001- Distillers dried grains with solubles (DDGS) in diets fed to swine. http://www.distillersgrains.org/files/feedsource/swine_brochure.pdf Accessed Feb. 2, 2009.

Stein, H. H., M. L. Gibson, C. Pedersen, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grains with soluble fed to growing pigs. J. Anim. Sci. 84: 853-860.

Weimer, D., J. Stevens, A. Schinckel, M. Latour, and B. Richert. 2008. Effects of feeding increasing levels of distillers dried grains with solubles to grow-finish pigs on growth performance and carcass quality. J. Anim. Sci. 86(E-Suppl. 3):85 (Abstr.).

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C> Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grains with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84: 3356-3363.

Williams, S. M., J. D. Hancock, S. Issa, and T. L. Gugle, 2008. Effects of feeding excess crude protein on growth performance and carcass traits in finishing pigs. J. Anim. Sci. 86(Suppl. 1): 776 (Abstr.).

Table 4.1 Composition of diets (as-fed basis)

Ingredient, %	Corn- Soy Control	DDGS	DDGS ME TID	DDGS NE TID	DDGS SID
Corn	88.52	57.85	52.78	54.44	57.83
DDGS[1]	—	40.00	40.00	40.00	40.00
Soybean meal (47.5% CP)	8.84	—	—	—	—
Choice white grease	—	—	4.83	3.18	—
Limestone	1.10	1.26	1.27	1.26	1.26
Monocalcium phosphate (21% P)	0.59	—	—	—	—
Salt	0.23	0.23	0.23	0.23	0.23
L-lysine HCl	0.39	0.51	0.56	0.56	0.49
DL- methionine	0.02	—	—	—	—
L-threonine	0.13	0.002	0.08	0.08	0.02
L-tryptophan	0.03	0.009	0.11	0.11	0.05
Vitamin premix[2]	0.04	0.04	0.04	0.04	0.04
Mineral premix[3]	0.04	0.04	0.05	0.05	0.05
Supplemental premix[4]	0.02	—	—	—	—
Antibiotic [5]	0.05	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis					
Crude protein, %	12.1	16.4	16.1	16.3	16.4
Metabolizeable energy, kcal/kg	3,351	3,131	3,351	3,276	3,370
Net energy, kcal/kg	2,318	2,230	2,362	2,318	2,230
Total lysine, %	0.80[6]	0.80[6]	0.69[7]	0.69[7]	0.69[7]
Available P, %	0.17	0.26	0.26	0.26	0.26

[1] Distillers dried grains with solubles. Chemical analysis,%: CP, 26.01; EE, 10.76; ADF, 11.52; NDF, 28.44 (CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), EE (AOAC 920.39), ADF and NDF were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

[2]Supplied per kilogram of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 mg vitamin E; 1,764 mg vitamin K (as menadione dimethylpyrimidinol bisulfate); 19,841 mg niacin; 11,023 mg pantothenic acid (as calcium pantothenate); 3,307 mg riboflavin, 15,432 μg vitamin B_{12}.

[3]Supplied per kilogram premix: 11,000 mg Cu, 200 mg I, 110,000 mg Fe; 26,400 mg Mn, 200 mg Se, 110,000 mg Zn.

[4]Supplied per kilogram of premix: 8,818 mg vitamin E; 88 mg biotin; 220,460 mg choline; 661 mg Folacin; 1,984 mg vitamin B_6.

[5] To provide 44 g/ton of tylosin.

[6] Formulated on total amino acid basis (NRC, 1998).

[7] Formulated on true ileal digestible amino acid basis (NRC, 1998) .

[8] Formulated on standardized ileal digestible amio acid basis (Stein, 2007).

Table 4.2 Chemical analysis[1]

Diets	Corn- Soy Control	DDGS	DDGS ME TID	DDGS NE TID	DDGS SID
Crude protein	11.1	14.0	13.7	14.2	14.4
Ether extract	2.6	5.7	10.5	8.4	5.7

[1] Crude protein (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39).

Table 4.3 Concentration and digestibility of amino acids in distillers dried grains with solubles as used for diet formulations

	True Ileal Digestible[1]		Standardized Ileal Digestible[2]	
Amino Acid	Amount, %	Digestibility, %	Amount, %	Digestibility, %
Arginine	1.13	77.0	1.16	81.1
Histidine	0.69	61.0	0.72	77.4
Isoleucine	1.03	73.0	1.01	75.2
Leucine	2.57	79.0	3.17	83.4
Lysine	0.62	59.0	0.78	62.3
Methionine	0.50	75.0	0.55	81.9
Cysteine	0.52	60.0	0.53	73.6
Phenylalanine	1.34	79.0	1.34	80.9
Tyrosine	0.83	90.0	1.01	80.9
Threonine	0.94	85.0	1.06	70.6
Tryptophan	0.25	87.0	0.21	69.9
Valine	1.30	86.0	1.35	74.5

[1]Swine NRC (1998).

[2]Swine Focus #001. Distillers dried grains with solubles (DDGS) in diets fed to swine (Stein, 2007).

Table 4.4 Effects of formulation strategy on the nutritional value of diets with 40% DDGS

							Bonferroni adjusted P value- Control vs.			
Item	Control	DDGS	ME TID	NE TID	SID	SE	DDGS	ME TID	NE TID	SID
ADG, g	1,117	1,039	1,136	1,135	1,061	30	0.09	—[4]	—	—
ADFI, kg	3.50	3.27	3.16	3.14	3.35	0.09	0.05	0.002	0.001	—
G:F, g/kg	319	318	359	361	317	9	—	0.002	0.001	—
HCW, kg	94.0	89.8	94.0	92.5	90.7	1.5	0.001	—	—	0.008
Dressing, %	73.6	72.5	73.0	71.9	72.6	0.4	—	—	0.03	—
Backfat, mm	24.8	22.6	23.4	23.9	22.4	1.3	—	—	—	0.19
Loin depth, mm	62.2	61.3	62.9	62.8	60.5	1.3	—	—	—	—
FFLI[3], %	51.4	52.3	52.2	51.7	52.5	0.9	—	—	—	—
Dressing, %[2]	73.4	72.6	72.9	72.0	72.7	0.3	—	—	0.02	—
Backfat, mm[2]	24.4	23.0	22.7	23.0	23.8	1.2	—	—	—	—
Loin depth, mm[2]	61.5	62.1	61.1	62.2	62.7	1.3	—	—	—	—
FFLI, %[2,3]	51.5	52.2	52.4	52.2	51.7	0.8	—	—	—	—

[1] A total of 176 pigs (avg. initial BW of 94 kg) with 11 pigs/pen and 4 pens/treatment.

[2] Hot carcass weight used as a covariate.

[3] Fat-free lean index (NPPC, 2001).

[4] Dashes indicate P > 0.15.