USE OF CORN- AND SORGHUM-BASED DISTILLERS DRIED GRAINS WITH SOLUBLES IN DIETS FOR NURSERY AND FINISHING PIGS

by

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B.S., University of Costa Rica, 2002
M.A.B., University of Costa Rica, 2006

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2008

Abstract

Twelve experiments were completed to evaluate corn- and sorghum-distillers dried grains with solubles (DDGS) in diets for nursery and finishing pigs. In Exp. 1, corn-DDGS had 223 kcal/kg greater DE than sorghum-DDGS ($P<0.02$). In Exp. 2, pigs fed a corn-soy control diet had greater ADG, nutrient digestibility, HCW, and dressing percentage ($P<0.02$) and lower iodine value (IV) of jowl fat ($P<0.001$) than pigs fed diets with 40% DDGS. High-energy DDGS supported lower ADG, ADFI, and digestibility of DM ($P<0.06$) than moderate-energy DDGS, and sorghum-DDGS resulted in lower IV than corn-DDGS ($P<0.001$). In Exp. 3 and 4, addition of sodium bicarbonate to adjust dietary pH and electrolyte balance did not improve growth performance in nursery or finishing pigs ($P>0.16$) and adding molasses to improve palatability decreased ($P<0.05$) G:F for finishing gilts. In Exp. 5 and 6, enzyme additions improved nutrient digestibility in nursery ($P<0.04$) and finishing ($P<0.01$) pigs fed diets with high inclusion of DDGS. In Exp. 7, expander processing improved ($P<0.02$) ADG, G:F, and digestibility of DM, N, GE, and cellulose compared with standard steam conditioning of diets for nursery pigs, with the greatest response in G:F for pigs fed sorghum-DDGS (DDGS source × conditioning; $P<0.02$). In Exp. 8 and 9, expander conditioning improved G:F and dressing percentage ($P<0.007$) and digestibility of DM, N, and GE compared with standard conditioning ($P<0.02$), with the greatest response in digestibility of DM for the DDGS diets (diet × conditioning, $P<0.01$). In Exp. 10, 11, and 12, increasing tallow from 0 to 5% in diets with 40% DDGS improved ($P<0.05$) G:F. Dressing percentage was improved with addition of tallow and palm oil ($P<0.08$), but IV become worse (linear, $P<0.06$) as tallow was increased in the diet. Adding coconut oil improved growth performance and carcass firmness in pigs fed diets with

40% DDGS (*P*<0.01). In conclusion, growth performance and nutrient digestibility decreased with addition of DDGS to diets for nursery and finishing pigs. However, adding enzymes partially restored nutrient digestibility; expander conditioning improved G:F, dressing percentage, and nutrient digestibility; and adding coconut oil to diets with 40% DDGS improved G:F and carcass firmness.

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Acknowledgements

I would like to express my appreciation to those people that through their support, additional effort, hours of work, and friendship assisted me with my research. First and foremost, a special thank you to Dr. Hancock for being my mentor, for your great research ideas, and for all the financial support. To the members of my committee, Drs. Drouillard, Carter, Behnke, and Bean, thank you for your ideas and your contribution with my education.

Scott W., thanks for always being willing to help with a great attitude and for going the extra mile for me. Salissou and Cynthia, along with all the student workers that put up with collecting feces, running the always exciting bombs, and helping with the pigs: thanks! Thanks to Mark, Lyle, Rick, Eldo, Frank and the rest of the farm crew. To Terry Gugle, thanks for your help and for offering a friendly face. To Adam, Matt, Cassie, Renée, and Johnny, thanks for your help at the feed mill dealing with pellet dies, melting fats in winter time, and unexpected situations. To Cheryl, Dave, and Theresa; thanks for your support at the lab and for your patience.

To the Farmland personnel at Crete, NE, your support to this research is very much appreciated. Cory Rains, thanks for getting even the last jowl and the very last belly.

A special thanks to my friends throughout this journey. Ian, thanks for great laughter and all your invaluable support. Vivian, Andrea M., Rommel, thanks for your words of encouragement and peace. I would like thank my good friends Jeff, Lisa, Emily, Bob, and Maggie Brummett. Thanks for adopting a Costa Rican and for making me part of your family. And most importantly, a big thank you to all my family for being always there when I needed and showing your love in many ways.

Dedication

To my family: for your support, encouragement, advice, and laughter at all times. Because of you, 4,000 km felt like no distance at all when I needed a word to keep my head up and continue moving forward. Pa, Ma, Manrique, Nella y Giovanna; I love you and this is to you.

CHAPTER 1 - Review Article

INTRODUCTION

According to the Renewable Fuels Association (2008), there were 176 bio-refineries operating in the United States as of September 11, 2008 with capacity to produce about 10.1 billion gallons of ethanol each year. Ethanol production has increased more than seven times in the last 10 years and still the Energy Independence and Security Act of 2007 (US Public Law 110–140—Dec. 19, 2007) mandates that 15 billion gallons of renewable fuel should be grain-based ethanol by 2015. Distillers dried grains with solubles (DDGS) is the feed ingredient resulting from the dry-mill fuel and beverage alcohol industries (DGTC, 2008). Thus, the ever increasing supply of DDGS represents an opportunity to decrease formulation cost of livestock diets.

Concerns with using DDGS in swine diets are nutrient variability and its effects on growth performance and carcass characteristics when included at high amounts in diets for pigs. According to Cromwell et al. (1993), several factors contribute to nutrient variability of DDGS. Cereal grains themselves have intrinsic variability even before use for production of ethanol. With conversion of starch to ethanol, the concentration of other proximate components is tripled and, thus, the variability in composition of DDGS increases the same in magnitude. Additionally, processing considerations such as type of yeast, efficiency of extracting starch from the grain, amount of solubles added back, and temperature and time of drying contribute further to variability and composition of the ending DDGS product. Many researchers have discussed the composition of DDGS and its variability (Spiehs et al., 2002; Batal and Dale, 2006; Noll et al., 2006; Stein et al., 2006; Feoli et al., 2007a; Pedersen et al., 2007; Pahm et al., 2008). However, while we acknowledge the importance of nutrient variability, the remainder of this article will be focused on what is known about the effects of DDGS on growth performance and carcass characteristics when fed to pigs.

GROWTH PERFORMANCE OF PIGS FED DDGS

Previous research from our laboratory suggests that 20 to 30% DDGS can be used in diets for nursery pigs without negative effects on growth performance as long as the diets are formulated to an equal energy concentration (Senne et al., 1995, 1996). As illustrated in Table 1.1, data from other laboratories also suggested levels of 20 to 30% DDGS in diets for nursery pigs do not compromise growth performance. Burkey et al. (2008) reported similar growth performance for nursery pigs fed 30% DDGS in phase 3 than pigs fed a control diet without DDGS; however when DDGS were introduced in the diet since phase 2 even at low levels (5%), growth performance was depressed. Most recently, results from our research (Feoli et al., 2007c, 2008d) show decreased growth rate with no effects on efficiency of gain when 30% DDGS are added to corn-soybean meal diets. However, no attempt was made to equalize the energy or fat content of diets used in these experiments. Thus, it still seems that 20 to 30% DDGS can be used in diets for nursery pigs without compromising growth performance. This still leaves the question, however, of why there should be a limit to inclusion of DDGS in otherwise nutritionally adequate diets.

In finishing pigs, data from our research suggests that up to 60% DDGS did not negatively affect growth performance (Senne et al., 1996; Table 1.2). Recent data with DDGS from “new generation” ethanol plants suggest that levels of 20 to 30% can be used without compromising growth performance but these levels can cause soft carcass fat and should be approached with caution.

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

		Inclusion level of DDGS, %										
Parameter	Type of DDGS	0	10	15	20	25	30	45	60	Initial and final wt, kg	No. Pigs	Reference
ADG, g	Sorghum	463	481		458					6.8 to 18	72	Senne et al. (1995)
Gain/feed		621	621		575							
ADG, g	Sorghum	485		499			463	399	322	5.9 to 15	180	Senne et al. (1996)
Gain/feed		621		680			719	613	552			
ADG, g	Corn	480	470	442	489	466				7.7 to 24	96	Whitney and Shurson (2004)
Gain/feed		650	650	590	620	620						
ADG, g	Corn	431	427	400	425	398				5.7 to 20	96	Whitney and Shurson (2004)
Gain/feed		700	680	710	660	660						
ADG, g	Corn	606					574			10 to 24	126	Feoli et al. (2007c)
Gain/feed[a]		667					661					
ADG, g	Corn/Sorg	576					534			7.5 to 22	180	Feoli et al. (2008d)
Gain/feed		699					695					

[a] Gain/feed expressed in g/kg.

Table 1.2. Effects of DDGS on growth performance in finishing pigs

		Inclusion level of DDGS, %								
Parameter	Type of DDGS	0	10	20	30	40	60	Initial and final wt, kg	No. Pigs	Reference
ADG, g	Sorghum	894	898	875	875			43 to 87	192	Senne et al. (1995)
Gain/feed		379	382	388	380					
ADG, g	Sorghum	948		1,007		1,007	993	54 to 112	80	Senne et al. (1996)
Gain/feed		299		329		333	344			
ADG, g	Sorghum	891				835		65 to 112	192	Senne et al. (1998)
Gain/feed		282				249				
ADG, g	Corn	862	859	827	808			28 to 115	240	Whitney et al. (2006)
Gain/feed		360	360	360	340					
ADG, g	Sorghum	943				913		64 to 130	132	Feoli et al. (2007b)
Gain/feed[a]		300				287				
ADG, g	Corn	1,115				897		71 to 128	70	Feoli et al. (2007c)
Gain/feed		331				307				
ADG, g	Sorghum	963				890		72 to 130	56	Feoli et al. (2007d)
Gain/feed		289				281				
ADG, g	Corn/Sorg	970				876		64 to 122	330	Feoli et al. (2008d)
Gain/feed		319				308				
ADG, g	Sorghum	1,029				926		63 to 129	56	Feoli et al. (2008a)
Gain/feed		308				296				
ADG, g	Sorghum	840				789		68 to 123	56	Feoli et al. (2008b)
Gain/feed		294				287				
ADG, g	Corn	894	929	903				22 to 124	36	Widmer et al. (2008)
Gain/feed		349	338	348						
ADG, g	Corn	849	858	834	835			46 to 124	1,038	Linneen et al. (2008)
Gain/feed		437	435	437	440					

[a] Gain/feed expressed in g/kg.

CARCASS CHARACTERISTICS OF PIGS FED DDGS

Pond et al. (1988) and Anugwa et al. (1989) suggested that pigs consuming high-fiber diets (16 to 28% ADF) have heavier viscera (kidney, liver, and digestive tract) resulting in lower carcass weight relative to live weight (i.e., dressing percentage). Adding 20 to 40% DDGS to diets for finishing pigs will increase the fiber content of the diet and Feoli et al. (2007b) reported a decrease in dressing percentage when 40% DDGS was added to corn-soybean meal diets. Decreased dressing percentage in response to DDGS in diets has been reported by other authors (Whitney et al., 2006; Cook et al., 2007; Linneen et al., 2008), and Weimer et al. (2008) suggested this response was associated with greater weight of viscera.

In addition to its fiber content, DDGS has 7 to 11% vegetable oil that, of course, is highly unsaturated. Pigs tend to deposit fat similar to that which they consume and there are data to suggest negative effects of DDGS on firmness of pork carcasses (Whitney et al., 2006; Feoli et al., 2007b; Xu et al., 2007; Benz, 2008; White et al., 2008). We conducted experiments to determine if adding sources of saturated fatty acids to diets with DDGS might mitigate these effects on carcass firmness. A summary of our results is offered in Table 1.3. In general, carcass leanness, backfat thickness, and loin depth were not affected by addition of DDGS in these experiments. Carcass fat did, however, become more unsaturated. To express degree of unsaturation in carcass fat, iodine value often is used. Iodine value is the number of grams of iodine absorbed per 100 g of fat sample (AOCS, 1998). However, it is important to note that factors such as gender, genotype, growth rate, density of pigs per pen, and immunological challenges also can affect iodine value of carcass fat. So, we conducted several well controlled experiments to determine the effects of adding 40% DDGS to diets of finishing pigs and the potential use of sources of saturated fatty acids to ameliorate any negative effects of DDGS on carcass firmness (Table 1.3).

Beef tallow and palm oil traditionally have been considered sources of saturated fat. Those are, however, only about 50% saturated and our data indicated they partially corrected the loss in dressing percentage but did not improve carcass firmness in pigs fed diets with 40% DDGS. Coconut oil, a source of more than 90% saturated fatty acids, did improve dressing percentage to a level similar to the control treatment and corrected the negative effects of DDGS on carcass firmness.

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

		Dressing, %				Iodine value			
Fat source	Fat, %	Control	40% DDGS	DDGS + fat	Fat effect	Control	40% DDGS	DDGS + fat	Fat effect
Beef tallow [a]	2.5	71.3	69.4	69.5	+0.1	67.8	72.4	73.3	+0.9
Beef tallow [a]	5			70.6	+1.2			74.2	+1.8
Beef tallow [b]	5	71.9	70.0	71.1	+1.1	67.0	72.5	73.5	+1.0
Palm oil [b]	5			70.4	+0.4			73.4	+0.9
Stearic acid [c]	5	71.7	70.8	70.5	-0.3	67.1	71.9	70.7	-1.2
Coconut oil [c]	5			71.4	+0.6			66.6	-5.3

[a] From Feoli et al. (2007d).
[b] From Feoli et al. (2008a).
[c] From Feoli et al. (2008b).

PROCESSING DIETS WITH DDGS

After consideration of its effects on growth performance and carcass measurements, concerns are often raised about the effects of DDGS on handling and processing characteristics of diets. Pelleting improves growth performance in pigs as well as reduces or eliminates bacteria and fungi found in the feed (Hancock and Behnke, 2001; Fairfield et al., 2005). Stark et al. (1994)

and Amornthewaphat et al. (1999) demonstrated the importance of pellet quality to this response. An expander is a conditioning device that takes feed to higher temperature and pressure than standard steam conditioning prior to pelleting. Traylor et al. (1999) reported that conditioning wheat midds-based diets (high in fiber) in an expander prior to pelleting improved nutrient digestibility in finishing pigs. Moreover, Peisker (1994) showed improvement in fiber digestibility and growth rate of nursery pigs by expanding diets with 30% wheat bran. Thus, we had interest in the effects of expander conditioning on nursery and finishing diets with high inclusion of DDGS (Tables 1.4 and 1.5).

Table 1.4. Effects of expander conditioning of diets with corn- and sorghum-based DDGS on growth performance and nutrient digestibility in nursery pigs (Feoli et al., 2008c)[a]

	Corn-soy control		30 % corn-DDGS		30 % sorghum-DDGS	
Item	Standard	Expander	Standard	Expander	Standard	Expander
Pellet durability index, %	88.5	94.9	93.0	95.0	91.9	96.6
Growth performance						
ADG, g[bdf]	670	719	605	655	548	632
ADFI, g[be]	973	1,011	874	928	937	940
G:F, g/kg[bdfg]	689	711	692	706	585	672
Apparent digestibility, %						
DM[bdf]	82.5	83.7	76.9	79.9	76.4	78.3
N[bdf]	78.3	81.5	76.4	79.6	70.1	73.4
GE[bef]	81.2	83.8	76.5	78.4	75.6	77.3
Cellulose[cdfg]	46.0	49.6	34.9	45.7	47.6	48.6

[a] A total of 180 nursery pigs with an average initial weight of 13.1 kg and average age of 42 d.
[bc] Corn-soybean meal vs DDGS diets ($P < 0.04$ and $P < 0.10$, respectively).
[de] Corn- vs sorghum-based DDGS ($P < 0.03$ and $P < 0.09$, respectively).
[f] Standard vs expander conditioning ($P < 0.02$).
[g] Corn- vs sorghum-based DDGS × standard vs expander conditioning ($P < 0.05$).

When feed was processed through a standard steam conditioner, pellet quality improved by 4 and 15% with addition of 30 and 40% DDGS to nursery and finishing diets, respectively, and expander conditioning improved pellet quality for both a corn-soybean meal and DDGS diets.

Pigs fed the diets with DDGS had poorer growth rate, feed intake, efficiency of growth, or digestibility of nutrients than pigs fed the corn-soybean control diet. However, expander conditioning partially alleviated these negative effects bringing rate and efficiency of gain for pigs fed diets with DDGS close to that of pigs fed the corn-soy control that was standard steam conditioned.

Furthermore, the detrimental effects on dressing percentage of 40% DDGS were corrected when diets were processed in the expander. Although it adds \$1 to \$3 per ton to process feed through an expander compared to traditional steam conditioning, savings on diet formulation with DDGS could make this processing option economically attractive.

Table 1.5. Effects of expander conditioning of diets with sorghum-based DDGS on growth performance and carcass characteristics in finishing pigs (Feoli et al., 2008c)[a]

	Corn-soybean meal		40% DDGS	
Item	Standard	Expander	Standard	Expander
Pellet durability index, %	76.3	90.8	87.7	96.0
Growth performance				
ADG, g[b]	1,077	1,052	981	1,013
ADFI, kg[bdf]	3.23	3.01	2.99	2.99
G:F, g/kg[bd]	333	350	328	339
Carcass characteristics				
HCW, kg[be]	97.7	97.8	92.5	95.3
Dressing, %[bd]	73.5	74.3	72.7	73.7
Backfat thickness, mm	20.2	20.6	19.6	20.7
Fat free lean index, %	53.8	53.6	54.0	53.3

[a] A total of 176 finishing pigs with an average initial weight of 75 kg and an average final weight of 130 kg.

[bc] Corn-soybean meal vs DDGS diet ($P < 0.03$ and $P < 0.06$, respectively).

[de] Standard vs expander conditioning ($P < 0.03$ and $P < 0.10$, respectively).

[f] Corn-soybean meal vs DDGS × standard vs expander conditioning ($P < 0.04$).

ADDITIVES FOR DIETS WITH DDGS

It seems that from the early days of the care and feeding of livestock and poultry, there has been interest in feed additives that might improve health or productivity. With current interest in use of DDGS into the formulation there certainly has been no shortage of interest in additives for these diets and it does seem logical that could improve utilization of nutrients.

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. However, individual minerals (e. g., Na, Cl, and S) can be 6 to 10 times that in corn. Therefore, addition of DDGS to swine diets alters dietary electrolyte balance (dEB; calculated as Na + K – Cl – S). We balanced the dEB of diets with DDGS by adding sodium bicarbonate to yield three experimental treatments (corn-soy control at a dEB of 134 mEq/kg, a diet with 30% corn-DDGS at a dEB of 83 mEq/kg, and the DDGS diet with 0.9% sodium bicarbonate to increase dEB over that of the control diet at 191 mEq/kg). When fed to nursery pigs, those given diets with DDGS had lower average daily gain than pigs fed the corn-soy diet (Feoli et al., 2007c). Supplementing the diet with sodium bicarbonate to balance dEB did not improve growth performance. Another experiment was conducted in finishing gilts with three levels of sodium bicarbonate (0, 1, and 2%). In this experiment, adding DDGS not only affected growth rate but decreased efficiency of growth and addition of sodium bicarbonate once again did not correct this problem. Other authors have suggested that balancing for dEB is important for pigs subjected to high temperature conditions or when extremely low dEB diets are fed (Patience et al. 1987; Haydon et al., 1990), but the electrolyte balance of diets with 30 to 40% DDGS apparently is not low enough to allow for a correction in loss of growth performance by adding sodium bicarbonate to the diet.

We also have tested the effects of molasses as a flavor enhancer for diets with DDGS. Two levels of molasses (none and 5%) were added to diets with 40% corn-DDGS and fed to finishing gilts. Pigs did not consume more of the diet with molasses and, thus, average daily gain was not affected. Furthermore, efficiency of growth tended to be lower for pigs fed diets with molasses. These results are similar to those of Hastad et al. (2005), who reported that use of another flavor additive, Sucram, in diets with 30% DDGS did not yield a preference response in growing pigs.

In a final attempt to improve utilization of diets with DDGS, we elected to investigate feed enzymes. Distillers dried grains with solubles have 16% cellulose, 8% xylans, and 5% arabinans (Kim et al., 2008) and these compounds are known to reduce digestibility of nutrients in growing pigs (Owusu-Asiedu et al., 2006). Therefore, we conducted two growth assays (Feoli et al., 2008d) with treatments of a corn-soy-based control and diets with 30% corn- and sorghum-DDGS without and with enzymes (a cocktail of beta-glucanase, xylanase, alpha-amylase, and pectinase). Nursery pigs fed the control diet had greater average daily gain and nutrient digestibility than pigs fed the DDGS treatments. Addition of enzymes improved growth rate for pigs fed corn-DDGS and tended to improve efficiency of growth and digestibility of dry matter regardless of DDGS source. In finishing pigs, those fed the control diet had greater growth rate, feed intake, and nutrient digestibility than pigs fed the 40% DDGS treatments. Enzymes improved nutrient digestibility, especially for diets with sorghum-DDGS, but did not affect growth performance. Other authors have reported positive responses in nutrient digestibility with addition of enzymes to diets having wheat-DDGS (Opapeju et al., 2006; Emiola et al., 2008). But, Sigfridson and Haraldsson (2007) reported no response in growth performance to addition of xylanase into diets for finishing pigs fed wheat-DDGS. When enzymes were supplemented to DDGS diets that were restricted in energy and lysine, Emiola et al. (2008) and

Pierce and Bannerman (2008) observed a positive response in growth performance to the addition of enzymes.

CONCLUSIONS

In conclusion, many factors can affect the nutritional value of DDGS for pigs (i.e., processing conditions at the ethanol plant, grain used as substrate, reincorporation of solubles, etc.). However, with accurate assessment of its chemical composition, DDGS is useful in diets for pigs. The question then becomes how much DDGS can be used and what strategies might be employed to yield similar growth performance and carcass characteristics to pigs fed a corn-soybean meal diet. When high inclusion of DDGS are to be used, alternatives like expander processing and saturated fat additions can help to alleviate any negative effects on growth performance, dressing percentage, and carcass firmness.

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CHAPTER 2 - Digestible energy content of corn- vs sorghum-based distillers dried grains with solubles and their effects on growth performance and carcass characteristics in finishing pigs

ABSTRACT: Two experiments were conducted to determine the nutritional value of corn- and sorghum-based distillers dried grains with solubles (DDGS). In Exp. 1, 120 finishing pigs (average initial weight of 111 kg) were used in a 19-d DE determination. The reference diet was 97% corn with vitamins, minerals, and amino acids added to meet or exceed all NRC suggested nutrient concentrations. Treatments were corn- and sorghum-based DDGS substituted as 50% of the reference diet in place of corn. Comparisons among the treatments indicated that DDGS from corn had 223 kcal/kg greater DE than DDGS from sorghum ($P < 0.02$). However, DE was different among the sources of corn-based DDGS ($P < 0.001$) and sorghum-based DDGS ($P < 0.03$) suggesting that plant of origin affects DE of DDGS. In Exp. 2, 176 finishing pigs (average initial weight of 64 kg) were used in a 72-d growth assay. There were 11 pigs/pen and four pens/treatment with feed and water consumed on an ad libitum basis until the pigs were slaughtered at an average weight of 130 kg. Treatments were a corn-soybean meal-based control diet and diets with 40% corn-based, high-energy DDGS (as determined in Exp. 1); 40% corn-based, moderate-energy DDGS; and 40% sorghum-based, moderate-energy DDGS. Pigs fed the control diet had greater overall ADG ($P < 0.003$) and digestibility of DM ($P < 0.001$), N ($P < 0.02$), and GE ($P < 0.001$) compared to pigs fed the DDGS treatments. Among the DDGS treatments, pigs fed the high-energy product had lower overall ADG ($P < 0.06$), ADFI ($P < 0.02$), and digestibility of DM ($P < 0.03$), but tended to have better G:F ($P < 0.06$) than pigs fed the moderate energy DDGS sources. As for carcass data, HCW ($P < 0.001$), dressing percentage ($P < 0.003$), and loin depth ($P < 0.05$) were greater, and iodine values of jowl fat were lower ($P < 0.001$) for pigs fed the control vs DDGS treatments. Among the DDGS treatments, pigs fed the sorghum-based DDGS had greater dressing percentage ($P < 0.04$) and lower iodine value ($P < 0.001$) than pigs fed the corn-based DDGS. Backfat thickness ($P > 0.58$) and fat-free lean index ($P > 0.25$) were not affected by treatment. In conclusion, plant of origin and substrate used in the fermentation process (corn vs sorghum) affected the nutritional value of DDGS for finishing pigs.

Key Words: digestibility, distillers dried grain with solubles, energy, growth performance, pig, sorghum

INTRODUCTION

Distillers dried grains with solubles (DDGS) are a feed ingredient resulting from the dry-mill fuel and beverage ethanol industries (DGTC, 2008). According to the Renewable Fuels Association (2008), there were 176 ethanol bio-refineries operating in the United States as of September 11, 2008, and the Energy Independence and Security Act of 2007 (US Public Law 110–140—Dec. 19, 2007) mandates that 15 billion gallons of renewable fuels should be corn based ethanol by 2015. Thus, the U.S. governmental policy of increasing ethanol production in an effort to improve air quality, stabilize farm prices, and reduce dependence on foreign oil has increased the availability of DDGS for use in livestock diets. Senne et al. (1996) suggested that as much as 60% DDGS could be used in diets for finishing pigs without negative effects on growth performance and carcass characteristics while other researchers have recommended a maximum of 20% to avoid negative effects (Thaler, 2002). Additionally, most reports about use of DDGS in diets for pigs are from experiments with only corn-based DDGS originating from a single source (DeDecker et al., 2005; Linneen et al., 2008). Therefore, the objective of the experiments reported herein was to determine the DE content of corn- vs sorghum-based DDGS from different processing plants and to elucidate the effects of those DDGS on growth performance and carcass characteristics in finishing pigs.

MATERIALS AND METHODS

Experiment 1

One hundred twenty finishing pigs (PIC line TR4 × 1050), with an average initial BW of 111 kg, were used in a 19-d DE determination[1]. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens in a finishing facility having 1.83-m × 4.88-m pens with concrete flooring that was half solid and half slatted. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water. There were 12 pigs/pen and 2 pens/treatment in 2 replicates to yield 4 observations/treatment. The reference diet (Table 2.1) was 97.5% corn with vitamins, minerals, and amino acids added to meet or exceed all nutrient concentrations suggested by the NRC (1998). Treatments were corn-based (Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS) and sorghum-based (Western Plains Energy, Oakley, KS and U.S. Energy Partners, Russell, KS) DDGS substituted as 50% of the reference diet in place of corn. Diets were fed in meal form and formulated using ingredient values from the NRC (1998) and to have 0.52% Lys, 0.45% Ca, and 0.40% total P with 0.25% chromic oxide added as an indigestible marker. The DDGS sources were analyzed for DM, CP, ether extract, crude fiber, ash, P, and GE (AOAC, 1995), and concentrations of amino acids (AOAC Official Method 982.30 Ea,b,c, chp. 45.3.05, 2006). Aditionally, mean geometric particle size and standard deviation of that mean (ANSI/ASAE S319.3.), and color (Hunter LAB

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[1] The animal care and management used in these experiments were approved by the Kansas State University Animal Care and Use Committee.

MiniScan XE Plus. Model 45/O-L. Serial 6049. Reston, VA) were determined. Tannin content was determined using the modified vanillin hydrochloric method as described by Earp et al. (1981) with a UV-vis spectrophotometer (Spectronic 20; Thermo Fisher Scientific Inc., Madison, WI).

The pigs were allowed to adjust to the experimental diets for 4 d. Each morning of the next 2 d, grab samples of feces were collected via rectal massage from at least 6 pigs in each pen. Then, the pigs were fed a common diet for 7 d and the treatments were reassigned with the only restriction to randomization being that a pen could not receive the same treatment twice. The end result was four observations per treatment for determination of DE. Pigs and feeders were weighed at the beginning and ending of each collection period to ensure that the pigs were gaining weight and consuming feed. Fecal samples were pooled within pen in a plastic bag and kept frozen until dried in an oven at 50ºC, ground, homogenized, and stored in a freezer. Feed and feces were analyzed for concentrations of DM (NFTA Method 2.1.2), N (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), and GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). Chromium concentrations in feed and feces were determined using atomic absorption spectrophotometry (Perkin Elmer 3110) according to the procedure of Williams et al. (1962) to allow calculation of apparent digestibilities using the indirect ratio method. Digestible energy content of each DDGS diet was calculated by multiplying GE of diets with 50% DDGS by the energy digestibility coefficient. Then, half of the DE in the reference diet was subtracted from the DE in each of the DDGS containing diets and the result multiplied by 2 to obtain DE in each of the DDGS samples.

All digestibility data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial BW as the blocking criterion and pen as the experimental unit. Orthogonal contrasts were used to separate treatment means with comparisons among the control vs DDGS diets, corn- vs sorghum-based DDGS, the two corn-based DDGS sources, and the two sorghum-based DDGS sources.

Experiment 2

One hundred and seventy six finishing pigs (PIC line TR4 × 1050), with an average initial BW of 64 kg, were used in a 72-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens in a finishing facility having 1.83-m × 4.88-m pens with concrete flooring that was half solid and half slatted. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water. There were 11 pigs/pen and 4 pens/treatment. The experimental diets (Table 2.2) were fed in 2 phases and formulated to 1.10% Lys, 0.60% Ca, and 0.50% total P for d 0 to 35, and 0.80% Lys, 0.55% Ca, and 0.45% total P for d 35 to 72. All other nutrients met or exceeded NRC (1998) recommendations for a genotype growing at about 325 g of lean/d, and the diets were fed in meal form. Treatments were a corn-soybean meal-based control diet and diets with 40% high-energy DDGS from Sioux River Ethanol (corn-based, crude fat of 10.4%, mean particle size of 328 μm, and DE of 3,628 kcal/kg as determined in Exp. 1), 40% moderate energy DDGS from MGP Ingredients (corn-based, crude fat of 8.5%, mean particle size of 796 μm, and DE of 2,940 kcal/kg as determined in Exp. 1), and 40% moderate energy DDGS from US Energy Partners (sorghum-based, crude fat of 7.3%, mean particle size of 563 μm, and DE of 3,205 kcal/kg as determined in Exp. 1).

Pigs and feeders were weighed on d 0, 35, and 72 to allow calculation of ADG, ADFI, and G:F. Chromic oxide (0.25%) was added to the diets as an indigestible marker, and on d 40 and 41, fecal samples were collected via rectal massage from no less than 6 pigs/pen, pooled within pen, and handled as in Exp. 1. Concentrations of DM, N, GE, and Cr in the diets and feces were determined as described for Exp. 1 to allow calculation of apparent nutrient digestibility. Pigs were tattooed on d 72 (average BW of 130 kg) and shipped to a commercial abattoir (Triumph Foods, LLC; St. Joseph, MO) for slaughter the following morning. Hot carcass weight, loin depth, and tenth rib fat thickness were measured immediately after slaughter. Dressing percentage was calculated with HCW as a percentage of preshipping live weight and fat free lean index was calculated according to the equation suggested by the National Pork Producers Council (NPPC, 2001). At 24-h postmortem, jowl samples were collected and frozen at -15° C until sample preparation and fatty acid analysis. Samples of jowl fat were dissected and a 5-g sub-sample of subcutaneous fat per pig was pooled within pen. The pooled sample of jowl fat was then submerged in liquid nitrogen for approximately 1 min, then ground and homogenized with a blender (Waring Commercial, Model 51BL32, Torrington, CT). Fatty acid profile was determined by GC (according to Sukhija and Palmquist, 1988) using a gas chromatograph (Shimadzu GC-17A) to allow estimation of iodine value using the regression equation IV = (%C16:1 x 0.950) + (%C18:1 x 0.860) + (%C18:2 x 1.732) + (%C18:3 x 2.616) + (%C20:1 x 0.785) + (%C22:1 x 0.723) according to AOCS Cd 1c-85 Official Method, as an indicator of carcass firmness.

All growth, digestibility, and carcass data were analyzed as a randomized complete block design using the MIXED procedure of SAS. Because differences in slaughter weight and, thus, HCW is known to affect carcass measurements, HCW was used as a covariate of dressing percentage, FFLI, backfat thickness, loin depth, and iodine value to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight.

Orthogonal contrasts were used to separate treatment means with comparisons of control vs the DDGS treatments, high vs moderate energy DDGS, and corn- vs sorghum-based DDGS.

RESULTS AND DISCUSSION

Analyses of the DDGS sources (Table 2.3) indicated that protein and fiber content were greater in DDGS that originated from sorghum than from corn, similar to previous studies comparing DDGS from corn or sorghum grains that were produced at a single ethanol plant (Al-Suwaiegh et al., 2002) and at different plants (Urriola et al., 2007). Fat and GE were greater for the corn-based DDGS produced at a "new generation" ethanol plant (i.e., Hudson) compared to the corn-based DDGS produced at an ethanol plant built in the 1960's (Atchison). Spiehs et al. (2002) determined the average fat content of corn DDGS from 10 ethanol plants built after 1995 to be 10.9% vs 8.2% for DDGS from an older plant, which is very comparable to our observations. As for essential amino acids, sorghum-based DDGS had greater concentration of Ile, Leu, Phe, Thr, and Val than the corn-based DDGS sources and reference values from NRC (1998). The corn-based DDGS sources had greater concentration of Arg and Trp compared with the sorghum-based DDGS. Our DDGS products had lower concentration of Trp than what others have reported (Cromwell et al., 1993; Spiehs et al., 2002) but similar to more recent data (Pedersen et al., 2007; Linneen et al., 2008). Particle size of DDGS varied among sources, especially when originating from corn. Hunter LAB (color) measurements showed that sorghum-based DDGS were darker (lower L*) and less yellow (lower b*) than corn-based DDGS, which is logical considering the differences in color of seed coat for corn vs sorghum. Measurement of catechin equivalents indicated zero tannin content for all the sources of DDGS and the corn grain used in these experiments.

Experiment 1

When the dietary treatments were fed to pigs, they gained weight (an average of 313 g/d) and consumed the diets well (greater than 2.5 kg/d) during the brief (6-d) feeding periods. As for nutrient utilization among pigs fed the treatments (Table 2.4), corn had greater ($P < 0.001$) digestibility of DM and GE than the DDGS treatments, which agrees with the data of Senne et al. (1998) for comparisons among sorghum grain and sorghum-based DDGS. Increasing fiber content of a diet, as would be the case with our DDGS treatments, is known to reduce total apparent digestibility of nutrients (Wilfart et al., 2007). Corn-based DDGS had greater ($P < 0.002$) digestibility of N than sorghum-based DDGS, and this result is in agreement with the greater N digestibility that was reported for corn grain compared to sorghum grain (Healy et al., 1994). Within the corn-based treatments, DDGS originating from Hudson had greater ($P < 0.002$) digestibility of DM, N, and GE compared to DDGS from Atchison. There also was variability among the sorghum-based treatments, with DDGS from Russell having greater ($P < 0.03$) digestibility of DM and GE compared to DDGS from Oakley. These data suggest that in addition to the cereal used for DDGS production, there could be intrinsic characteristics of that grain (i.e., endosperm type as described by Senne et al., 1998) or of the fermentation process (i.e., addition of solubles as described by Noll et al., 2006 and drying conditions as suggested by Cromwell et al., 1993) that caused differences in nutrient utilization among our DDGS sources. Also, when trying to identify factors affecting this variability among DDGS sources, Pahm et al. (2008) observed that AA digestibility of DDGS varies within a region as much as it varies among ethanol vs beverage plants. Corn-based DDGS had greater ($P < 0.002$) N digestibility than sorghum-based DDGS, which agrees with the report of Lodge et al. (1997) when comparing corn wet distillers grains with sorghum wet distillers grains fed to lambs. However, in our case there was a difference between the 2 sources of corn-based DDGS, and only the DDGS from Hudson was superior ($P < 0.001$) in N digestibility vs the other sources.

The DE concentration of the 4 DDGS sources varied from 3,297 to 4,027 kcal of DE per kg DM with an average of 3,574 kcal of DE per kg DM. In a comparison of 10 sources of corn-based DDGS, Stein et al. (2006) reported less variable DE than we observed, but a similar average (3,556 kcal of DE per kg DM). However, in a more recent report from that same group (Pedersen, 2007), values determined for DE in another 10 samples of DDGS averaged 4,140 kcal per kg DM which is considerably greater than the NRC (1998) value of 3,440 kcal of DE per kg of DM.

Our data indicated that DDGS from the Hudson plant were higher ($P < 0.001$) in DE content compared to DDGS from the Atchison plant. The greater DE of the Hudson DDGS corresponded well with its greater fat content (10.4%) and small particle size (328 μm) compared to other DDGS sources. In contrast, the DDGS from Atchison had 382 kcal/kg less DE than corn grain. Others have reported greater energy content of substrate grains vs the DDGS derived from them, i.e., a difference of 325 kcal of DE per kg in the NRC (1998) for corn, 251 kcal of DE per kg as reported by Senne et al. (1998) for sorghum, and 262 kcal of DE per kg as reported by Nyachoti et al. (2005) for wheat. Finally, it has been noted that lighter and more yellow DDGS are of greater nutritional value for poultry (Batal and Dale, 2006) and growing pigs (Fastinger and Mahan, 2006; Pahm et al., 2008). However, in our experiment, the darkest and least yellow DDGS had greater DE content than two of the other three DDGS treatments. This suggested that color of DDGS was not a good predictor of energetic value.

Experiment 2

Pigs fed the control diet had greater overall ADG ($P < 0.003$) and digestibility of DM ($P < 0.001$), N ($P < 0.02$), and GE ($P < 0.001$) compared to pigs fed diets with 40% DDGS (Table 2.5). Among the DDGS treatments, pigs fed the high-energy product had lower ADG ($P < 0.06$), ADFI ($P < 0.02$), and digestibility of DM ($P < 0.03$), but tended to have better G:F ($P < 0.06$) and digestibility of N ($P < 0.05$) than pigs fed the moderate energy DDGS sources. These findings are in contrast to what others have reported (Senne et al., 1995, 1996; Cook et al., 2005; DeDecker et al., 2005), in which they observed no negative effects in growth performance with inclusion of 30 to 60% DDGS for finishing pigs when fat was added to the diets. However, when diets with 40% sorghum-based DDGS were not formulated to be isocaloric (as was our approach in the present study), ADG, G:F, and digestibility of DM and GE were lower than the sorghum grain control diet (Senne et al., 1998). Other authors have reported similar decreases in growth rate with inclusion of corn-based DDGS into their formulations (Whitney et al., 2006; Linneen et al., 2008). These data suggest that the use of accurate energy values for DDGS during diet formulation should help to resolve disparity in growth performance when this ingredient is added to diets for finishing pigs.

As for carcass data, the effects of DDGS on ADG were reflected in greater ($P < 0.001$) HCW for pigs fed the control diet. Furthermore, even when corrected to a constant HCW (via covariate analysis) dressing percentage ($P < 0.003$) and loin depth ($P < 0.05$) were greater and iodine value of jowl fat lower ($P < 0.001$) for pigs fed the DDGS treatments. It has been demonstrated that increasing fiber content in diets for pigs results in heavier digestive tract weights (Pond et al., 1988; Anugwa et al., 1989). In addition, increasing levels of DDGS has been shown to increase kidney and liver weights (Weimer et al., 2008). Therefore, it would be expected for pigs fed diets with DDGS to have lower dressing percentages compared with pigs fed a corn-soybean meal diet. This has been confirmed by other researchers (Cook et al., 2005; Linneen et al., 2008).

Among the DDGS sources, iodine value was greater ($P < 0.001$) for pigs fed the high vs moderate energy and the corn- vs sorghum-based DDGS treatments. These results confirm that increased oil content, as in high-energy corn-based DDGS, causes increased unsaturation of carcass fat. However, backfat thickness ($P > 0.58$) and fat-free lean index were not affected ($P > 0.25$) by treatment, which is in agreement with previous reports (Senne et al., 1998; Cook et al., 2005), suggesting no effects of feeding DDGS on the amount of fat deposited.

In conclusion, our experiments indicated that plant of origin and substrate used in the fermentation process (corn vs sorghum) affect the nutritional value of DDGS when fed to finishing pigs.

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

Ingredient, %	Corn	DDGS [2]
Corn	97.49	48.63
DDGS	—	50.00
Limestone	0.89	0.94
Monocalcium phosphate (21% P)	0.60	—
Salt	0.20	—
L-lysine HCl	0.34	0.11
L-threonine	0.03	—
L-tryptophan	0.04	—
L-isoleucine	0.02	—
Vitamin premix [3]	0.05	0.03
Mineral premix [3]	0.09	0.04
Chromic oxide [4]	0.25	0.25
Total	100.00	100.00

[1] The diets were formulated to 0.52% Lys, 0.45% Ca, and 0.40% total P.

[2] Distillers dried grains with solubles. Substituted for corn on a wt:wt basis. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS. Sorghum-based DDGS supplied by Western Plains Energy, Oakley, KS and U.S. Energy Partners, Russell, KS.

[3] Supplied per kilogram of complete diet: 1,323 IU vitamin A; 198 IU vitamin D_3; 5.29 IU vitamin E; 0.53 mg vitamin K (as menadione nicotinamide bisulfite); 4.6 µg vitamin B_{12}, 5.95 mg niacin, 3.31 mg pantothenic acid (as calcium pantothenate), 0.99 mg riboflavin, 0.13 mg folic acid, 0.40 mg pyridoxine, 44.1 mg choline, 0.018 mg biotin, 9.9 mg Cu, 0.2 mg I, 99.2 mg Fe, 23.8 mg Mn, 0.18 mg Se, and 99.2 mg Zn for the corn diet and 1,323 IU vitamin A; 198 IU vitamin D_3; 5.29 IU vitamin E; 0.53 mg vitamin K (as menadione nicotinamide bisulfite); 4.6 µg vitamin B_{12}, 5.95 mg niacin, 3.31 mg pantothenic acid (as calcium pantothenate), 0.99 mg riboflavin, 4.4 mg Cu, 0.08 mg I, 44.1 mg Fe, 10.6 mg Mn, 0.079 mg Se, and 44.1 mg Zn for the DDGS diets.

[4] Used as an indigestible marker.

Table 2.2. Composition of diets (Exp. 2; as-fed basis)[1]

	d 0 to 35		d 35 to 72	
Ingredient, %	Control	DDGS [2]	Control	DDGS
Corn	69.64	46.86	81.37	54.57
DDGS	—	40.00	—	40.00
Soybean meal (47.5% CP)	28.00	11.00	16.15	3.25
Limestone	1.04	1.31	1.06	1.24
Monocalcium phosphate (21% P)	0.66	—	0.53	—
Salt	0.43	0.20	0.38	0.15
L-lysine HCl	0.10	0.50	0.13	0.40
DL-methionine	0.01	—	—	—
Vitamin premix [3]	0.04	0.04	0.04	0.04
Mineral premix [4]	0.03	0.04	0.04	0.05
Antibiotic [5]	0.05	0.05	0.05	0.05
Chromic oxide [6]	—	—	0.25	0.25
Total	100.00	100.00	100.00	100.00

[1] Formulated to 1.10% Lys, 0.60% Ca, and 0.50% total P for d 0 to 35, and 0.80% Lys, 0.55% Ca, and 0.45% total P for d 35 to 72.

[2] Distillers dried grains with solubles. Substituted for corn on a wt:wt basis. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[3] Supplied per kilogram of complete diet: 1,764 IU vitamin A; 265 IU vitamin D_3; 7.05 IU vitamin E; 0.71 mg vitamin K (as menadione nicotinamide bisulfite); 6.2 μg vitamin B_{12}, 7.94 mg niacin, 4.41 mg pantothenic acid (as calcium pantothenate), and 1.32 mg riboflavin.

[4] Supplied per kilogram of complete diet: 3.3 mg Cu, 0.06 mg I, 33.1 mg Fe, 7.9 mg Mn, 0.060 mg Se, and 33.1 mg Zn for the control diet for d 0 to 35; 4.4 mg Cu, 0.08 mg I, 44.1 mg Fe, 10.6 mg Mn, 0.079 mg Se, and 44.1 mg Zn for the control diet for d 35 to 72 and for the DDGS diets for d 0 to 35; and 5.5 mg Cu, 0.099 mg I, 55.1 mg Fe, 13.2 mg Mn, 0.099 mg Se, and 55.1 mg Zn for the DDGS diets for d 35 to 72.

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

[6] Used as an indigestible marker.

Table 2.3. Chemical analyses and physical characteristics of distillers dried grains with solubles (DDGS) sources (as-fed basis)[1]

		Corn-based DDGS		Sorghum-based DDGS	
Item	Corn	Hudson	Atchison	Oakley	Russell
Chemical Analysis [2]					
Dry matter, %	87.0	90.1	88.2	88.5	88.1
Crude protein, %	8.7	26.4	25.6	29.8	30.5
Ether extract, %	3.4	10.4	8.5	7.9	7.3
Crude fiber, %	1.8	6.0	6.0	7.9	6.4
Ash, %	1.1	5.1	4.7	3.5	3.7
Nitrogen free extract, %	72.0	42.2	43.4	39.4	40.2
P, %	0.25	0.77	0.77	0.62	0.66
Gross energy, Mcal/kg	3.90	4.74	4.52	4.08	4.61
Essential AA, % [3]					
Arginine	0.44	1.24	1.23	1.19	1.20
Histidine	0.27	0.78	0.70	0.78	0.72
Isoleucine	0.35	1.11	1.05	1.35	1.44
Leucine	1.19	3.10	2.77	4.05	4.00
Lysine	0.25	0.94	0.86	0.86	0.85
Methionine	0.21	0.55	0.50	0.54	0.50
Phenylalanine	0.47	1.35	1.29	1.67	1.69
Threonine	0.31	0.99	0.92	1.06	1.03
Tryptophan	0.05	0.17	0.17	0.15	0.15
Valine	0.47	1.42	1.36	1.65	1.73
Nonessential AA, % [3]					
Alanine	0.71	1.85	1.64	2.45	2.58
Aspartic Acid	0.59	1.68	1.59	1.90	1.99
Cysteine	0.23	0.55	0.57	0.54	0.49
Glutamic acid	1.77	3.85	3.79	4.83	4.89
Glycine	0.36	1.07	1.05	1.02	0.96
Hydroxylysine	—	0.09	—	—	—
Lanthionine	—	0.17	0.22	0.22	0.14
Ornithine	—	0.05	0.03	0.03	0.03
Proline	0.75	2.18	1.75	2.26	2.09
Serine	0.37	1.03	1.00	1.19	1.14
Taurine	0.05	0.03	0.03	0.01	0.03
Tyrosine	0.27	1.11	0.97	1.28	1.27
Physical characteristics					
d_{gw}, µm [4]	666	328	796	606	563
s_{gw} [4]	2.5	1.7	1.9	1.8	1.9
L* [5]	86	61	65	60	57
a* [5]	4	12	8	9	9
b* [5]	27	32	25	20	16

[1] Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS. Sorghum-based DDGS supplied by Western Plains Energy, Oakley, KS and U.S. Energy Partners, Russell, KS.

[2] DM (NFTA Method 2.1.2). CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), crude fiber (AOAC 962.09), ash (AOAC 942.05), P (AOAC 965.17; AOAC, 1995). GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL).

[3] AA (AOAC Official Method 982.30 E(a,b,c), chp. 45.3.05, 2006).

[4] Geometric mean particle size and standard deviation of the mean particle size (ANSI/ASAE S319.3).

[5] Color spectrophotometry (Hunter LAB MiniScan XE Plus. Model 45/O-L. Serial 6049, Reston, VA).

Table 2.4. Digestible energy content of corn and corn- or sorghum-based distillers dried grains with solubles (DDGS) in finishing pigs (as-fed basis)[1]

		Corn DDGS [2]		Sorghum DDGS [2]			*P* value			
Item	Corn	Hudson	Atchison	Oakley	Russell	SE	Cont vs DDGS	Corn vs Sorg	Hud vs Atch	Oak vs Rus
Dig of DM, %	87.4	81.6	76.1	76.6	80.6	1.1	0.001	—[3]	0.002	0.02
Dig of N, %	74.4	82.9	74.3	73.9	72.4	1.5	—	0.002	0.001	—
Dig of GE, %	85.4	81.1	74.6	74.0	77.9	1.1	0.001	0.10	0.001	0.03
DE of DDGS, kcal/kg	3,322	3,628	2,940	2,918	3,205	88	0.13	0.02	0.001	0.03

[1] A total of 120 finishing pigs (12 pigs/pen and 2 pens/treatment with 2 replicates) with an average initial BW of 111 kg.

[2] Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS. Sorghum-based DDGS supplied by Western Plains Energy, Oakley, KS and U.S. Energy Partners, Russell, KS.

[3] Dashes indicate $P > 0.15$.

Table 2.5. Effects of corn- and sorghum-based distillers dried grains with solubles (DDGS) in diets for finishing pigs[1]

		High energy	Moderate energy				*P* value		
		Corn-based [2]		Sorg-based		Control vs DDGS	High vs Mod energy	Corn vs Sorg
Item	Control	Hudson	Atchison	Russell	SE			
d 0 to 35								
ADG, g	944	871	931	911	34	0.09	0.05	—[3]
ADFI, kg	2.88	2.63	2.83	2.85	0.19	0.13	0.02	—
G:F, g/kg	328	331	329	320	16	—	—	—
d 0 to 72								
ADG, kg	943	891	918	908	26	0.003	0.06	—
ADFI, kg	3.14	2.92	3.13	3.24	0.14	—	0.02	—
G:F, g/kg	300	305	293	280	9	—	0.06	—
Apparent digestibilities, % [4]								
DM	82.5	76.0	78.4	78.4	1.3	0.001	0.03	—
N	75.4	73.8	74.9	66.3	1.7	0.02	0.05	0.001
GE	80.0	74.7	76.2	75.2	1.3	0.001	—	—
HCW, kg	98.7	94.4	94.5	95.2	1.7	0.001	—	—
Dressing, % [5]	74.8	73.7	72.7	73.6	0.8	0.003	0.11	0.04
FFLI, % [5,6]	53.2	53.0	53.2	53.0	0.8	—	—	—
Backfat, mm[5]	16.4	16.1	15.9	16.4	1.3	—	—	—
Loin depth, mm [5]	62.5	58.7	58.8	60.1	1.2	0.05	—	—
Iodine value [5,7]	69.3	80.2	78.4	74.2	0.8	0.001	0.001	0.001

[1] A total of 176 finishing pigs (11 pigs/pen and 4 pens/treatment) with an average initial BW of 64 kg.

[2] Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD and MGP Ingredients, Atchison, KS. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[3] Dashes indicate $P > 0.15$.

[4] Fecal samples for digestibility determinations were collected on d 40 and 41 with chromic oxide used as an indigestible marker.

[5] HCW used as a covariate.

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

[7] As calculated from fatty acid profile of jowls (AOCS Cd 1c-85 Official Method).

CHAPTER 3 - Effects of dietary electrolyte balance and molasses in diets with distillers dried grains with solubles on growth performance in nursery and finishing pigs

ABSTRACT: Two experiments were conducted to determine the effects of dietary electrolyte balance (dEB) and molasses in diets with corn-based distillers dried grains with solubles (DDGS) on growth performance of nursery and finishing pigs. For the first experiment, 126 nursery pigs (35 d old and avg BW of 10.2 kg) were assigned with 6 pigs/pen and 7 pens/treatment. Treatments were a corn-soybean meal-based control and diets with DDGS as 30% of the formula without and with sodium bicarbonate to bring the dEB to as much or greater than that calculated for the control diet. Diets were formulated to 1.4% Lys, 0.75% Ca, and 0.35% available P. Pigs fed the control diet had greater ADG ($P < 0.04$), but did not differ in ADFI or G:F ($P > 0.12$) compared to those fed diets with DDGS. Addition of sodium bicarbonate did not improve growth performance ($P > 0.32$). For the second experiment, a total of 70 gilts (avg BW of 71 kg) were assigned with 2 pigs/pen and 5 pens/treatment. The pigs were fed the experimental diets for 26 d, fed a common diet for 6 d, and then reassigned to a different treatment for an additional 26-d assay. The end result was 10 pens/treatment. Treatments were a corn-soybean meal-based control and diets with DDGS as 40% of the formulation with none or 5% molasses and 0, 1, or 2% sodium bicarbonate arranged as a 2 × 3 factorial plus control. Diets were formulated to 0.9% Lys, 0.6% Ca, and 0.22% available P. Pigs fed the control diet had greater ADG, ADFI, and G:F ($P < 0.01$) compared to those fed diets with DDGS. Adding molasses or sodium bicarbonate did not improve ADG or ADFI ($P > 0.16$), and adding molasses actually decreased ($P < 0.05$) G:F. In conclusion, adding sodium bicarbonate and molasses to diets with high inclusion of DDGS did not improve growth performance of nursery or finishing pigs.

Key Words: distillers dried grains with solubles, electrolyte balance, molasses, pig, sodium bicarbonate.

INTRODUCTION

Distillers dried grains with solubles (DDGS) are a coproduct of dry milling grains for ethanol production. In the last decade, there has been a dramatic increase in production of ethanol for fuel purposes, thus increasing the availability of DDGS for use in livestock diets. It has been reported that diets with 20 to 25% DDGS for finishing and nursery pigs will support similar growth performance to that of a corn-soybean meal diet (Thaler, 2002). However, studies from our laboratory (Feoli et al., 2007) suggested that high inclusion (i.e., 40% for finishing pigs) of some DDGS sources decreased average daily feed intake and growth rate. Patience et al. (1987) reported poor feed consumption in growing pigs fed a corn-soybean meal diet with low dietary electrolyte balance (dEB). Haydon et al. (1990) reported that as dEB was increased there was a linear positive response in feed intake and, consequently, growth rate for both growing and finishing pigs subjected to high temperatures. Additionally, data from our laboratory suggested a similar response in lactating sows (DeRouchey et al., 2003). Thus, it seems plausible that balancing diets with DDGS for dEB might have a positive effect on feed intake and growth performance. Therefore, the objectives of the experiments reported herein were to determine the effects of dEB and a flavoring agent (molasses) in diets with high inclusion of corn-based DDGS on growth performance of nursery and finishing pigs.

MATERIALS AND METHODS

General

The DDGS for both experiments were corn-based and secured from Sioux River Ethanol, Hudson, SD, in a single load. Samples of feed were collected from feeders at the beginning of each assay, pooled by treatment into one bag, ground, and kept frozen at -15ºC until analysis. Diets and DDGS were analyzed for Na, K, Cl, and S to allow calculation of dEB using the formula Na + K – Cl – S (Goff and Horst, 2004). For Na determination, quadruplicate 1-g samples of the feed were ashed at 600ºC for 6 h. After cooling, 5 mL of 1 M HCl solution was added and allowed to stand for 15 min before further dilution with 1 M HCl solution to a total volume of 50 mL. Sodium concentration was then determined by flame emission via atomic absorption spectrophotometry (model 3110; Perkin Elmer Corp., Norwalk, CT). Samples for analyses of K and SO_4 were digested in perchloric acid (Gieseking et al., 1935) and read using an inductively coupled plasma spectrometer (model 720-ES ICP Optical Emission Spectrometer; Varian Australia Pty Ltd, Mulgrave, Vic Australia). Chloride was determined via calcium nitrate extraction and colorimetric analysis according to the mercury thiocyanate method (Gelderman et al., 1998) using an Alpkem RFA analyzer (methodology No. A303-S090; OI Analytical, College Station, TX).

Experiment 1

One hundred twenty six nursery pigs (PIC line TR4 × 1050) were weaned at an average age of 21 d (average BW of 6.5 kg), sorted by sex and ancestry, blocked by weight, and assigned to pens[1]. There were 6 pigs/pen (3 barrows and 3 gilts) and 7 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 32ºC and was lowered by 1.5ºC each week. All pens had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

Immediately after weaning, pigs were fed a common diet in pellet form (Rapid Start N/T; Suther Feeds Inc., Frankfort, KS) for 4 d and a common diet in meal form for the next 10 d (corn-soybean meal based with 15% whey, 2.5% spray-dried animal plasma, and 3% Menhaden fishmeal, formulated to 1.6% Lys, 0.8% Ca, and 0.43% available P). When the pigs were 35 d old (average BW of 10.2 kg), treatments were assigned and the experimental diets were fed for 24 d. Treatments (Table 3.1) were a corn-soybean meal-based control and diets with 30% DDGS with 0 or 0.93% sodium bicarbonate to bring the dEB and pH to as much or greater than that of the corn-soybean meal control diet. All diets were formulated to 1.4% Lys, 0.75% Ca, and 0.35% available P. Other nutrients met or exceeded NRC (1998) recommendations for nursery pigs and the diets were fed in meal form. Pigs and feeders were weighed on d 0 and 24 to allow calculation of ADG, ADFI, and G:F.

Growth data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial BW as a covariate and pen as the experimental unit. Orthogonal contrasts were used to separate treatment means with comparison of the control vs DDGS diets and without vs with sodium bicarbonate.

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[1] The animal care and management used in these experiments were approved by the Kansas State University Animal Care and Use Committee.

Experiment 2

Seventy gilts (PIC line TR4 × 1050), were used in a 58-d growth assay to determine the effects of molasses and dEB on palatability of diets with 40% DDGS in finishing pigs. Ten days before the start of the experiment, the pigs were sorted by ancestry, blocked by weight, assigned to pens and fed a common grower diet. There were 2 pigs/pen and 5 pens/treatment. The pigs were fed the experimental diets from d 0 to 26, a common diet for 6 d, and the treatments were reassigned for a second replicate with the only restriction to randomization being that a pen could not receive the same treatment twice. The end result was 10 observations per treatment. The pigs were housed in an environmentally-controlled finishing facility having 1.52-m x 1.52-m pens with slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water with pigs and feeders weighed on d 0, 26, 32, and 58 to allow calculation of ADG, ADFI, and G:F.

Treatments (Table 3.2) were a corn-soybean meal-based control and diets with 40% DDGS with 0 or 5% molasses (cane molasses, 43% invert sugar, 79.5 brix; Quality Liquid Feeds Inc., Dodgeville, WI) and 0, 1, or 2% sodium bicarbonate. Treatments were arranged as a 2 × 3 factorial plus control. All diets were formulated to 0.90% Lys, 0.60% Ca, and 0.22% available P. All other nutrients met or exceeded NRC (1998) recommendations for a genotype growing at about 325 g of lean/d and the diets were fed in meal form.

All growth data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial BW as a covariate and pen as the experimental unit. Orthogonal contrasts were used to separate treatment means with comparisons of control vs DDGS treatments, 0 vs 5% molasses, linear and quadratic effects of sodium bicarbonate, and interactions among the molasses and sodium bicarbonate main effects.

RESULTS AND DISCUSSION

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 3 times in DDGS. However, concentrations of some minerals can be increased by 6 to 10 times in DDGS relative to corn.

Levels of sodium bicarbonate were chosen for our experiments based on a pilot evaluation of diet pH in our laboratory. One-kilogram samples of corn-soybean meal diets without DDGS and with 40% corn DDGS plus 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5% $NaHCO_3$ were made. Ten grams of each diet were dissolved in 20 mL of deionized water, stirred, and allowed to equilibrate for 5 min prior to determination of pH (Corning model 340). After manufacturing the actual diets fed to pigs, pH was determined using the same procedure. Analyses of electrolytes in the corn and DDGS used in our diets (Table 3.3) indicated that actual concentration of S was 8 times greater in DDGS vs corn. For most of the literature regarding electrolyte balance in pig diets the equation Na + K – Cl (Patience, 1987; Haydon et al., 1990; Wondra et al., 1995; Ivers et al., 2002; DeRouchey et al., 2003) was used. Because of the high concentration of S in DDGS, we elected to account for the contribution of this anion to the electrolyte balance by including it in the dEB equation (Na + K – Cl – S; Goff et al., 2004). When S was considered in calculation of electrolyte balance, adding DDGS to corn-soybean meal diets results in a decrease of about 50 to 90 mEq/kg (Table 3.1 and 3.2), whereas the simple formula did not indicate a difference for diets without and with DDGS.

Experiment 1

When our diets were fed to nursery pigs (Table 3.4), those given the control diet had greater ADG ($P < 0.04$) but did not differ in ADFI and G:F ($P > 0.12$) compared to those fed diets with

DDGS. These effects on ADG and G:F are in agreement with data we reported (Feoli et al., 2008a,b) for addition of 30% of this source of corn-based DDGS to diets for nursery pigs. As for ADFI, it seems noteworthy that when comparing the control with the DDGS treatments, feed consumption was numerically lower for the DDGS treatments (908 vs 868 g/d) for pigs fed the DDGS diets. Similarly, in previous studies we observed that nursery pigs fed diets with 30% DDGS consumed 9% less than pigs fed a corn-soybean meal control (Feoli et al., 2008a,b). Whitney and Shurson (2004) also found a trend for decreased feed intake when DDGS was increased from 0 to 25% in a titration study with nursery pigs.

Addition of sodium bicarbonate to diets with 30% DDGS did not improve growth performance ($P > 0.32$). This finding is in agreement with data reported by Patience et al. (1987), where no effects on growth performance resulted with addition of up to 2% $NaHCO_3$ to diets for 15-kg pigs.

In addition to dEB of the diets, we determined the acidity of diets by measuring pH. For the corn-soybean meal diet and diets with 40% DDGS plus 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5% $NaHCO_3$, pH was 5.65, 4.20, 4.79, 5.36, 5.92, 6.17, 6.40, 6.50, and 6.62, respectively. Because the DDGS diet required between 1 and 1.5% $NaHCO_3$ to bring the pH back to that of the corn-soybean meal control, we elected to include $NaHCO_3$ at 1 and 2% of the formulation for the diets in Exp. 2. These levels would ensure that not only dEB (calculated as Na + K – Cl – S) of adjusted diets would bracket that of the corn-soybean meal control, but concentration of total acidogenic ions also would be bracketed. It is noteworthy that inclusion of 40% DDGS into diets caused a drop in pH from 5.65 to 4.20.

Experiment 2

When the experimental diets were fed (Table 3.5), pigs consuming the control diet had greater ADG, ADFI, and G:F ($P < 0.01$) compared to those consuming diets with DDGS. This response is in agreement with previous findings from our laboratory (Feoli et al., 2008a,b) and those of others where a decrease in growth rate resulted from inclusion of corn-based DDGS into formulations for finishing pigs (Whitney et al., 2006; Feoli et al., 2007; Linneen et al., 2008). Adding sodium bicarbonate to diets with 40% DDGS to adjust dEB and pH did not affect ADG, ADFI, or G:F ($P > 0.26$). Wondra et al. (1995) added from 0 to 3% $NaHCO_3$ to corn-soybean meal diets for finishing pigs to change dEB (calculated as Na + K – Cl) from 177 to 399 mEq/kg. They reported a linear decrease in growth rate with no effects on ADFI or G:F as sodium bicarbonate was increased. Patience et al. (1987) documented negative effects on ADFI when dEB of diets for growing pigs was decreased from 0 to -85 mEq/kg; but no real effects when dEB was between 0 and 341 mEq/kg. Golz and Crenshaw (1990) used CaCl to achieve low dEB in corn-soy diets. This left Cl at almost twice the level of K and caused negative effects on growth rate. Shaw et al. (2006) added 0.5% salt to a grower diet to decrease dEB from 235 to 154 mEq/kg and did not find any effects on growth performance. Furthermore, other data show increased feed intake with lower pH of diets for weanling pigs (Straw et al., 1991). In general, it seems that DDGS diets do not have sufficiently low dEB to produce a response to addition of sodium bicarbonate, and this is supported by the literature.

Adding molasses did not affect ADG or ADFI ($P > 0.16$) and actually decreased ($P < 0.05$) G:F. Hastad et al. (2005) reported that even when given a choice, adding a feed flavor additive (Sucram) to corn-soybean meal diets or to diets with 30% DDGS did not affect feed consumption in growing pigs. Data from Mavromichalis et al. (2001) indicated no effect in growth performance with addition of 10% molasses at the expense of lactose in diets for weanling pigs, and actually a numerical decrease in efficiency of growth. The decreased G:F in our experiment could be attributed to the lower energy content of diets with molasses and pigs not equalizing their calorie intake by increasing feed consumption.

In conclusion, adding sodium bicarbonate to adjust dEB and molasses to enhance flavor of diets with high inclusion of DDGS did not improve growth performance in nursery or finishing pigs.

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Table 3.1. Composition of nursery diets (Exp. 1; as-fed basis)[1]

Ingredient, %	Control	DDGS[2]	DDGS + $NaHCO_3$
Corn	63.11	43.03	42.00
Soybean meal (47.5% CP)	32.60	22.90	23.00
DDGS	—	30.00	30.00
Limestone	1.11	1.50	1.50
Monocalcium phosphate (21% P)	1.30	0.65	0.65
Salt	0.36	0.35	0.35
L-lysine HCl	0.32	0.53	0.53
DL-methionine	0.12	0.03	0.03
L-threonine	0.09	0.05	0.05
Vitamin premix[3]	0.11	0.11	0.11
Mineral premix[4]	0.08	0.05	0.05
Copper sulfate[5]	0.10	0.10	0.10
Antibiotic[6]	0.70	0.70	0.70
Sodium bicarbonate	—	—	0.93
Analyzed electrolytes			
Na, %	0.15	0.15	0.45
K, %	0.97	1.02	1.06
Cl, %	0.34	0.35	0.30
S, %	0.25	0.40	0.41
dEB (Na + K) – (Cl + S), mEq/kg[7]	139	101	253
dEB (Na + K – Cl), mEq/kg	217	226	381
pH	5.54	4.77	5.53

[1] Diets were formulated to 1.40 % Lys, 0.75% Ca, and 0.35% available P.

[2] Distillers dried grains with solubles. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD.

[3] Supplied per kilogram of complete diet: 4,840 IU vitamin A; 726 IU vitamin D_3; 19.36 IU vitamin E; 1.94 mg vitamin K (as menadione dimethylpyrimidinol bisulfite); 16.94 µg vitamin B_{12}, 21.78 mg niacin, 12.10 mg pantothenic acid (as calcium pantothenate), and 3.63 mg riboflavin.

[4] Supplied per kilogram of complete diet: 8.8 mg Cu, 0.16 mg I, 88.16 mg Fe, 21.12 mg Mn, 0.16 mg Se, and 88.16 mg Zn for the corn diet and 5.5 mg Cu, 0.1 mg I, 55.1 mg Fe, 13.2 mg Mn, 0.1 mg Se, and 55.1 mg Zn for the DDGS diets.

[5] To supply 250 mg/ton copper.

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

[7] Dietary electrolyte balance.

Table 3.2. Composition of finishing diets (Exp. 2; as-fed basis)[1]

		No Molasses			5% Molasses		
Ingredient	Control	0% $NaHCO_3$	1% $NaHCO_3$	2% $NaHCO_3$	0% $NaHCO_3$	1% $NaHCO_3$	2% $NaHCO_3$
Corn	77.48	50.36	50.26	50.10	45.20	45.10	44.99
DDGS [2]	—	40.00	40.00	40.00	40.00	40.00	40.00
Soybean meal (47.5% CP)	18.10	5.25	5.35	5.50	5.50	5.60	5.70
Limestone	1.08	1.52	1.51	1.51	1.40	1.39	1.39
Monocalcium P (21% P)	0.76	0.05	0.06	0.07	0.08	0.09	0.10
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-lysine HCl	0.20	0.47	0.47	0.47	0.47	0.47	0.47
L-threonine	0.03	—	—	—	—	—	—
Vitamin premix [3]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mineral premix [4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sodium bicarbonate	—	—	1.00	2.00	—	1.00	2.00
Sand [5]	2.00	2.00	1.00	—	2.00	1.00	—
Molasses [6]	—	—	—	—	5.00	5.00	5.00
Analyzed electrolytes							
Na, %	0.08	0.16	0.48	0.79	0.15	0.48	0.80
K, %	0.68	0.70	0.74	0.75	0.93	0.92	0.91
Cl, %	0.18	0.36	0.40	0.36	0.34	0.39	0.42
S, %	0.17	0.43	0.44	0.44	0.48	0.48	0.46
dEB (Na + K) − (Cl + S), mEq/kg [7]	104	12	145	299	59	186	320
dEB (Na + K – Cl), mEq/kg	157	146	282	436	209	335	464
pH	5.64	4.28	5.27	6.11	4.56	5.27	6.21

[1] The diets were formulated to 0.90% Lys, 0.60% Ca, and 0.22% available P.

[2] Distillers dried grains with solubles. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD.

[3] Supplied per kilogram of complete diet: 2,200 IU vitamin A; 330 IU vitamin D_3; 8.8 IU vitamin E; 0.88 mg vitamin K (as menadione dimethylpyrimidinol bisulfite); 7.7 µg vitamin B_{12}, 9.9 mg niacin, 5.5 mg pantothenic acid (as calcium pantothenate), and 1.65 mg riboflavin.

[4] Supplied per kilogram of complete diet: 5.5 mg Cu, 0.1 mg I, 55.1 mg Fe, 13.2 mg Mn, 0.1 mg Se, and 55.1 mg Zn.

[5] As a non-nutritive ingredient to be replaced by $NaHCO_3$.

[6] Cane molasses (43% invert sugar, 79.5 brix). Supplied by Quality Liquid Feeds Inc., Dodgeville, WI.

[7] Dietary electrolyte balance.

Table 3.3. Chemical composition of electrolytes of corn and distillers dried grains with solubles (DDGS; as-fed basis)[1]

Ingredient, %	Corn	DDGS
NRC (1998) reference value		
Na	0.02	0.25
K	0.33	0.84
Cl	0.05	0.20
S	0.13	0.30
Assumed value[2]		
Na	0.02	0.19
K	0.33	0.98
Cl	0.05	0.20
S	0.13	0.86
Chemical analysis		
Na	0.02	0.20
K	0.28	1.01
Cl	0.04	0.26
S	0.10	0.82

[1] Distillers dried grains with solubles. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD.

[2] Assumed values of DDGS according to specifications by the supplier with exception of Cl, for which NRC (1998) recommendations were used.

Table 3.4. Effect of dietary electrolyte balance (dEB) in diets with distillers dried grains with solubles (DDGS)[1] on growth performance of nursery pigs[2]

					P value	
Item	Control	DDGS	DDGS + $NaHCO_3$ [3]	SE	Control vs DDGS	w/ or w/o $NaHCO_3$
ADG, g	606	574	587	9	0.04	—[4]
ADFI, g	908	868	886	15	0.13	—
G:F, g/kg	667	661	663	6	—	—

[1] Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD.

[2] A total of 126 nursery pigs (35 d old and avg initial BW of 10.2 kg) with 6 pigs/pen and 7 pens/treatment.

[3] Electrolyte balance was adjusted via addition of $NaHCO_3$ to the DDGS diet.

[4] Dashes indicate $P > 0.15$.

Table 3.5. Effects of dietary electrolyte balance (dEB) and molasses in diets with distillers dried grains with solubles (DDGS)[1] on growth performance of finishing pigs[2]

		40% DDGS							*P* value [3]		
		No molasses			5% molasses						
Item	Control	0% $NaHCO_3$	1% $NaHCO_3$	2% $NaHCO_3$	0% $NaHCO_3$	1% $NaHCO_3$	2% $NaHCO_3$	SE	DDGS effect	w/ or w/o molasses	w/ or w/o $NaHCO_3$
ADG, g	1,115	938	884	880	908	893	878	114	0.001	—	—
ADFI, kg	3.37	2.92	2.84	2.86	3.03	2.98	2.91	0.09	0.001	—	—
G:F, g/kg	331	321	311	308	300	300	302	37	0.01	0.05	—

[1] Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD.

[2] A total of 70 finishing gilts (average initial BW of 71 kg for the first replication and 107 kg for the second replication), with 2 pigs/pen and 5 pens/treatment in each of 2 replicates for a total of 10 observations/treatment.

[3] Dashes indicate $P > 0.15$. There were no molasses × $NaHCO_3$ interactions or linear or quadratic effects of $NaHCO_3$.

CHAPTER 4 - Effects of adding enzymes to diets with corn- and sorghum-based distillers dried grains with solubles on growth performance and nutrient digestibility in nursery and finishing pigs

ABSTRACT: Two experiments were conducted to determine the effects of enzyme additions on the nutritional value of diets with corn- and sorghum-based distillers dried grains with solubles (DDGS). For Exp. 1, 180 weanling pigs were fed the same starter diet for 10 d and then used in a 27-d growth assay. There were 6 pigs/pen and 6 pens/treatment with an average initial BW of 7.5 kg. Treatments were a corn-soy-based control and diets with 30% corn-based and sorghum-based DDGS without and with enzymes (a cocktail of beta-glucanase, protease, alpha-amylase, and xylanase to supply 150, 500, 1,000, and 4,000 units of activity, respectively, per kg of diet). Pigs fed the control diet had greater ADG, ADFI, and digestibility of DM, N, and GE ($P < 0.003$) than pigs fed the DDGS treatments and DDGS that were sorghum-based yielded poorer ($P < 0.04$) G:F and digestibilities of N and GE than DDGS that were corn-based. Addition of enzymes improved ADG for pigs fed corn-based DDGS (DDGS source × enzyme interaction, $P < 0.08$). Addition of enzymes improved G:F ($P < 0.08$) and digestibility of DM ($P < 0.04$) regardless of DDGS source. For Exp. 2, 330 finishing pigs (avg BW of 64 kg) were used in a 65-d growth assay. There were 11 pigs/pen and 6 pens/treatment. Treatments were the same as in Exp. 1, but 40% DDGS were used in diets for the finishing experiment. Pigs fed the control diet had greater ADG, ADFI, HCW, and digestibility of DM, N, and GE, and lower iodine value than pigs fed the DDGS treatments ($P < 0.008$). Also, pigs fed the corn-based DDGS treatments had greater G:F, digestibility of DM, N, and GE, and iodine value of jowl fat than pigs fed the sorghum-based DDGS treatments ($P < 0.04$). Enzymes improved digestibility of DM, N, and GE ($P < 0.01$), especially for diets with sorghum-based DDGS (DDGS source × enzyme interaction, $P < 0.10$). In conclusion, growth performance and nutrient digestibility were decreased with addition of DDGS to diets for nursery and finishing pigs but adding enzymes partially restored nutrient digestibility.

Key Words: digestibility, distillers dried grain with solubles, enzyme supplementation, growth performance, pig, sorghum.

INTRODUCTION

Price and availability of coproducts from the ethanol industry favors their use in diets for pigs. However, previous studies from our laboratory indicated that inclusion of high levels of DDGS in diets for nursery (30%) and finishing pigs (40%) had negative effects on growth performance and nutrient digestibility (Feoli et al., 2007a,b; Feoli et al., 2008). Distillers dried grains with solubles have approximately 16% cellulose, 8% xylans, and 5% arabinans (Kim et al., 2008), constituents known to reduce digestibility of nutrients in growing pigs (Owusu-Asiedu et al., 2006) and chickens (Choct and Annison, 1992). It has been reported that exogenous enzymes can improve nutrient digestibility when their specific substrates are present. Moreover, in vitro studies have revealed enzyme blends have synergistic effects (Härkönen et al., 1995). Improvements in nutrient digestibility with addition of carbohydrases have been observed in nursery and growing pigs fed diets containing rapeseed meal (Fang et al., 2007), wheat, barley, soybean meal, canola meal, and peas (Omogbenigun et al., 2004), corn and soybean meal (Ji et al., 2008), and barley (Yin et al., 2001). Recent studies of the addition of multi-enzyme preparations to diets with up to 30% barley-wheat-based (Emiola et al., 2008) or corn-based (Pierce and Bannerman, 2008) DDGS showed some beneficial effects on nutrient utilization and growth performance in growing pigs. However, Sigfridson and Haraldsson (2007) did not observe a growth response when xylanase was added to diets with 20% wheat-based DDGS.

It seems likely that adding exogenous multi-enzyme preparations to DDGS-based diets might improve nutrient utilization. But, there still is a lack of data on the use of enzymes in diets with

DDGS for young piglets and on the response to enzymes for different DDGS sources. Therefore, the objective of the experiments reported herein was to determine the effects of enzyme additions on the nutritional value of diets with corn- and sorghum-based DDGS in nursery and finishing pigs.

MATERIALS AND METHODS

General

The DDGS sources used in our experiments were corn-based DDGS from Sioux River Ethanol, Hudson, SD, and sorghum-based DDGS from US Energy Partners, Russell, KS. A 1-kg sample of each DDGS shipment was collected and analyzed for DM (NFTA Method 2.2.2.5), CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL), ash (AOAC 942.05), Ca (AOAC 927.02), P (AOAC 965.17), and crude fiber (AOAC 962.09). Additionally, NDF, ADF, and ADL were determined using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY). Concentrations of soluble and total pentosans (arabinoxylans) were determined according to the method of Rouau and Surget (1994), and starch by AOAC official method 979.10 using a Spectronic 21 colorimeter (Bausch & Lomb, Rochester, NY). Cellulose was estimated by subtracting ADL from ADF. Additionally, tannin content was determined using the modified vanillin hydrochloric method as described by Earp et al. (1981) with a UV-vis spectrophotometer (Spectronic 20; Thermo Fisher Scientific Inc., Madison, WI).

The enzyme product (Porzyme tp100; Danisco Animal Nutrition, Copenhagen, Denmark) was a cocktail of endo-1,3(4)-beta-glucanase (EC 3.2.1.6), subtilisin protease (EC 3.4.21.62), alpha-amylase (EC 3.2.1.1), and endo-1,4-beta-xylanase (EC 3.2.1.8) as derived from the fermentation of *Trichoderma longibrachiatum, Bacillus subtilis*, and *Bacillus amyloliquefaciens.* There were at least 150, 500, 1,000, and 4,000 units of activity per gram, respectively, and the cocktail was added as 0.1% of the finished diets.

Experiment 1.

One hundred eighty weanling pigs (PIC line TR4 × 1050) were weaned at an average age of 21 d, fed a common starter diet in pellet form (Excel-R-Ate MX; Suther Feeds Inc., Frankfort, KS) for 10 d, and then used in a 27-d growth assay[1]. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 6 pigs/pen (3 barrows and 3 gilts) and 6 pens/treatment with an average initial BW of 7.5 kg and average age of 31 d. The pigs were housed in an environmentally-controlled nursery having 1.22-m × 1.22-m pens with woven-wire flooring. Temperature at animal level initially was 32ºC and was lowered by 1.5ºC each week. All pens had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

Treatments were arranged as a 2 × 2 factorial plus control with main effects of DDGS source (corn- vs sorghum-based) and enzyme addition (without vs with enzymes). The experimental diets (Table 4.1) were fed in two phases and formulated to 1.60% Lys, 0.80% Ca, and 0.70% total P for d 0 to 10, and 1.40% Lys, 0.75% Ca, and 0.65% total P for d 10 to 27. All other nutrients met or exceeded NRC (1998) recommendations for nursery pigs and the diets were fed in meal form. Finally, chromic oxide (0.25%) was added to the diets for d 10 to 16 to allow determination of nutrient digestibility.

Pigs and feeders were weighed on d 0, 10, and 27 to allow calculation of ADG, ADFI, and G:F. Feces were collected via rectal massage on d 15 and 16 from no less than 3 pigs/pen. Fecal

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[1] The animal care and management used in these experiments were approved by the Kansas State University Animal Care and Use Committee.

samples were pooled within pen in a plastic bag and kept frozen at -15ºC until dried in an oven at 50ºC, ground, homogenized, and stored in a freezer. Feed and feces were analyzed for concentrations of DM (NFTA Method 2.1.2), N (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), and GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). Chromium concentrations in feed and feces were determined using an atomic absorption spectrophotometer (Perkin Elmer 3110) according to the procedure of Williams et al. (1962) to allow calculation of apparent digestibilities using the indirect ratio method.

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial weight as the blocking criterion and pen as the experimental unit. Orthogonal contrasts were used to separate treatment means with comparisons of: 1) control vs DDGS treatments; 2) effect of DDGS source; 3) effect of enzyme addition; and 4) interaction among DDGS source and enzyme addition.

Experiment 2

Three hundred thirty finishing pigs (PIC line TR4 × 1050), with an average initial BW of 64 kg, were used in a 65-d growth assay. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 11 pigs/pen and 5 pens/treatment, with gilts and barrows penned separately. The pigs were housed in a finishing facility having 1.83-m × 4.88-m pens with concrete flooring that was half solid and half slatted. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

Treatments were arranged as a 2 × 2 factorial plus control as in Exp. 1, but 40% DDGS were used in diets for the finishing experiment. The diets (Table 4.2) were formulated to 0.90% Lys, 0.60% Ca, and 0.50% total P for d 0 to 35, and 0.80% Lys, 0.55% Ca, and 0.45% total P for d 35 to 65. All other nutrients met or exceeded NRC (1998) recommendations for a genotype growing at about 325 g of lean/d, and the diets were fed in meal form.

Pigs and feeders were weighed at d 0, 35, and 65 to allow calculation of ADG, ADFI, and G:F. Chromic oxide (0.25%) was added to the diets as an indigestible marker and fecal samples were collected at mid-experiment (via rectal massage) from no less than 6 pigs/pen, pooled, and handled as in Exp. 1. Concentrations of DM, N, GE, and Cr in the diets and feces were determined as described for Exp. 1 to allow calculation of apparent nutrient digestibility. Half of the pigs were tattooed on d 65 (average BW of 122 kg) and shipped to a commercial abattoir (Triumph Foods, LLC; St. Joseph, MO) for slaughter the following morning. Hot carcass weight, loin depth, and tenth rib fat thickness were measured immediately after slaughter. Dressing percentage was calculated with HCW as a percentage of preshipping live weight and fat free lean index (FFLI) was calculated according to the equation suggested by the National Pork Producers Council (NPPC, 2001). At 24-h postmortem, jowl samples were collected and frozen at -15° C until sample preparation and fatty acid analysis. Samples of jowl fat were dissected and a 5-g sub-sample of subcutaneous fat per pig was pooled within pen. The pooled sample of jowl fat was then submerged in liquid nitrogen for approximately 1 min, then ground and homogenized with a blender (Waring Commercial, Model 51BL32, Torrington, CT). Fatty acid profile was determined by GC (according to Sukhija and Palmquist, 1988) using a gas chromatograph (Shimadzu GC-17A) to allow estimation of iodine value using the regression equation IV = (%C16:1 x 0.950) + (%C18:1 x 0.860) + (%C18:2 x 1.732) + (%C18:3 x 2.616) + (%C20:1 x 0.785) + (%C22:1 x 0.723) according to AOCS Cd 1c-85 Official Method, as an indicator of carcass firmness.

Growth performance, nutrient digestibility, and carcass data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial weight as the blocking criterion and pen as the experimental unit. Because differences in slaughter weight and, thus, HCW are known to affect carcass measurements, HCW was used as a covariate for analyses of dressing percentage, FFLI, backfat thickness, loin depth, and iodine value to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight. Orthogonal contrasts were used to separate treatment means with comparisons of: 1) control vs DDGS treatments; 2) effect of DDGS source; 3) effect of enzyme addition; and 4) interaction among DDGS source and enzyme addition.

RESULTS AND DISCUSSION

The corn-based DDGS was greater in fat content and gross energy than the sorghum-based DDGS (Table 4.3). This can be related not only to the oil content of the grains from which the DDGS were produced but also to the process at the ethanol plant and possibly to the addition of different amounts of solubles back to the wet grains before drying (Noll et al., 2006). Crude protein and fiber were greater in DDGS that originated from sorghum than from corn, which is consistent with other studies (Al-Suwaiegh et al., 2002; Feoli et al., 2007a; Urriola et al., 2007). Measurement of catechin equivalents revealed zero tannin content for the sources of DDGS used in our experiments, indicating no likelihood that growth performance might have been affected by the presence of tannins. Sorghum-based DDGS had 33% more cellulose than corn DDGS, but corn DDGS had greater content of pentosans. For both sources of DDGS, 10% or less pentosans were soluble. In contrast, about 22% of the pentosans in wheat are soluble (Choct, 1997). The content of total pentosans in our DDGS sources (3.4 and 2.2% pentosans in the nursery diets with corn- and sorghum-based DDGS, respectively, and about 4.1 and 3.2% pentosans in the finishing diets with corn- and sorghum-based DDGS, respectively) seemed to provide a lower amount of enzyme substrate than found in the research of others (Mavromichalis et al., 2000; Yin et al., 2001). In their studies, supplementing an enzyme from *Trichoderma longibrachiatium* (as used in our experiments), resulted in greater nutrient digestibility when barley-based diets with 3.6% arabinoxylans and 4.5 to 6% β-glucans and when wheat-based diets with 5.6% pentosans were fed to pigs, but did not improve growth performance consistently (Mavromichalis et al., 2000; Yin et al., 2001).

Experiment 1

In the nursery experiment (Table 4.4), pigs fed the control diet had greater overall ADG, ADFI, and digestibility of DM, N, and GE than pigs fed the DDGS treatments ($P < 0.003$). Our DDGS diets had greater fiber content than the corn-soybean meal diet, and Wilfart et al. (2007) found that increasing the fiber content in diets negatively affected digestibility of CP, ether extract, and energy in pigs. Owusu-Asiedu et al. (2006) also observed reduced ileal and total tract energy and CP digestibility in growing pigs when sources of insoluble and soluble fiber (cellulose and guar gum, respectively) were added to the diet. They related this effect to increased viscosity of digesta for pigs fed the higher fiber diets. Fiber not only causes changes in gut morphology and digesta viscosity as shown in pigs (Wiese et al., 2003; Hedemann et al., 2006) and broilers (Viveros et al., 1994), but also slows enzymatic hydrolysis and decreases amylase, lipase, trypsin, and chymotrypsin activities (Schneeman and Gallaher, 2001). In other studies, increasing levels of pentosans in the diet from 1 to 4% resulted in depressed ileal digestibility of starch, protein, and lipids, apparent metabolizable energy, N retention, growth rate, and efficiency of growth in broilers (Choct and Annison, 1992). Those levels of pentosans would be similar to our diets with DDGS (3.4% in the nursery diets and 4.1% in finishing diets with corn-based DDGS).

Pigs fed diets with corn-based DDGS had 10% greater (*P* < 0.001) digestibility of N and 2% greater (*P* < 0.04) digestibility of GE than pigs fed diets with sorghum-based DDGS. This is in agreement with previous data we reported (Feoli et al., 2007a) for finishing pigs fed diets with 50% DDGS from various sources. Similarly, Healy et al. (1994) determined that corn grain had 4.5% greater digestibility of N than sorghum grain when both were ground to an optimum particle size of 500 μm and fed to nursery pigs. Johnston et al. (1999) also reported greater digestibility of N for corn-based vs sorghum-based diets fed to finishing pigs and sows, respectively, with no difference in digestibility of DM or GE.

Addition of enzymes improved ADG for pigs fed corn-based DDGS but decreased ADG for pigs fed sorghum-based DDGS (DDGS source × enzyme interaction, *P* < 0.04). This effect on ADG was not expected and may be explained by the greater ADFI of pigs fed the sorghum-based DDGS without enzymes, thus causing those pigs to grow much faster compared with pigs fed other DDGS treatments. Additionally, enzyme addition tended to improve overall G:F (*P* < 0.08) and digestibility of DM (*P* < 0.04) regardless if DDGS were derived from corn or sorghum. In contrast to our observations, evaluations of a blend of amylase and beta-glucanase in corn- vs sorghum-based diets for roosters showed that DM and N digestibility of both grains responded similarly to addition of enzymes (Carvalho et al., 2008a,b).

Experiment 2

In the finishing experiment (Table 4.5), pigs fed the control diet had greater (*P* < 0.008) overall ADG and ADFI and digestibility of DM, N, and GE than pigs fed the DDGS diets. The effect on ADG is in agreement with data reported by Whitney et al. (2006) and agrees with the effects in both ADG and nutrient digestibility reported by Feoli et al. (2007b) when 30 and 40% DDGS were added to diets for finishing pigs. Furthermore, pigs fed the corn-based DDGS treatments had better ($P < 0.04$) overall G:F and digestibility of DM, N, and GE than pigs fed the sorghum-based DDGS treatments. This may be related to the lower fiber and greater fat content of the corn-based DDGS source in comparison with the sorghum-based DDGS.

Enzymes had no effect on growth performance ($P > 0.19$), but improved ($P < 0.01$) apparent total tract digestibility of DM, N, and GE, especially for diets with sorghum-based DDGS (DDGS source × enzyme interaction, $P < 0.10$). Others also have demonstrated increased nutrient digestibility with addition of enzymes to diets with DDGS (Opapeju et al., 2006; Emiola et al., 2008). Several researchers reported that enzyme supplementation to DDGS or to cereal grain based diets did not affect growth performance in weanling or growing pigs (Thacker et al., 1989, 1992; Olukosi et al., 2007; Sigfridson and Haraldsson, 2007; Woyengo et al., 2008). However, Pierce and Bannerman (2008) showed that supplementing a diet with enzymes prevented the drop in ADG caused by increasing levels of DDGS in grow-finish pigs.

As for carcass data, the effects of DDGS on growth rate were reflected in lower ($P < 0.002$) HCW for pigs fed diets with DDGS. Also, dressing percentages tended to be lower ($P < 0.06$) for pigs fed diets with sorghum-based DDGS than for pigs fed diets with corn-based DDGS. The greater fiber content in sorghum-based DDGS could have caused heavier digestive tract weights as suggested by Pond et al. (1988) and Anugwa et al. (1989). In a comparison of corn vs sorghum grain diets fed to finishing pigs, Benz (2008) observed that pigs fed sorghum grain diets tended to have 1% lower dressing percentage.

Fat free lean index, backfat thickness, and loin depth were not affected ($P > 0.12$) by DDGS treatment, which is similar to responses observed by others (Senne et al., 1998; Cook et al., 2005). Addition of 40% DDGS increased (*P* < 0.001) IV of jowl fat in our experiment. Other researchers also have reported increased IV of carcass fat in pigs fed diets with DDGS at 5 to 30% of the diet (Whitney et al., 2006; Benz, 2008; Widmer et al., 2008). Diets with corn-based DDGS resulted in greater (*P* < 0.001) iodine value of jowl fat than diets with sorghum-based DDGS.

Addition of enzymes to DDGS diets did not affect carcass measurements. This lack of effect is consistent with results reported by Mavromichalis et al. (2000) and Feoli et al. (2006) when xylanase was added to wheat-based diets and to what Thacker et al. (1989) reported when barley-based diets were supplemented with beta-glucanase.

In conclusion, rate of gain and nutrient digestibility were decreased with addition of DDGS to diets for nursery and finishing pigs. Addition of enzymes partially restored losses in nutrient digestibility but did not have significant positive effects on growth performance or carcass characteristics.

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Table 4.1. Composition of nursery diets (Exp. 1; as-fed basis)

	d 0 to 10		d 10 to 27	
Ingredient, %	Control	DDGS [1]	Control	DDGS
Corn	47.60	27.58	62.86	42.97
DDGS	—	30.00	—	30.00
Soybean meal (47.5% CP)	28.70	19.00	32.60	22.85
Whey	15.00	15.00	—	—
Fishmeal	3.00	3.00	—	—
Spray-dried plasma	2.50	2.50	—	—
Limestone	0.87	1.06	1.11	1.36
Monocalcium phosphate (21% P)	0.62	0.11	1.30	0.67
Salt	0.30	0.30	0.36	0.35
L-lysine HCl	0.21	0.41	0.32	0.53
DL-methionine	0.13	0.03	0.12	0.02
L-threonine	0.02	—	0.09	0.05
Vitamin premix [2]	0.08	0.08	0.11	0.11
Mineral premix [3]	0.07	0.03	0.08	0.05
Antibiotic [4]	0.70	0.70	0.70	0.70
Chromic oxide [5]	—	—	0.25	0.25
Zinc oxide [6]	0.20	0.20	—	—
Copper sulfate [6]	—	—	0.10	0.09
Enzyme [7]	—	—	—	—
Calculated composition				
Lys	1.60	1.60	1.40	1.40
Ca	0.80	0.80	0.75	0.75
Total P	0.70	0.70	0.65	0.65

[1] Distillers dried grains with solubles. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] Supplied per kilogram of complete diet: 3,527 IU vitamin A; 529 IU vitamin D_3; 14.1 IU vitamin E; 1.41 mg vitamin K (as menadione nicotinamide bisulfite); 12.35 μg vitamin B_{12}, 15.87 mg niacin, 8.82 mg pantothenic acid (as calcium pantothenate), and 2.65 mg riboflavin for d 0 to 10 and 4,850 IU vitamin A; 728 IU vitamin D_3; 19.4 IU vitamin E; 1.94 mg vitamin K (as menadione nicotinamide bisulfite); 16.98 μg vitamin B_{12}, 21.83 mg niacin, 12.13 mg pantothenic acid (as calcium pantothenate), and 3.64 mg riboflavin for d 10 to 27.

[3] Supplied per kilogram of complete diet: 7.7 mg Cu, 0.14 mg I, 77.14 mg Fe, 18.48 mg Mn, 0.14 mg Se, and 77.14 mg Zn for the control diet and 3.3 mg Cu, 0.06 mg I, 33.1 mg Fe, 7.9 mg Mn, 0.06 mg Se, and 33.1 mg Zn for the DDGS diets for d 0 to 10; and 8.8 mg Cu, 0.16 mg I,

88.2 mg Fe, 21.1 mg Mn, 0.16 mg Se, and 88.2 mg Zn for the control diet and 5.5 mg Cu, 0.1 mg I, 55.1 mg Fe, 13.2 mg Mn, 0.1 mg Se, and 55.1 mg Zn for the DDGS diets for d 10 to 27.

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

[5] Used as an indigestible marker.

[6] Total Zn concentration for d 0 to 10 was 1,500 mg/kg and total Cu concentration for d 10 to 27 was 250 mg/kg.

[7] Porzyme tp100 (Danisco Animal Nutrition, Copenhagen, Denmark) was added at 0.1% of finished diets in place of corn.

Table 4.2. Composition of finishing diets (Exp. 2; as-fed basis)

	d 0 to 35		d 35 to 65	
Ingredient, %	Control	DDGS [1]	Control	DDGS
Corn	79.72	52.75	81.56	54.67
DDGS	—	40.00	—	40.00
Soybean meal (47.5% CP)	17.80	4.95	16.20	3.25
Limestone	1.09	1.34	1.06	1.24
Monocalcium phosphate (21% P)	0.73	0.05	0.54	—
Salt	0.30	0.30	0.38	0.30
L-lysine HCl	0.20	0.47	0.13	0.40
L-threonine	0.03	—	—	—
Vitamin premix [2]	0.04	0.04	0.04	0.04
Mineral premix [3]	0.04	0.05	0.04	0.05
Antibiotic [4]	0.05	0.05	0.05	0.05
Enzyme [5]	—	—	—	—
Calculated composition				
Lys	0.90	0.90	0.80	0.80
Ca	0.60	0.60	0.55	0.55
Total P	0.50	0.50	0.45	0.45

[1] Distillers dried grains with solubles. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] Supplied per kilogram of complete diet: 1,764 IU vitamin A; 265 IU vitamin D_3; 7.05 IU vitamin E; 0.71 mg vitamin K (as menadione nicotinamide bisulfite); 6.2 μg vitamin B_{12}, 7.9 mg niacin, 4.4 mg pantothenic acid (as calcium pantothenate), and 1.32 mg riboflavin.

[3] Supplied per kilogram of complete diet: 4.4 mg Cu, 0.08 mg I, 44.1 mg Fe, 10.6 mg Mn, 0.08 mg Se, and 44.1 mg Zn for the control diet and 5.5 mg Cu, 0.1 mg I, 55.1 mg Fe, 13.2 mg Mn, 0.1 mg Se, and 55.1 mg Zn for the DDGS diets.

[4] To provide 44 g/ton tylosin.

[5] Porzyme tp100 (Danisco Animal Nutrition, Copenhagen, Denmark) was added at 0.1% of finished diets in place of corn.

Table 4.3. Chemical characteristics of the distillers dried grains with solubles (DDGS; as-fed basis)[1]

Item	Exp. 1		Exp. 2	
	Corn-DDGS	Sorghum-DDGS	Corn-DDGS	Sorghum-DDGS
DM, % [2]	92.2	89.2	92.1	89.6
CP, %	25.9	30.4	26.1	30.5
Ether extract, %	10.1	7.0	10.2	6.8
GE, Mcal/kg	4.86	4.59	4,83	4,62
Ash, %	4.4	3.6	4.8	3.7
Ca, %	0.05	0.08	0.07	0.09
P, %	0.76	0.65	0.77	0.65
Crude fiber, %	6.38	5.32	6.19	6.26
NDF, %	26.70	29.05	25.74	29.62
ADF, %	7.15	10.08	7.07	10.42
ADL, %	0.78	1.74	0.78	1.84
Cellulose, % [3]	6.40	8.34	6.30	8.58
Pentosans, %				
Soluble	0.61	0.83	0.68	0.82
Insoluble	10.60	6.59	9.60	7.20
Starch, %	5.50	6.96	4.63	5.30

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[1] Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD and sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] DM (NFTA 2.2.2.5), CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), crude fiber (AOAC 962.09), ash (AOAC 942.05), Ca (AOAC 927.02), P (AOAC 965.17), starch (AOAC 979.10; AOAC, 1995). GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). NDF, ADF, and ADL were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

[3] Cellulose = ADF – ADL

Table 4.4. Effects of adding enzymes to diets with corn- and sorghum-based distillers dried grains with solubles (DDGS) on growth performance and nutrient digestibility in nursery pigs[1]

		Corn-DDGS[2]		Sorghum-DDGS[3]			*P* value			
Item	Control	w/o enzyme	w/ enzyme[4]	w/o enzyme	w/ enzyme	SE	Cont. vs DDGS	DDGS source effect	Enzyme effect	DDGS × Enzyme
d 0 to 10										
ADG, g	501	426	448	495	462	22	0.003	0.002	—[5]	0.02
ADFI, g	606	520	526	598	560	27	0.001	0.001	—	0.07
G:F, g/kg	827	819	852	828	825	10	—	—	—	0.08
d 0 to 27										
ADG, g	576	526	542	546	521	18	0.001	—	—	0.04
ADFI, g	824	742	747	815	772	28	0.001	0.001	0.15	0.08
G:F, g/kg	699	709	726	670	675	7	—	0.001	0.08	—
Apparent digestibilities, %[6]										
DM, %	80.4	75.0	76.7	75.6	76.3	0.5	0.001	—	0.04	—
N, %	75.9	75.5	76.4	68.5	68.2	1.0	0.003	0.001	—	—
GE, %	78.4	73.6	75.0	72.6	72.9	0.7	0.001	0.04	—	—

[1] A total of 180 nursery pigs (6 pigs/pen and 6 pens/treatment) with an average initial BW of 7.5 kg and average age of 31 d.

[2] Supplied by Sioux River Ethanol, Hudson, SD.

[3] Supplied by U.S. Energy Partners, Russell, KS.

[4] Porzyme tp100 supplied by Danisco Animal Nutrition, Copenhagen, Denmark is a cocktail of endo-1,3(4)-beta-glucanase, subtilisin protease, alpha-amylase, and endo-1,4-beta-xylanase.

[5] Dashes indicate *P* > 0.15.

[6] Fecal samples for digestibility determinations were collected on d 15 and 16 with chromic oxide used as an indigestible marker.

Table 4.5. Effects of adding enzymes to diets with corn- and sorghum-based distillers dried grains with solubles (DDGS) on growth performance, nutrient digestibility, and carcass characteristics in finishing pigs[1]

		Corn-DDGS[2]		Sorghum-DDGS[3]			*P* value			
Item	Control	w/o enzyme	w/ enzyme[4]	w/o enzyme	w/ enzyme	SE	Cont. vs DDGS	DDGS source effect	Enzyme effect	DDGS × Enzyme
d 0 to 35										
ADG, g	1,010	858	869	892	905	35	0.001	0.06	—[5]	—
ADFI, kg	2.95	2.53	2.54	2.71	2.78	0.08	0.001	0.001	—	—
G:F, g/kg	342	339	342	329	326	11	0.10	0.02	—	—
d 0 to 65										
ADG, g	970	868	861	887	887	30	0.001	0.13	—	—
ADFI, kg	3.04	2.72	2.78	2.92	2.97	0.12	0.008	0.004	—	—
G:F, g/kg	319	319	310	304	299	7	0.07	0.03	—	—
Apparent digestibilities, %[6]										
DM	84.5	77.5	79.1	73.0	78.5	1.1	0.001	0.04	0.004	0.10
N	78.0	76.1	77.5	62.3	70.0	1.3	0.001	0.001	0.002	0.02
GE	82.9	76.7	77.9	70.3	75.6	1.1	0.001	0.001	0.01	0.09
HCW, kg	90.6	85.7	83.5	85.1	85.3	3.1	0.002	—	—	—
Dressing, %[7]	73.0	72.7	72.7	72.1	72.3	0.2	0.11	0.06	—	—
FFLI, %[7,8]	53.2	53.2	53.3	53.5	53.7	0.9	—	—	—	—
Backfat thickness, mm[7]	16.5	16.1	16.1	15.8	15.3	1.3	—	—	—	—
Loin depth, mm[7]	59.3	57.1	57.0	58.3	57.0	0.9	0.12	—	—	—
Iodine value[7,9]	70.3	80.4	80.1	74.6	74.3	0.7	0.001	0.001	—	—

[1] A total of 330 finishing pigs (11 pigs/pen and 6 pens/treatment) with an average initial BW of 64 kg.

[2] Supplied by Sioux River Ethanol, Hudson, SD.

[3] Supplied by U.S. Energy Partners, Russell, KS.

[4] Porzyme tp100 supplied by Danisco Animal Nutrition, Copenhagen, Denmark is a cocktail of endo-1,3(4)-beta-glucanase, subtilisin protease, alpha-amylase, and endo-1,4-beta-xylanase.

[5] Dashes indicate $P > 0.15$.

[6] Fecal samples were collected mid-experiment with chromic oxide used as an indigestible marker.

[7] HCW used as a covariate.

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

[9] As calculated from fatty acid profile of jowls (AOCS Cd 1c-85 Official Method).

CHAPTER 5 - Effects of expander conditioning on the nutritional value of diets with distillers dried grains with solubles in nursery and finishing pigs

ABSTRACT: Three experiments were conducted to determine the effects of expander conditioning on nutritional value of diets without and with corn- and sorghum-based distillers dried grains with solubles (DDGS). In Exp. 1, 180 nursery pigs (average BW of 13 kg) were assigned to 30 pens. Treatments were arranged as a 3 × 2 factorial with main effects of diet formulation (corn-soybean meal vs 30% corn- and sorghum-based DDGS) and conditioning (standard steam vs expander) prior to pelleting. Pigs fed corn-soy had better ADG, ADFI, G:F, and digestibility of DM, N, GE, NDF, ADF, and ADL ($P < 0.04$) than pigs fed diets with DDGS. Diets with corn-based DDGS supported better ADG, G:F, and digestibility of DM, N, and ADL than diets with sorghum-based DDGS ($P < 0.03$), but worse digestibility of NDF and cellulose ($P < 0.004$). Expander processing improved ($P < 0.02$) ADG, G:F, and digestibility of DM, N, GE, NDF, ADF, and cellulose compared with standard conditioning, with the greatest response in G:F for pigs fed diets with sorghum-based DDGS (DDGS source × conditioning; $P < 0.02$). In Exp. 2, 176 finishing pigs (average BW of 75 kg) were assigned to 16 pens. Treatments were arranged as a 2 × 2 factorial with main effects of diet formulation (corn-soy vs 40% sorghum-based DDGS) and conditioning (standard steam vs expander) prior to pelleting. Net electrical energy required for feed processing was lower ($P < 0.001$) and production rate was greater ($P < 0.005$) for the corn-soy diets than for diets with DDGS, but pellet durability was improved ($P < 0.001$) by addition of DDGS to the diets. Pigs fed corn-soy diets had better overall ADG and G:F than pigs fed diets with DDGS ($P < 0.03$). Expander conditioning improved overall G:F and dressing percentage ($P < 0.007$). In Exp. 3, 192 finishing pigs (average BW of 101 kg) were assigned to 16 pens for a 8-d nutrient digestibility determination. Treatments were the same as in Exp. 2. Corn-soybean meal diets had greater digestibility of DM, N, GE, and cellulose than diets with DDGS ($P < 0.001$), but lower digestibility of NDF and ADL ($P < 0.001$). Expander conditioning improved ($P < 0.02$) digestibility of DM, N, and GE with the greatest improvement in digestibility of DM for the DDGS diets (diet × conditioning, $P < 0.01$). However, expanding decreased ($P < 0.03$) digestibility of fiber compared with standard conditioning. In conclusion, expanding diets improved ADG, G:F, and nutrient digestibility in nursery pigs and G:F, dressing percentage, and nutrient digestibility in finishing pigs fed diets without and with DDGS.

Key Words: carcass characteristics, digestibility, distillers dried grain with solubles, expander conditioning, growth performance, pig.

INTRODUCTION

The U.S. Renewable Fuel Standard mandates that 15 billion gallons of ethanol from grain starch will be needed by 2015. This is 40% more than currently produced it seems certain that coproducts from the ethanol industry, such as distillers dried grains with solubles (DDGS), will continue to increase in supply. Our previous results (Feoli et al., 2008a) suggested that high levels of DDGS in diets for nursery and finishing pigs had negative effects on nutrient digestibility and growth rate.

Pelleting improves growth performance in pigs as well as reduces or eliminates bacteria and fungi found in the feed (Hancock and Behnke, 2001; Fairfield et al., 2005). An expander is a conditioning device that takes feed to higher temperature and pressure than standard steam conditioning prior to pelleting. Other experiments from our laboratory demonstrated that conditioning wheat midds-based diets (high in fiber) in an expander prior to pelleting improved nutrient digestibility in finishing pigs (Traylor et al., 1999). However, the effects of feed processing with high shear conditioning techniques on pig diets with DDGS have not been evaluated. Therefore, the objective of the present experiments was to determine the effects of expander conditioning on the nutritional value of nursery and finishing pig diets without and with DDGS.

MATERIALS AND METHODS

General

The DDGS sources were corn-based DDGS from Sioux River Ethanol, Hudson, SD and sorghum-based DDGS from US Energy Partners, Russell, KS. A 1-kg sample of each DDGS shipment was collected and analyzed for DM (NFTA Method 2.2.2.5), CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL), and ash (AOAC 942.05). Fiber components (NDF, ADF, and ADL) were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY). Cellulose was estimated by subtraction of ADL from ADF. Additionally, tannin content was evaluated using the modified vanillin hydrochloric method as described by Earp et al. (1981) with a UV-vis spectrophotometer (Spectronic 20; Thermo Fisher Scientific Inc., Madison, WI).

Experiment 1

One hundred eighty nursery pigs (PIC line TR4 × 1050) were weighed at an average age of 28 d (average BW of 7.9 kg), sorted by sex and ancestry, blocked by weight, assigned to pens and fed a common diet for 14 d until the start of the experiment[1]. There were 6 pigs/pen (3 barrows and 3 gilts) and 5 pens/treatment. The pigs were housed in an environmentally

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[1] The animal care and management used in these experiments were approved by the Kansas State University Animal Care and Use Committee.

controlled nursery having 1.22-m × 1.22-m pens with woven-wire flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

When the pigs were at an average age of 42 d (average BW of 13.1 kg) treatments were assigned and the experimental diets were fed for 14 d. Treatments were arranged as a 3 × 2 factorial with main effects of diet formulation (corn-soybean meal vs diets with 30% corn-based DDGS from Sioux River Ethanol, Hudson, SD, and 30% sorghum-based DDGS from U.S. Energy Partners, Russell, KS) and conditioning (standard steam vs expander) prior to pelleting. The diets (Table 5.1) were formulated to 1.4% Lys, 0.75% Ca, and 0.65% P. All other nutrients met or exceeded NRC (1998) recommendations for nursery pigs. Chromic oxide (0.25%) was added to the diets to allow determination of nutrient digestibility.

The diets were mixed for 5 min in a horizontal paddle mixer and then either steam conditioned to 82°C using a conditioner (30.48-cm diameter and 122-cm length custom made Bliss conditioner, Bliss Industries, Ponca City, OK) or expanded conditioned using a 100 hp Amandus-Kahl expander at 150ºC. The conditioned mash was then passed through a pelleting press (30 HD Master Model, California Pellet Mill, San Francisco, CA) equipped with a 22-mm-thick die having 4-mm openings. Voltage and cone pressure of the expander were kept constant at 250 volts and 14 kg/cm^2, respectively. Samples of the processed diets were collected and pellet durability index (PDI) was determined (tumbling-box technique, ASAE S269.4 DEC1991). Additionally, the PDI procedure was modified to induce more stress on the pellets by adding five 12.7-mm hexagonal nuts into the tumbling box.

Pigs and feeders were weighed on d 0 and 14 to allow calculation of ADG, ADFI, and G:F. Feces were collected via rectal massage on d 4 and 5 from no less than 3 pigs/pen. The fecal samples were pooled within pen and kept frozen at -15ºC until dried in an oven (50ºC), ground, homogenized, and stored in a freezer. Feed and feces were analyzed for concentrations of DM (NFTA Method 2.1.2), N (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL), NDF, ADF, and ADL (fiber fractions were analyzed using an ANKOM 200 fiber analyzer; ANKOM Technology Corp., Fairport, NY). Cellulose was estimated by subtraction of ADL from ADF. Chromium concentrations in the feed and feces were determined using an atomic absorption spectrophotometer (Perkin Elmer 3110) according to the procedure of Williams et al. (1962) and used to calculate apparent digestibilities using the indirect ratio method.

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC). Initial body weight was used as a covariate with BW at 28 d of age as the blocking criterion and pen as the experimental unit. Orthogonal contrasts were used to separate treatment means with comparisons of: 1) corn-soybean meal vs DDGS diets, 2) corn- vs sorghum-based DDGS, 3) standard vs expander conditioning, 4) corn-soybean meal vs DDGS × standard vs expander conditioning, and 5) corn- vs sorghum-based DDGS × standard vs expander conditioning.

Experiment 2

One hundred seventy six finishing pigs (PIC line TR4 × 1050), with an average initial BW of 74.6 kg, were used in a 54-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, with gilts and barrows penned separately. The pigs were housed in an environmentally controlled finishing facility having 1.83-m × 4.88-m pens with concrete flooring that was half solid and half slatted. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water.

Treatments were arranged as a 2 × 2 factorial with main effects of diet formulation (corn-soybean meal vs 40% sorghum-based DDGS) and conditioning (standard steam vs expander) prior to pelleting. The experimental diets (Table 5.2) were formulated to 0.90% Lys, 0.60% Ca, and 0.50% P for d 0 to 26, and 0.80% Lys, 0.55% Ca, and 0.45% total P for d 26 to 54. All other nutrients met or exceeded NRC (1998) recommendations for a genotype growing at about 325 g of lean/d. Feed was processed as in Exp. 1, but 6 batches of feed were made, and more extensive processing data were collected. Voltage and cone pressure of the expander were kept constant at 250 volts and 14 kg/cm^2, respectively. Then, motor load and production rate for the pellet mill, net electrical consumption for the pellet mill and the expander, and PDI were measured and analyzed as a randomized complete block design by using the MIXED procedure of SAS with batch as the blocking criterion. Orthogonal contrasts for a 2 × 2 factorial were used to separate means for the main effects of diet formulation and conditioning.

Pigs and feeders were weighed on d 0, 26, and 54 to allow calculation of ADG, ADFI, and G:F. The pigs were tattooed on d 54 (average BW of 130 kg) and shipped to a commercial abattoir (Farmland, Crete, NE) for slaughter the following morning. 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).

Growth performance and carcass data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial weight as the blocking criterion and pen as the experimental unit. Because differences in slaughter weight and, thus, HCW are known to affect carcass measurements, HCW was used as a covariate for analyses of dressing percentage, FFLI, backfat thickness, and loin depth to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight. Orthogonal contrasts for a 2 × 2 factorial were used to separate treatment means with main effects of diet formulation and conditioning.

Experiment 3

One hundred ninety two finishing pigs (PIC line TR4 × 1050), with an average initial BW of 101 kg, were used in an 8-d digestibility determination. The pigs were sorted by sex and ancestry, blocked by weight, and assigned to pens. There were 12 pigs/pen and 4 pens/treatment, with gilts and barrows penned separately. The pigs were housed in an environmentally controlled finishing facility having 1.83-m × 4.88-m pens with concrete flooring that was half solid and half slatted. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water with pigs and feeders weighed on d 0 and 8.

Treatments and diets were the same as in Exp. 2. Chromic oxide (0.25%) was added to the diets as an indigestible marker and mid-experiment, fecal samples were collected via rectal massage from no less than 6 pigs/pen, pooled within pen, and handled as in Exp. 1. Concentrations of DM, N, GE, NDF, ADF, ADL, cellulose, and Cr in the diets and feces were determined to allow calculation of apparent nutrient digestibility.

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial weight as the blocking criterion and pen as the experimental unit. Orthogonal contrasts for a 2 × 2 factorial were used to separate treatment means with main effects of diet formulation and conditioning.

RESULTS AND DISCUSSION

Analyses of the DDGS (Table 5.3) demonstrated that corn-based DDGS had lower CP and fiber with greater fat content than the sorghum-based DDGS. As per variability between samples of the sorghum-based DDGS from each experiment, most of the nutrients had a 5% CV, except for the fat content that varied 10% among samples. Variability in composition of the corn-based DDGS was not determined because only one shipment was used for our experiments. Measurement of tannin content revealed zero catechin equivalents for the sources of DDGS used in these experiments, indicating no likelihood of growth performance to be affected by the presence of tannins. In Exp. 1 (Table 5.4), diets with DDGS had greater CP, fat, and GE than the corn-soybean meal diets, but also greater fiber content.

Experiment 1

In this nursery experiment (Table 5.5), the corn-soybean meal diets supported better ADG, ADFI, G:F, and digestibility of DM, N, GE, NDF, ADF, and ADL ($P < 0.04$), than diets with DDGS. The detrimental effects of high inclusion levels of DDGS in growth rate are in agreement with data we have reported (Feoli et al., 2007c; Feoli et al., 2008a).

Pigs fed diets with corn-based DDGS had better ADG, G:F, and digestibilities of DM, N, and ADL than pigs fed diets with sorghum-based DDGS ($P < 0.03$), but poorer digestibilities of NDF and cellulose ($P < 0.004$). The decreased efficiency of gain of nursery pigs fed diets with sorghum-based DDGS, and no apparent effect with corn-based DDGS, has been observed before (Feoli et al., 2007c; Feoli et al., 2008a) and seems to be related to the lower digestible energy content value of the sorghum-based DDGS compared to the corn-based DDGS (Feoli et al., 2007a). When comparing the cereal grains, Healy et al. (1994) determined that corn had greater digestibilities of GE and N than sorghum when both grains were ground to an optimum particle size of 500 μm and fed to nursery pigs. In contrast, when corn-vs sorghum-based diets were fed to finishing pigs and sows, there was greater digestibility of N but no difference in digestibilities of DM or GE (Johnston et al., 1999a).

Expander conditioning improved ($P < 0.02$) ADG, G:F, and digestibilities of DM, N, GE, NDF, ADF, and cellulose compared with standard steam conditioning regardless of diet formulation. This effect in nutrient utilization is in agreement with a previous publication evaluating standard vs expander conditioning of nursery diets under very similar circumstances to ours (Johnston et al., 1999c). However, in their study, similarly to Hongtrakul et al. (1998) and Lundblad et al. (2007), the authors did not find significant differences in ADG and G:F between standard and expander conditioning of nursery diets.

Pigs fed diets with sorghum-based DDGS had greater improvement in G:F with expander conditioning than pigs fed diets with corn-based DDGS (DDGS source × conditioning; $P < 0.02$), similar to what Johnston et al. (1999a) found when they fed expanded sorghum grain diets to sows. In their study, sows fed sorghum diets responded more to expander conditioning of the diet by having greater sow weight gain than sows fed expanded corn diets.

Expander conditioning tended to improve digestibility of DM mostly in diets with DDGS as indicated by the diet formulation × conditioning interaction ($P < 0.08$). This could be related with the greater response in fiber digestibility of diets with DDGS to expander conditioning. Due to the greater content of cellulose in diets with DDGS, absolute cellulose digestion was greater for these diets than for corn-soybean meal diets. Total apparent digestibility of cellulose was greater for corn-based DDGS diets than for diets with sorghum-based DDGS (DDGS source × conditioning; $P < 0.05$).

Experiment 2

Milling data (Table 5.6) for the finishing diets used in Exp. 2 indicated that addition of 40% DDGS decreased pellet mill throughput (i.e., production rate) and increased energy used in the pelleting process ($P < 0.005$). The mechanical energy inputs to convey the feed mash when there is material buildup in the expander to obtain high pressure results in greater energy expenditure of expanding vs standard pelleting. The effect in throughput could be related to the lower bulk density of our diets with high inclusion of DDGS (0.59 vs 0.52 g/cm^3 for the corn-soybean meal and the DDGS diets prior to conditioning, respectively; data not shown), requiring more time per unit of weight to go through the system because all the feeding conveyors were set to a constant speed. Similar differences in bulk density were observed by Wang et al. (2008) when adding high levels of DDGS to poultry diets. This could indicate that increasing speed of feeding conveyors when manufacturing diets with DDGS could result in better production rate relative to a corn-soybean meal diet.

Contrary to some reports in finishing pig (Stender and Honeyman, 2008) and poultry (Min et al., 2008) diets with 20% or more DDGS, our findings indicate that under the conditions of this experiment, adding 30 or 40% DDGS to pig diets improved PDI ($P < 0.001$). This result was consistent in both nursery and finishing diets and for every batch of feed that was manufactured, regardless of the source of DDGS. However, because of the lower starch and the greater oil content of DDGS compared to corn grain (i.e., the degree of gelatinization is lower and has hydrophobic properties), the bonding potential of DDGS when forming a pellet is expected to be reduced (Behnke, 2007). Expander conditioning further increased pellet durability compared to standard steam conditioning regardless of the diet formulation, in agreement with data from Johnston et al. (1999a,c) and Traylor (1999). However, the corn-soybean meal diets had more room for improvement in PDI when expander conditioned than DDGS diets, as indicated by the diet × conditioning interaction ($P < 0.007$). Standard PDI of corn-soybean meal diets increased from 76 to 91% with expander conditioning and the DDGS diets already had a high PDI and still increased from 88 to 96%. It could be presumed that the greater starch content and, therefore, greater gelatinization of corn compared to DDGS would be responsible for this response in pellet quality to the expander technique.

As for pig growth (Table 5.7), adding 40% DDGS to diets for finishing pigs reduced ($P < 0.03$) overall ADG, ADFI, and G:F, in agreement with data reported by Senne et al. (1998), Whitney et al. (2006), and Feoli et al. (2007b,c,d; 2008a,b,c). These responses in growth performance to addition of high levels of DDGS could be partially explained by reduced feed consumption, but also to poorer nutrient digestibility. Like in the nursery experiment, high inclusion of DDGS in finishing diets decreased digestibility coefficients of DM, N, GE, and cellulose, in agreement with data of Feoli et al. (2008a) for nursery pigs and of Senne et al. (1998), Nyachoti et al. (2005), Stein et al. (2006), Pedersen et al. (2007), and Feoli et al. (2007a,b; 2008a) for growing or finishing pigs. Conversely, digestibility of fiber in finishing pigs was greater for pigs fed DDGS than for pigs fed the corn-soybean meal diets, in contrast to what was observed with nursery pigs. This could possibly be related with the adaptation of microbial population in the hindgut of finishing pigs to digest more fibrous materials as the dietary concentration increases. It has been shown that digestibility coefficients of DM, GE, CP, and fat decrease with increasing levels of fiber in the diet (Owusu-Asiedu et al., 2006; Wilfart et al., 2007); as would be the case in diets with 30 or 40% DDGS.

Expander conditioning improved ($P < 0.002$) G:F for diets with and without DDGS and our findings are in agreement with Hancock et al. (1996), but in contrast with other data that did not find any effects of expanding corn or sorghum diets on growth performance of finishing pigs (Johnston et al., 1999a).

Pigs had lower ($P < 0.001$) HCW when fed diets with 40% DDGS as a result of the effects of DDGS on ADG, in agreement with Whitney et al. (2006) and Feoli et al. (2007b,d). Even when corrected to a constant HCW (via covariate analysis), dressing percentage ($P < 0.03$) and loin depth ($P < 0.06$) were greater for pigs fed the corn-soybean meal diets than for pigs fed the DDGS treatments. This response to addition of DDGS in dressing percentage have been confirmed by other researchers (Cook et al., 2005; Benz, 2008; Linneen et al., 2008; Weimer et al., 2008) and it could be related to heavier visceral weight, as observed by Weimer et al. (2008), because of greater content of dietary fiber (Pond et al., 1988; Anugwa et al., 1989). However, the effects on loin depth are conflicting. While we observed a trend for a decrease in loin depth, similar to Whitney et al. (2006) and Feoli et al. (2007b), others found no effect (Senne et al., 1998; Cook et al., 2005; Feoli et al., 2008a). However, half the loss in HCW and all the loss in dressing percentage were recovered when diets with DDGS were expander processed prior to pelleting.

Experiment 3

Diets for Exp. 3 (Table 5.8) have lower moisture content when expanded conditioned than when standard conditioned, this could be related with the greater temperature of the pellets after conditioning which facilitated the drying process. Likewise diets for Exp. 1, expanded conditioned finishing diets had lower fat content. Expander conditioned also altered the fiber content, but mainly for DDGS-based diets. Similarly to the nursery diets in Exp. 1, diets with DDGS had greater CP, fat, and GE than the corn-soybean meal diets, but also greater fiber content.

Digestibility of DM, N, and GE in finishing pigs (Table 5.9) was greater ($P < 0.001$) for pigs fed diets without DDGS and this finding is consistent to previous reports (Feoli et al., 2007b, 2008a). Contrary to what was observed for nursery pigs in Exp. 1, finishing pigs had greater digestibility of NDF and ADL for DDGS diets than for corn-soybean meal diets ($P < 0.001$). The coefficient for cellulose digestibility decreased with addition of DDGS to the diets ($P < 0.001$); however, due to the greater content of cellulose in diets with DDGS, pigs fed DDGS digested a greater amount of cellulose than pigs fed the control diets. Expander conditioning improved ($P < 0.02$) digestibilities of DM, N, and GE compared with standard conditioning, but digestibility of DM was improved with expander conditioning only in the DDGS diets (diet × conditioning, $P < 0.01$). Johnston et al. (1999a,b,c), Traylor et al. (1999), and Kim (2002) also observed improved nutrient digestibility when corn and sorghum grain diets were expander conditioned. Martinez Amezcua et al. (2004) reported an improvement on P digestibility in broiler chicks when fed diets with DDGS that had been autoclaved at 121ºC for at least 60 min. This might be an indication that harsh conditions (i.e., cone pressure and high temperature) could improve nutrient bioavailability in DDGS contributing to greater overall nutrient utilization.

In contrast with our findings in Exp. 1, finishing pigs had poorer digestibility of fiber (NDF, ADF, ADL, and cellulose) with expander conditioning than with standard conditioning ($P < 0.03$). Some authors (Björck et al., 1984; Siljeström et al., 1986) have determined that diets with high levels of fiber tended to redistribute the fiber towards the insoluble fraction when diets were submerged to extrusion conditions, being one of the factors that contribute to greater digestibility. Although we did not test specifically for solubility, our data do not show any improvement in fiber digestibility in finishing pigs with the use of expander conditioning. However, the positive effects on nutrient digestibility by expander conditioning could be affecting digestive tract weight, leading to an improvement in dressing percentage when pigs were fed expanded diets. This response in dressing percentage by the use of the expander conditioning technique compensated the loss by the addition of DDGS.

In conclusion, adding 30 and 40% DDGS to nursery and finishing diets decreased growth performance and nutrient digestibility compared with a corn-soybean meal control. However, expanding diets improved ADG, G:F, and nutrient digestibility in nursery pigs and G:F, dressing percentage, and digestibilities of DM, N, and GE in finishing pigs fed diets without and with DDGS.

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Table 5.1. Composition of nursery diets (Exp. 1; as-fed basis)

Ingredient, %	Control	DDGS[1]
Corn	62.86	42.97
DDGS	—	30.00
Soybean meal (47.5% CP)	32.60	22.85
Limestone	1.11	1.36
Monocalcium phosphate (21% P)	1.30	0.67
Salt	0.36	0.35
L-lysine HCl	0.32	0.53
DL-methionine	0.12	0.02
L-threonine	0.09	0.05
Vitamin premix [2]	0.11	0.11
Mineral premix [3]	0.08	0.05
Antibiotic [4]	0.70	0.70
Chromic oxide [5]	0.25	0.25
Copper sulfate [6]	0.10	0.09
Calculated composition		
Lys	1.40	1.40
Ca	0.75	0.75
Total P	0.65	0.65

[1] Distillers dried grains with solubles. Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] Supplied per kilogram of complete diet: 4,850 IU vitamin A; 728 IU vitamin D_3; 19.4 IU vitamin E; 1.94 mg vitamin K (as menadione nicotinamide bisulfite); 16.98 μg vitamin B_{12}, 21.83 mg niacin, 12.13 mg pantothenic acid (as calcium pantothenate), and 3.64 mg riboflavin.

[3] Supplied per kilogram of complete diet: 8.8 mg Cu, 0.16 mg I, 88.2 mg Fe, 21.1 mg Mn, 0.16 mg Se, and 88.2 mg Zn for the control diet and 5.5 mg Cu, 0.1 mg I, 55.1 mg Fe, 13.2 mg Mn, 0.1 mg Se, and 55.1 mg Zn for the DDGS diets.

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

[5] Used as an indigestible marker.

[6] Total Cu concentration in the diet was 250 mg/kg.

Table 5.2. Composition of finishing diets (Exp. 2 and 3; as-fed basis)

	d 0 to 26		d 26 to 54	
Ingredient, %	Control	DDGS[1]	Control	DDGS
Corn	79.63	52.67	81.22	54.29
DDGS	—	40.00	—	40.00
Soybean meal (47.5% CP)	17.80	4.95	16.20	3.30
Limestone	1.09	1.34	1.06	1.24
Monocalcium phosphate (21% P)	0.73	0.05	0.54	—
Salt	0.30	0.30	0.38	0.30
L-lysine HCl	0.20	0.47	0.13	0.40
L-threonine	0.03	—	—	—
Vitamin premix [2]	0.12	0.12	0.12	0.12
Mineral premix [3]	0.05	0.05	0.05	0.05
Antibiotic [4]	0.05	0.05	0.05	0.05
Chromic oxide [5]	—	—	0.25	0.25
Calculated composition				
Lys	0.90	0.90	0.80	0.80
Ca	0.60	0.60	0.55	0.55
Total P	0.50	0.50	0.45	0.45

[1] Distillers dried grains with solubles. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] Supplied per kilogram of complete diet: 3,527 IU vitamin A; 529 IU vitamin D_3; 14.11 IU vitamin E; 1.41 mg vitamin K (as menadione nicotinamide bisulfite); 12.3 µg vitamin B_{12}, 15.9 mg niacin, 8.8 mg pantothenic acid (as calcium pantothenate), 2.65 mg riboflavin, 0.26 mg folic acid, 0.79 mg pyridoxine, 88.2 mg choline, and 0.035 mg biotin.

[3] Supplied per kilogram of complete diet: 5.5 mg Cu, 99 µg I, 55.1 mg Fe, 13.2 mg Mn, 99 µg Se, and 55.1 mg Zn.

[4] To provide 44 g/ton tylosin.

[5] Used as an indigestible marker.

Table 5.3. Chemical characteristics of the distillers dried grains with solubles (DDGS; as-fed basis)[1]

Item	Exp. 1		Exp. 2	Exp. 3
	Corn-DDGS	Sorghum-DDGS	Sorghum-DDGS	Sorghum-DDGS
DM, % [2]	92.2	90.0	90.8	90.4
CP, %	26.3	29.5	31.1	28.0
Ether extract, %	10.2	7.0	8.3	8.6
GE, kcal/kg	4,832	4,578	4,673	4,527
Ash, %	4.4	3.6	3.7	3.5
NDF, %	24.8	29.1	29.7	26.9
ADF, %	7.0	10.1	10.5	9.6
ADL, %	0.8	1.7	1.9	1.8
Cellulose, % [3]	6.2	8.4	8.7	7.8

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[1] Corn-based DDGS supplied by Sioux River Ethanol, Hudson, SD and sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] DM (NFTA 2.2.2.5), CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), ash (AOAC 942.05; AOAC, 1995). GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). NDF, ADF, and ADL were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

[3] Cellulose = ADF – ADL.

Table 5.4. Chemical composition of nursery diets (Exp. 1; as-fed basis)

	Corn-soybean meal		Corn-based DDGS[1]		Sorghum-based DDGS[2]	
Item	Std[3]	Exp[4]	Std	Exp	Std	Exp
DM, %[5]	89.5	88.7	89.8	89.8	89.1	89.4
CP, %	21.0	21.3	22.4	22.8	23.9	24.2
Ether extract, %	2.4	2.2	4.8	4.1	4.1	2.3
GE, kcal/kg	4,132	4,393	4,395	4,309	4,381	4,281
Ash, %	6.8	6.6	6.0	5.9	5.6	6.1
NDF, %	10.6	10.5	15.2	14.6	14.5	14.5
ADF, %	3.7	3.8	4.7	4.6	5.0	4.9
ADL, %	0.8	0.8	0.9	0.8	0.8	0.9
Cellulose, %[6]	2.9	3.0	3.8	3.8	4.2	4.0

[1] Supplied by Sioux River Ethanol, Hudson, SD.

[2] Supplied by U.S. Energy Partners, Russell, KS.

[3] Standard conditioning prior to pelleting.

[4] Expander conditioning prior to pelleting.

[5] DM (NFTA 2.1.4), CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), and ash (AOAC 942.05; AOAC, 1995). GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). NDF, ADF, and ADL were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

[6] Cellulose = ADF – ADL

Table 5.5. Effects of expander conditioning of diets with corn- and sorghum-based distillers dried grains with solubles (DDGS) on growth performance and nutrient digestibility in nursery pigs[1]

	Corn-soybean meal		Corn-based DDGS[2]		Sorghum-based DDGS[3]			Contrasts[4]				
Item	Std[5]	Exp[6]	Std	Exp	Std	Exp	SE	1	2	3	4	5
PDI, %[7]	88.5	94.9	93.0	95.0	91.9	96.6						
ADG, g	670	719	605	655	548	632	16	0.001	0.02	0.002	—[8]	—
ADFI, g	973	1,011	874	928	937	940	22	0.001	0.09	—	—	—
G:F, g/kg	689	711	692	706	585	672	14	0.004	0.001	0.009	—	0.02
Apparent digestibilities, %[9]												
DM	82.5	83.7	76.9	79.9	76.4	78.3	0.4	0.001	0.03	0.001	0.08	—
N	78.3	81.5	76.4	79.6	70.1	73.4	0.7	0.001	0.001	0.001	—	—
GE	81.2	83.8	76.5	78.4	75.6	77.3	0.5	0.001	0.09	0.001	—	—
NDF	50.5	51.9	40.2	47.9	50.2	52.4	1.8	0.04	0.001	0.02	—	0.15
ADF	48.6	53.0	39.1	48.2	45.8	47.4	2.3	0.009	—	0.02	—	0.12
ADL	58.5	65.3	56.2	59.0	35.4	41.7	3.4	0.001	0.001	0.06	—	—
Cellulose	46.0	49.6	34.9	45.7	47.6	48.6	2.3	0.10	0.004	0.02	—	0.05

[1] A total of 180 nursery pigs (6 pigs/pen and 5 pens/treatment) with an average initial BW of 13.1 kg and average age of 42 d.

[2] Supplied by Sioux River Ethanol, Hudson, SD.

[3] Supplied by U.S. Energy Partners, Russell, KS.

[4] Contrasts were (1) corn-soybean meal vs DDGS diets, (2) corn- vs sorghum-based DDGS, (3) standard vs expander conditioning, (4) corn-soybean meal vs DDGS × standard vs expander conditioning, and (5) corn- vs sorghum-based DDGS × standard vs expander conditioning.

[5] Standard conditioning prior to pelleting.

[6] Expander conditioning prior to pelleting.

[7] Pellet durability index (ASAE S269.4 DEC1991).

[8] Dashes indicate $P > 0.15$.

[9] Fecal samples for digestibility determinations were collected on d 4 and 5 with chromic oxide used as an indigestible marker.

Table 5.6. Effects of expander conditioning of finishing diets with sorghum-based distillers dried grains with solubles (DDGS) on pelleting efficiency (Exp. 2)[1]

	Corn-soybean meal		DDGS			*P* value		
Item	Std[2]	Exp[3]	Std	Exp	SE	Diet effect	Cond. effect	Diet × Cond.
Conditioning temp, °C[4]	82.7	117.5	83.2	157.4	2.2	0.001	0.001	0.001
Amperage, amps	19.0	18.9	17.4	16.2	0.3	0.001	0.03	0.04
Motor load, %	33.5	30.0	29.8	28.2	1.4	0.05	0.07	—[5]
Production rate, kg/h	1,158	1,158	1,004	1,049	51	0.005	—	—
Net energy, kWh/t	9.6	41.9	10.1	53.8	1.6	0.001	0.001	0.001
Pellet durability								
Standard, %[6]	76.3	90.8	87.7	96.0	1.3	0.001	0.001	0.007
Modified, %[7]	69.6	88.8	85.2	95.5	1.6	0.001	0.001	0.002

[1] Each diet was replicated by manufacturing a new batch of feed 6 times.

[2] Standard conditioning prior to pelleting.

[3] Expander conditioning prior to pelleting.

[4] Measured at the exit of the standard conditioner and at the expander cone.

[5] Dashes indicate *P* > 0.15.

[6] Pellet durability index (ASAE S269.4 DEC1991).

[7] Modified by adding 5 hexagonal nuts (12.7-mm diameter) to the tumbling box.

Table 5.7. Effects of expander conditioning of diets with sorghum-based distillers dried grains with solubles (DDGS) on growth performance and carcass characteristics in finishing pigs[1]

	Corn-soybean meal		DDGS			*P* value		
Item	Std[2]	Exp[3]	Std	Exp	SE	Diet effect	Condit. effect	Diet × Cond.
d 0 to 26								
ADG, g	1,102	1,117	1,005	1,020	38	0.02	—[4]	—
ADFI, kg	3.07	2.93	2.82	2.75	0.14	0.004	0.09	—
G:F, g/kg	359	381	356	371	10	—	—	—
d 0 to 54								
ADG, g	1,077	1,052	981	1,013	23	0.004	—	0.14
ADFI, kg	3.23	3.01	2.99	2.99	0.12	0.02	0.03	0.04
G:F, g/kg	333	350	328	339	7	0.03	0.002	—
Final BW, kg	132.7	131.5	127.6	129.3	3.3	0.004	—	0.15
HCW, kg	97.7	97.8	92.5	95.3	2.5	0.001	0.10	0.13
Dressing, %[5]	73.5	74.3	72.7	73.7	0.3	0.03	0.007	—
FFLI, %[5,6]	53.8	53.6	54.0	53.3	0.7	—	—	—
Backfat thickness, mm[5]	20.2	20.6	19.6	20.7	1.0	—	—	—
Loin depth, mm[5]	60.5	61.5	58.7	58.8	1.0	0.06	—	—

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[1] A total of 176 finishing pigs (11 pigs/pen and 4 pens/treatment) with an average initial BW of 74.6 kg.

[2] Standard conditioning prior to pelleting.

[3] Expander conditioning prior to pelleting.

[4] Dashes indicate $P > 0.15$.

[5] HCW used as a covariate.

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

Table 5.8. Chemical composition of finishing diets (Exp. 3; as-fed basis)

	Corn-soybean meal		DDGS[2]	
Item	Std[2]	Exp[3]	Std	Exp
DM, %[4]	86.6	88.2	86.4	89.4
CP, %	14.0	14.7	17.4	17.8
Ether extract, %	2.7	2.2	4.7	4.0
GE, kcal/kg	3,718	3,927	4,034	4,166
Ash, %	4.5	4.4	4.5	4.4
NDF, %	9.3	9.1	15.0	13.9
ADF, %	2.7	2.6	4.5	4.1
ADL, %	0.8	0.7	1.0	1.0
Cellulose, %[5]	1.9	1.9	3.5	3.1

[1] Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] Standard conditioning prior to pelleting.

[3] Expander conditioning prior to pelleting.

[4] DM (NFTA 2.1.4), CP (AOAC 990.03; FP-2000, Leco Corp., St. Joseph, MO), ether extract (AOAC 920.39), and ash (AOAC 942.05; AOAC, 1995). GE (adiabatic bomb calorimetry; Parr Instruments, Moline, IL). NDF, ADF, and ADL were analyzed using an ANKOM 200 fiber analyzer (ANKOM Technology Corp., Fairport, NY).

[5] Cellulose = ADF – ADL.

Table 5.9. Effects of expander conditioning of diets with sorghum-based distillers dried grain with solubles (DDGS) on nutrient digestibility in finishing pigs[1]

	Corn-soybean meal		DDGS			*P* value		
Item	Std[2]	Exp[3]	Std	Exp	SE	Diet effect	Cond. effect	Diet × Cond.
Pellet durability								
Standard, % [4]	74.6	94.7	90.9	97.2				
Modified, % [5]	67.7	94.4	89.2	97.1				
ADG, g	804	916	828	818	51	— [6]	—	—
ADFI, kg	3.09	2.98	2.98	2.87	0.14	—	—	—
G:F, g/kg	260	307	278	285	19	—	0.14	—
Apparent digestibility, % [7]								
DM	86.8	86.7	79.5	81.9	0.4	0.001	0.02	0.01
N	83.2	85.4	72.5	76.5	0.7	0.001	0.001	—
GE	86.1	87.7	77.5	81.1	0.8	0.001	0.02	—
NDF	52.5	43.2	58.1	54.8	1.6	0.001	0.004	0.10
ADF	55.4	46.1	52.4	47.3	1.5	—	0.001	—
ADL	49.4	41.2	54.3	49.0	1.5	0.001	0.001	—
Cellulose	70.7	60.2	45.2	42.4	2.6	0.001	0.03	—

[1] A total of 192 finishing pigs (12 pigs/pen and 4 pens/treatment) with an average initial BW of 101 kg.

[2] Standard conditioning prior to pelleting.

[3] Expander conditioning prior to pelleting.

[4] Pellet durability index (ASAE S269.4 DEC1991).

[5] Modified by adding five hexagonal nuts (12.7-mm diameter) to the tumbling box.

[6] Dashes indicate $P > 0.15$.

[7] Fecal samples collected on d 7 and 8 with chromic oxide used as an indigestible marker.

CHAPTER 6 - Effects of adding saturated fat to diets with sorghum-based distillers dried grains with solubles on growth performance and carcass characteristics in finishing pigs

ABSTRACT: Three experiments were conducted to determine the effects of adding sources of saturated fat to diets with sorghum-based distillers dried grains with solubles (DDGS). In Exp. 1, 112 barrows (average BW of 72 kg) were fed for 65 d. Treatments were a corn-soybean meal-based control and diets having 40% DDGS with none, 2.5, and 5% added tallow. The control diet supported greater ($P < 0.03$) ADG and ADFI than the DDGS treatments whereas increasing fat additions in diets with DDGS improved G:F (linear effect, $P < 0.03$). Adding DDGS to diets reduced ($P < 0.03$) HCW and dressing percentage but increased ($P < 0.001$) iodine value (IV) of jowls compared to pigs fed the control diet. Among the DDGS treatments, HCW, dressing percentage, fat free lean index (FFLI), and backfat thickness tended to respond positively (linear effect, $P < 0.08$) to fat addition, but IV tended to increase (linear effect, $P < 0.06$). In Exp. 2, 112 barrows (average BW of 63 kg) were assigned to 16 pens for 69 d. Treatments were a control and diets having 40% DDGS without and with 5% added tallow or palm oil. The control supported greater ($P < 0.001$) overall ADG and ADFI compared to the DDGS treatments whereas adding beef tallow and palm oil to diets with DDGS improved overall G:F ($P < 0.02$). Pigs fed the control diet had greater ($P < 0.04$) HCW and dressing percentage compared to pigs fed the DDGS treatments but adding fat to the DDGS diets tended to improve dressing percentage ($P < 0.07$). Changes in IV indicated softer fat in pigs fed DDGS ($P < 0.001$) compared to the control diet with no improvement from adding tallow or palm oil ($P > 0.27$). In Exp. 3, 112 barrows (average BW of 68 kg) were assigned to 16 pens for 67 d. Treatments were as in Exp. 2, but the fat sources were stearic acid and coconut oil. At slaughter, belly firmness was determined using a subjective scoring system and by the distance from tip to tip of the belly after it was drooped over a 2.54-cm^2 bar. The control diet tended to support greater overall ADG ($P < 0.09$) compared to the DDGS treatments. Adding the fat sources to diets with DDGS improved ($P < 0.05$) overall G:F and coconut oil improved ($P < 0.001$) G:F compared to stearic acid. Pigs fed the control diet had greater ($P < 0.05$) HCW, IV, and belly firmness score than pigs fed the DDGS treatments. However, adding the fat sources to diets with DDGS improved estimates of carcass firmness ($P < 0.01$) with coconut oil having a much greater effect than stearic acid ($P < 0.001$). In conclusion, adding beef tallow, palm oil, and coconut oil to diets with 40% DDGS improved efficiency of gain in finishing pigs. However, only coconut oil restored carcass firmness to levels at or above a corn-soybean meal diet without DDGS.

Key Words: carcass firmness, coconut oil, distillers dried grain with solubles, palm oil, pig, tallow.

INTRODUCTION

With conversion of cereal starch to ethanol, the other proximate components (such as protein, fiber, and fat) are concentrated by about 3 times in distillers dried grains with solubles (DDGS). Nonruminants tend to deposit fat similar to that which they consume and there are data that suggest negative effects of the fat (i.e., vegetable oil) in DDGS on iodine value and firmness of pork carcasses (Xu et al., 2007; Benz, 2008; White et al., 2008; Whitney et al., 2006). In an investigation of the effects of dietary fat on carcass characteristics, Averette-Gatlin et al. (2003) found that hydrogenation of choice white grease increased the level of saturation of carcass fat and improved carcass firmness in pigs. So, there is a question of whether feeding sources of saturated fat can counteract the negative effects of DDGS on carcass fat firmness. Therefore, the objective of the experiments reported herein was to determine the effects of adding various sources of saturated fat (beef tallow, palm oil, stearic acid, and coconut oil) into diets with sorghum-based DDGS.

MATERIALS AND METHODS

General

The experiments were conducted in an environmentally controlled finishing facility having 1.83-m × 4.88-m pens with concrete flooring that was half solid and half slatted. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water[1].

The DDGS for these experiments were sorghum-based and secured from U.S. Energy Partners (Russell, KS). Tannin content of the DDGS was evaluated using the modified vanillin hydrochloric method as described by Earp et al. (1981) with a UV-vis spectrophotometer (Spectronic 20; Thermo Fisher Scientific Inc., Madison, WI). Samples of feed were collected from the feeders at the beginning of each assay, pooled by treatment into one bag, ground, and kept frozen at -15ºC until analysis of fatty acid profile according to the procedure of Sukhija and Palmquist (1988) using a gas chromatograph (Shimadzu GC-17A).

Experiment 1

One hundred twelve finishing barrows (PIC line 1050), were weighed, sorted by ancestry, blocked by BW, and assigned to pens. There were 7 pigs/pen and 4 pens/treatment. The pigs were fed a common diet for 8 d and then treatments were assigned to the experimental diets for 65 d (average initial BW of 72 kg).

Treatments were a corn-soybean meal-based control (Table 6.1) and diets having 40% sorghum-based DDGS with none, 2.5, and 5% added beef tallow (Darling International Industries, Omaha, NE). The control diet and the diet with DDGS with no added fat were formulated to 0.90% Lys, 0.60% Ca, and 0.50% total P for d 0 to 31 and 0.70% Lys, 0.55% Ca,

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[1] The animal care and management used in these experiments were approved by the Kansas State University Animal Care and Use Committee.

and 0.45% total P for d 31 to 65. All other nutrients met or exceeded NRC (1998) recommendations for a genotype growing at about 325 g of lean/d. Nutrient:calorie ratios were kept constant for diets with added fat.

Pigs and feeders were weighed on d 0, 31, and 65 to allow calculation of ADG, ADFI, and G:F. The pigs were tattooed on d 65 (average BW of 130 kg) and shipped to a commercial abattoir (Farmland; Crete, NE) for slaughter the following morning. Hot carcass weight, 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 pre-shipping live weight and fat-free lean index (FFLI) was calculated according to the equation suggested by the National Pork Producers Council (NPPC, 2001). At 24-h postmortem, jowl samples were collected and frozen at -15° C until sample preparation and fatty acid analysis. Samples of jowl fat were dissected and a 5-g sub-sample of subcutaneous fat per pig was pooled within pen. The pooled sample of jowl fat was then submerged in liquid nitrogen for approximately 1 min, then ground and homogenized with a blender (Waring Commercial, Model 51BL32, Torrington, CT). Fatty acid profile was determined by GC (according to Sukhija and Palmquist, 1988) using a gas chromatograph (Shimadzu GC-17A) to allow estimation of iodine value using the regression equation $IV = (\%C16{:}1 \times 0.950) + (\%C18{:}1 \times 0.860) + (\%C18{:}2 \times 1.732) + (\%C18{:}3 \times 2.616) + (\%C20{:}1 \times 0.785) + (\%C22{:}1 \times 0.723)$ according to AOCS Cd 1c-85 Official Method, as an indicator of carcass firmness.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC). Initial weight was used as a covariate with location within the barn as the blocking criterion and pen as the experimental unit for analysis of the growth data. Because differences in slaughter weight and, thus, HCW is known to affect carcass measurements, HCW was used as a covariate of dressing percentage, FFLI, backfat thickness, and loin depth to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight. Orthogonal contrasts were used to separate treatment means with comparisons among the control vs DDGS treatments and linear and quadratic effects of increasing tallow additions in diets with DDGS.

Experiment 2

One hundred twelve finishing barrows (PIC line 1050), with an average initial BW of 63 kg were used in a 69-d growth assay. The pigs were sorted by ancestry, blocked by BW, and assigned to pens. There were 7 pigs/pen and 4 pens/treatment. Treatments were a corn-soybean meal-based control and diets having 40% DDGS without and with 5% tallow and palm oil (Table 6.1). The tallow was supplied by Darling International Industries, Omaha, NE and the palm oil was supplied by Diversified Ingredients, Inc., St. Louis, MO. The diets were formulated to the same nutrient specifications as in Exp. 1.

Pigs and feeders were weighed at d 0, 36, and 69 to allow for calculation of ADG, ADFI, and G:F. The pigs were tattooed on d 69 (average BW of 129 kg) and shipped to a commercial abattoir (Farmland, Crete, NE) for slaughter the following morning. Hot carcass weight, loin depth, and tenth rib fat thickness (SFK Technology A/S model S 82; Herlev, Denmark) were measured immediately after slaughter. Dressing percentage and FFLI were calculated as in Exp. 1. At 24-h postmortem, jowl samples were collected, processed, and analyzed for fatty acid concentration as in Exp. 1.

All data were analyzed as a randomized complete block design using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial body weight as the blocking criterion and pen as the experimental unit for analysis of the growth data. Because differences in slaughter weight and, thus, HCW are known to affect carcass measurements, HCW was used as a covariate for analyses of dressing percentage, FFLI, backfat thickness, and loin depth to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight. Orthogonal contrasts were used to separate treatment means with comparisons among the control vs DDGS treatments, DDGS without vs with added fat, and tallow vs palm oil.

Experiment 3

One hundred twelve finishing barrows (PIC line 1050), with an average initial BW of 68 kg were used in a 67-d growth assay. The pigs were sorted by ancestry, blocked by BW, and assigned to pens. There were 7 pigs/pen and 4 pens/treatment. Treatments were a corn-soybean meal-based control and diets having 40% DDGS without and with 5% added stearic acid and coconut oil (Table 6.1). The stearic acid was technical grade (Emery 420; Cognis Oleochemical, Cincinnati, OH) and the coconut oil was supplied by Diversified Ingredients, Inc., St. Louis, MO. Diets were formulated to the same nutrient specifications as used in Exp. 1.

Pigs and feeders were weighed on d 0, 30, and 67 to allow calculation of ADG, ADFI, and G:F. The pigs were tattooed on d 67 (average BW of 123 kg) and shipped to a commercial abattoir (Farmland, Crete, NE) for slaughter the following morning. Hot carcass weight, loin depth, and tenth rib fat thickness (SFK Technology A/S model S 82; Herlev, Denmark) were measured immediately after slaughter. Dressing percentage and FFLI were calculated as in Exp. 1 and 2. At 24-h postmortem, jowl samples were collected, processed, and analyzed for fatty acid profile as in Exp. 1 and 2. Belly firmness was determined using a subjective scoring system (scale of 1 = very soft to 10 = very firm) by a person experienced in carcass evaluation and unaware of the dietary treatments. Finally, the bellies were drooped over a 2.54-cm^2 bar, skin-face up, for 5 min and the distance from tip to tip of the belly was measured as described by

Waylan et al. (2003). The superior angle of the isosceles triangle formed was calculated as $\cos^{-1}\{[0.5(L^2) - D^2]/[0.5(L^2)]\}$ as proposed by Whitney et al. (2006), with L being length measured on a flat surface and D being the distance from tip to tip of a suspended belly. Greater distance from tip to tip and angle indicate firmer bellies. Additionally, individual belly weight, length while on a flat surface, and thickness were recorded and used as correction factors. Belly thickness was measured by inserting a metallic ruler at the level of the 10th rib.

All data were analyzed as a randomized complete block design by using the MIXED procedure of SAS (v9.1; SAS Inst. Inc., Cary, NC) with initial body weight as the blocking criterion and pen as the experimental unit for analysis of the growth data. Because differences in slaughter weight and, thus, HCW is known to affect carcass measurements, HCW was used as a covariate of dressing percentage, FFLI, backfat thickness, loin depth, and firmness indicators to separate any effect of treatment from the effects of slaughtering our pigs at a constant age rather than constant weight. Orthogonal contrasts were used to separate treatment means with comparisons among the control vs DDGS treatments, DDGS without vs with added fat, and stearic acid vs coconut oil.

RESULTS AND DISCUSSION

Analyses of the DDGS (Table 6.2) indicated that its fat was mainly long chain and unsaturated (e.g., C18:2) as would be expected for the oil in cereal grains (NRC, 1998). Fatty acid composition of the fat sources was similar to that expected for tallow and palm oil (i.e., 50% saturated) and the stearic acid and coconut oil products being more than 90% saturated. Although palm oil and beef tallow had similar degree of saturation, palm oil had greater content of palmitic and linoleic acid and lower content of stearic and oleic acid. The stearic acid source was 99% SFA with 65% stearic acid and 27% palmitic acid. Coconut oil had 79% medium-chain fatty acids of 14 carbons or lower. Measurement of tannin content revealed zero catechin equivalents for the DDGS used in these experiments, indicating no likelihood of growth performance to be affected by the presence of tannins.

Experiment 1

The corn-soybean meal control diet supported greater ADG and ADFI for d 0 to 31 ($P <$ 0.04) and 0 to 65 ($P < 0.03$) with no differences in G:F ($P > 0.32$) compared to the DDGS treatments (Table 6.3). The same effects of decreased ADG and ADFI without affecting G:F were observed in previous studies from our laboratory (Feoli et al., 2007; 2008b) when 40% DDGS were added to diets for finishing pigs compared to a corn-soybean meal control. Whitney et al. (2006) and Feoli et al. (2008a) reported decreased ADG and G:F when 30 and 40% DDGS were fed to growing-finishing pigs. Conversely, DeDecker et al. (2005) observed improved efficiency of growth with no effects on ADG or ADFI of growing pigs fed diets with 20 and 30% DDGS.

Increasing tallow additions from none to 5% in diets with DDGS did not affect overall ADG ($P > 0.77$) but improved (linear effect, $P < 0.03$) G:F by 10%. Thus, as would be expected in a simple corn-soybean meal diet, each 1% fat added to a diet with DDGS increased G:F by about 2%. These effects of fat addition in diets for finishing pigs have been reported by other authors that included from 2.5 to 5% of different fat sources into corn-soybean meal diets (Nichols et al., 1991; Weber et al., 2006) or into diets with DDGS (DeDecker et al., 2005).

As for carcass data, adding DDGS to diets reduced HCW ($P < 0.004$) and dressing percentage ($P < 0.03$) compared to pigs fed the corn-soybean meal control diet. Cook et al. (2005) observed a linear decrease in dressing percentage as corn-based DDGS was increased in the formulation from none to 30%. In their study, dressing percentage was decreased by 0.56%

for each 10% DDGS added to the diet. Others also have reported negative effects of DDGS on HCW and dressing percentage (Feoli et al., 2008a; Weimer et al., 2008). No effects were observed for carcass leanness, BF, or loin depth ($P > 0.22$) in response to inclusion of DDGS to the diet. Whitney et al. (2006) observed a linear decrease in HCW and dressing percentage with no effects on BF and leanness, but they did detect decreased loin depth with increasing levels of DDGS in the diet. Among the DDGS treatments, HCW (linear increase, $P < 0.08$), dressing percentage (linear increase, $P < 0.08$), FFLI (linear increase, $P < 0.03$), and backfat thickness (linear decrease, $P < 0.03$) responded positively as fat addition to the diets was increased from none to 5%.

As for jowl fat composition (Table 6.4), pigs fed diets with DDGS deposited lower proportion of C14:0, C16:0, C16:1, C18:0, C18:1, C20:0, total SFA, and total MUFA ($P < 0.05$) and greater proportion of C17:0, C18:2, C18:3, total PUFA, and total unsaturated fatty acids ($P < 0.002$). These results agree with data reported by Xu et al. (2007). They reported that pigs reared in commercial conditions and fed diets with 10% DDGS had lower concentration of C18:1 and MUFA and greater concentration of C18:2 and PUFA. As the degree of unsaturation of jowl fat increased for pigs fed diets with 40% DDGS, the calculated IV also increased ($P < 0.001$) compared to pigs fed the corn-soybean meal control diet. Other data have confirmed increased IV with use of DDGS (Whitney et al., 2006; Feoli et al., 2007; Xu et al., 2007; Benz, 2008; Feoli et al., 2008b; White et al., 2008). The effect of DDGS on IV has been considered a reason for some processing plants to break commercial relations with pig producers if the IV goes above 72.

Among the DDGS treatments, increasing amounts of beef tallow resulted in greater concentration of C18:1 in jowl fat (linear effect, $P < 0.007$), linear decreases in C16:0 and total

SFA ($P < 0.002$), and no effect on the concentration of C18:0 ($P > 0.11$). Averette Gatlin et al. (2002) reported a positive correlation between daily intake of C18:2 and backfat concentration of that same fatty acid. The researchers also observed an increase in C18:1 concentration of backfat in response to increasing levels of tallow in the diet. Hallenstvedt et al. (2006) showed that pigs fed diets with added soybean oil (source of unsaturated fatty acids) had greater PUFA and lower total SFA and MUFA in backfat than pigs fed barley-soybean meal-based diets without fat. Whilst increasing the supply of a specific fatty acid has been shown by others to increase its concentration in carcass fat, our data only confirmed this effect for one fatty acid (C18:1).

Changes in IV indicated a trend for deposition of softer fat in pigs fed DDGS when additions of beef tallow were increased in the diet (linear effect, $P < 0.06$). Thus, even what traditionally has been considered a source of saturated fat, tallow did not counteract the negative effects on IV of adding DDGS to diets for finishing pigs. In contrast to our data, Averette Gatlin et al. (2002) observed a linear decrease in IV of backfat when 0 to 5% tallow was added to corn-soybean meal diets. However, Benz (2008) reported greater IV of jowl from pigs fed either choice white grease, a source of 59% unsaturated fatty acids (NRC, 1998).

Experiment 2

Pigs fed a corn-soybean meal control diet had greater ADG and ADFI ($P < 0.002$) with no difference in G:F ($P > 0.58$) for d 0 to 36 and overall compared to pigs fed the DDGS treatments (Table 6.5). Adding 5% beef tallow or palm oil to diets with DDGS improved overall G:F by 9% ($P < 0.02$), but there was no difference ($P > 0.12$) in growth performance among pigs fed tallow vs palm oil. Other authors have reported no difference in growth performance among pigs fed tallow vs choice white grease (Weber et al., 2006), tallow vs soybean oil (Nichols et al., 1991), and fat at increasing levels of hydrogenation (Averette Gatlin et al., 2003). Conversely, Averette Gatlin et al. (2002) reported a reduction in G:F as a response to increased ADFI of pigs fed diets with hydrogenated fat in substitution for soybean oil.

As for carcass data in our experiment, pigs fed the control diet had greater ($P < 0.04$) HCW and dressing percentage compared to pigs fed the DDGS treatments. Adding fat to the DDGS diets tended to improve dressing percentage ($P < 0.07$) but there were no effects of fat source on carcass measurements ($P > 0.13$).

Analyses of fatty acid composition of jowl samples indicated that pigs fed the DDGS treatments deposited more PUFA ($P < 0.001$) and less MUFA and SFA ($P < 0.001$) than pigs fed the corn-soybean meal control (Table 6.6). Adding fat to DDGS diets tended to further decrease the content of SFA ($P < 0.06$), but to increase MUFA ($P < 0.02$) mainly through the effect of increasing C18:1 ($P < 0.003$) in jowl fat. These effects on fatty acid composition of the jowl by addition of DDGS and fat are comparable to those observed in Exp. 1.

Pigs fed diets with palm oil had lower content of C14:0, C16:1, and C17:0 than pigs fed diets with beef tallow ($P < 0.001$). However, these differences were small and did not result in differences for SFA, MUFA, and PUFA ($P > 0.17$). This result is in agreement with Weber et al. (2006), who did not observe effects of dietary fat source (choice white grease vs tallow) on SFA, MUFA, or PUFA composition of belly fat. Hallenstvedt et al. (2006) also reported similar results in SFA and MUFA composition of backfat of pigs fed either soybean oil or a blend of fish oil and soybean oil. In their study, however, because of the high content of PUFA in both fat sources, pigs fed soybean oil had higher backfat PUFA than backfat from pigs fed the soybean oil/fish oil blend. Feeding finishing pigs 5 to 15% ground flaxseed, a source rich in C18:3, C20:5, and C22:6, resulted in greater composition of these fatty acids in backfat and visceral organs but did not affect carcass traits (Romans et al., 1995).

Changes in IV indicated softer fat in pigs fed DDGS (*P* < 0.001) compared to the control diet and there was no difference in IV of jowl fat when pigs were fed either tallow or palm oil. This could be caused by their IV being fairly similar (44 vs 55 for tallow vs palm oil, respectively). Weber et al. (2006) did not find a response in belly fat IV to tallow vs choice white grease, and these sources also have similar IV (46 vs 54, respectively).

Experiment 3

The control treatment tended to support greater ADG (*P* < 0.09) with no difference in ADFI and G:F (*P* > 0.17) compared to the DDGS treatments (Table 6.7). Adding the fat sources to diets with DDGS improved (*P* < 0.05) G:F and coconut oil improved G:F compared to stearic acid (*P* < 0.001). As for carcass data, pigs fed the control diet had greater (*P* < 0.05) HCW than pigs fed the DDGS treatments. However, dressing percentage, FFLI, backfat thickness, and loin depth were not affected by adding DDGS or fat to the diets (*P* > 0.18). As for estimates of carcass firmness, pigs fed the control diet had greater firmness score compared to diets with added DDGS (*P* < 0.02), but no effects were observed in belly firmness as determined by tip to tip measurements. Weimer et al. (2008) reported a decrease in tip to tip distance with increasing levels of DDGS in the diet from 0 to 30%. Whitney et al. (2006) showed a reduction in belly firmness with 30% vs 20% DDGS in the diet, but that effect disappeared when belly firmness was adjusted to a constant belly thickness. Adding the fat sources to diets with DDGS improved firmness score, tip to tip distance, and angle of repose after suspending the belly (*P* < 0.01) with coconut oil having a much greater effect than stearic acid (*P* < 0.001). Previous publications evaluating the effect of fat source on carcass firmness indicate conflicting results. Nichols et al. (1991) reported a trend for pigs fed beef tallow to have firmer carcass as determined by subjective score than pigs fed soybean oil. Averette Gatlin et al. (2002) observed decreased fat firmness (measured on an Instron apparatus as kg/cm^2) as soybean oil was used to replace hydrogenated fat. Weber et al. (2006) did not detect differences in carcass firmness among pigs fed choice white grease vs tallow. Finally, Averette Gatlin et al. (2003) found no differences in loin firmness when pigs were fed diets supplemented with fat having increasing IV (i.e., increasing level of unsaturated fatty acids).

Because fat in DDGS is 80% unsaturated and mostly comprised of PUFA, pigs fed diets with DDGS had jowls with greater ($P < 0.002$) content of C18:2 and C18:3, and IV ($P < 0.001$), than pigs fed the corn-soybean meal control diet (Table 6.8).

Adding stearic acid and coconut oil decreased PUFA and IV in jowl fat ($P < 0.007$), and this effect was more pronounced for the coconut oil than for the stearic acid treatment ($P < 0.003$). Averette Gatlin et al. (2002, 2003) demonstrated that as IV of dietary fat decreases, PUFA, and IV of belly fat also decrease, in agreement with our observation. The stearic acid treatment did not affect jowl composition, in agreement with Smith et al. (1996) when a diet rich in C18:0 was fed to nursery pigs. Pigs fed coconut oil had greater content of medium-chain fatty acids, lower content of long-chain fatty acids, and total unsaturated fatty acids in their jowl fat than pigs fed the stearic acid treatment ($P < 0.04$).

In conclusion, the use of 40% DDGS in diets for finishing pigs tended to reduce ADG and indicators of carcass firmness. Adding fat to diets with DDGS increased efficiency of growth but tallow, palm oil, and stearic had little effect on indicators of carcass firmness. Alternatively, coconut oil restored indicators of carcass firmness to levels as good as or better than the corn-soybean meal control treatment.

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Table 6.1. Composition of diets (as-fed basis)

	Phase I				Phase II			
Ingredient	Control	0% fat	2.5% fat	5% fat	Control	0% fat	2.5% fat	5% fat
Corn	79.90	53.10	49.32	45.50	84.96	58.10	54.56	50.96
DDGS [1]	—	40.00	40.00	40.00	—	40.00	40.00	40.00
Fat [2]	—	—	2.50	5.00	—	—	2.50	5.00
Soybean meal (47.5% CP)	17.70	4.80	6.00	7.20	12.90	—	1.00	2.00
Limestone	1.09	1.35	1.34	1.35	1.07	1.27	1.31	1.32
Monocalcium phosphate (21% P)	0.73	0.04	0.13	0.22	0.59	—	—	0.08
Salt	0.23	0.10	0.10	0.11	0.23	0.10	0.10	0.11
L-lysine HCl	0.20	0.47	0.47	0.48	0.12	0.39	0.39	0.39
L-threonine	0.03	—	—	—	—	—	—	—
Vitamin premix [3]	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Mineral premix [4]	0.03	0.05	0.05	0.05	0.04	0.05	0.05	0.05
Antibiotic [5]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated Analysis [6]								
Lys, %	0.90	0.90	0.93	0.96	0.70	0.70	0.73	0.75
Ca, %	0.60	0.60	0.62	0.64	0.55	0.55	0.57	0.59
P total, %	0.50	0.50	0.52	0.53	0.45	0.45	0.47	0.48

[1] Distillers dried grains with solubles. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[2] Beef tallow supplied by Darling Intl. Ind., Omaha, NE. Palm oil and coconut oil supplied by Diversified Ingredients, Inc., St. Louis, MO. Stearic acid produced from Cognis Oleochemical, Cincinnati, OH.

[3] Supplied per kilogram of complete diet: 1,764 IU vitamin A; 265 IU vitamin D_3; 7.05 IU vitamin E; 0.71 mg vitamin K (as menadione nicotinamide bisulfite); 6.2 µg vitamin B_{12}, 7.9 mg niacin, 4.4 mg pantothenic acid (as calcium pantothenate), and 1.32 mg riboflavin.

[4] Supplied per kilogram of complete diet: 3.3 mg Cu, 60 µg I, 33.1 mg Fe, 7.9 mg Mn, 60 µg Se, and 33.1 mg Zn for the control diet on phase I, 4.4 mg Cu, 79 µg I, 44.1 mg Fe, 10.6 mg Mn, 79 µg Se, and 44.1 mg Zn for the control diet on phase II, and 5.5 mg Cu, 99 µg I, 55.1 mg Fe, 13.2 mg Mn, 99 µg Se, and 55.1 mg Zn for the fat added diets.

[5] To provide 44 g/ton tylosin.

[6] Nutrient:calorie ratios were kept constant for diets with added fat.

Table 6.2. Fatty acid composition of dried distillers grains with solubles (DDGS) and fat sources

Fatty acid[1]	DDGS[2]	Beef tallow[3]	Palm oil	Stearic acid	Coconut oil
C8:0, %	0.43	0.01	0.05	0.01	7.87
C10:0, %	0.00	0.10	0.05	0.06	6.02
C12:0, %	0.04	0.07	0.35	0.09	47.82
C14:0, %	0.11	3.17	1.09	2.65	17.53
C16:0, %	16.58	24.24	42.46	27.20	8.61
C16:1, %	0.50	2.15	0.07	0.40	0.06
C17:0, %	0.16	2.00	0.14	1.89	0.02
C18:0, %	1.96	20.25	4.45	65.34	3.24
C18:1, %	28.15	41.88	37.81	0.08	6.14
C18:2, %	48.30	3.04	11.68	0.27	2.08
C18:3, %	2.70	0.25	0.59	0.02	0.06
C20:0, %	0.30	0.15	0.38	1.25	0.09
Other fatty acids, %	0.77	2.68	0.90	0.74	0.46
SFA, %[4]	19.9	50.6	49.1	99.0	91.3
Unsaturated fatty acids, %[5]	80.1	49.4	50.9	1.0	8.7
MUFA, %	28.9	45.7	38.2	0.6	6.3
PUFA, %	51.2	3.7	12.7	0.4	2.4
Unsaturated:saturated ratio	4.03	0.98	1.04	0.01	0.10
Iodine value[6]	115.6	44.1	54.5	1.0	9.1

[1] Fatty acid profile determined by GLC (according to Sukhija and Palmquist, 1988).

[2] Distillers dried grains with solubles. Sorghum-based DDGS supplied by U.S. Energy Partners, Russell, KS.

[3] Beef tallow supplied by Darling Intl. Ind., Omaha, NE. Palm oil and coconut oil supplied by Diversified Ingredients, Inc., St. Louis, MO. Stearic acid produced from Cognis Oleochemical, Cincinnati, OH.

[4] SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]). Brackets indicate concentration.

[5] Unsaturated fatty acids = ([C14:1] + [C15:1] + [C16:1] + [C17:1] + [C18:1] + [C18:2] + [C18:3] + [C20:1] + [C20:2] + [C20:3n6] + [C20:4n6] + [C20:5n3] + [C20:6n3] + [C24:1]). Brackets indicate concentration.

[6] Calculated from fatty acid profile using AOCS Official Method Cd 1c-85.

Table 6.3. Effects of increasing amounts of beef tallow in diets with sorghum-based distillers dried grains with solubles (DDGS)[1] on growth performance and carcass characteristics of finishing pigs[2]

		40% DDGS				*P* value		
Item	Control	0% tallow	2.5% tallow	5% tallow	SE	Control vs DDGS	Tallow lin	Tallow quad
d 0 to 31								
ADG, g	975	884	866	877	37	0.04	—[3]	—
ADFI, kg	3.00	2.90	2.81	2.61	0.08	0.03	0.02	—
G:F, g/kg	325	305	308	336	7	—	0.02	—
d 0 to 65								
ADG, g	963	890	879	886	25	0.03	—	—
ADFI, kg	3.33	3.17	2.92	2.87	0.05	0.001	0.003	0.12
G:F, g/kg	289	281	301	309	7	—	0.03	—
Final BW, kg	134.2	129.5	128.7	129.2	1.6	0.03	—	—
HCW, kg	95.5	89.1	89.3	92.4	3.2	0.004	0.08	—
Dressing, %[4]	71.3	69.4	69.5	70.6	0.5	0.03	0.08	—
FFLI, %[4,5]	50.6	49.8	51.3	51.2	0.3	—	0.03	0.07
Backfat thickness, mm[4]	19.3	20.4	18.1	18.4	0.5	—	0.03	0.07
Loin depth, mm[4]	51.5	49.5	50.2	50.2	1.0	—	—	—

[1] Supplied by U.S. Energy Partners, Russell, KS.

[2] A total of 112 barrows (initial weight of 72 kg) with 7 pigs/pen and 4 pens/treatment.

[3] Dashes indicate *P* > 0.15.

[4] HCW used as a covariate.

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

Table 6.4. Effects of increasing amounts of beef tallow in diets with sorghum-based distillers dried grains with solubles (DDGS)[1] on jowl fat composition[2]

		40% DDGS				*P* value		
Item[3]	Control	0% tallow	2.5% tallow	5% tallow	SE	Control vs DDGS	Tallow lin	Tallow quad
C12:0, %	0.09	0.09	0.09	0.08	0.002	0.04	0.004	—[4]
C14:0, %	1.45	1.40	1.36	1.40	0.02	0.04	—	—
C16:0, %	23.54	22.47	21.44	20.84	0.15	0.001	0.001	—
C16:1, %	3.09	2.72	2.63	2.71	0.10	0.006	—	—
C17:0, %	0.61	0.64	0.78	0.80	0.03	0.002	0.002	0.08
C18:0, %	10.15	9.70	9.60	9.13	0.23	0.04	0.12	—
C18:1, %	45.15	43.16	44.19	45.06	0.42	0.05	0.007	—
C18:2, %	13.31	16.92	16.96	16.99	0.42	0.001	—	—
C18:3, %	0.76	0.88	0.89	0.89	0.03	0.002	—	—
C20:0, %	0.21	0.20	0.19	0.18	0.01	0.009	0.14	—
Other fatty acids, %	1.65	1.83	1.88	1.91	0.03	0.001	0.11	—
SFA, %[5]	36.3	34.7	33.7	32.7	0.3	0.001	0.002	—
Unsaturated fatty acids, %[6]	63.7	65.3	66.3	67.3	0.3	0.001	0.002	—
MUFA, %	48.5	46.1	47.1	48.0	0.5	0.03	0.02	—
PUFA, %	15.2	19.2	19.2	19.3	0.5	0.001	—	—
Unsaturated:saturated ratio	1.75	1.88	1.96	2.06	0.03	0.001	0.002	—
Iodine value[7]	67.8	72.4	73.3	74.2	0.6	0.001	0.06	—

[1] Supplied by U.S. Energy Partners, Russell, KS.

[2] A total of 112 barrows (initial weight of 72 kg) with 7 pigs/pen and 4 pens/treatment.

[3] Fatty acid profile determined by GLC (according to Sukhija and Palmquist, 1988).

[4] Dashes indicate $P > 0.15$.

[5] SFA = ([C8:0] + [C10:0] + [C11:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C24:0]). Brackets indicate concentration.

[6] Unsaturated fatty acids = ([C14:1] + [C15:1] + [C16:1] + [C17:1] + [C18:1] + [C18:2] + [C18:3] + [C20:1] + [C20:2] + [C20:3n6] + [C20:4n6] + [C20:5n3] + [C22:5n3] + [C22:6n3] + [C24:1]). Brackets indicate concentration.

[7] Calculated from fatty acid profile using AOCS Official Method Cd 1c-85.

Table 6.5. Effects of adding beef tallow and palm oil to diets with sorghum-based distillers dried grains with solubles (DDGS)[1] on growth performance and carcass characteristics in finishing pigs[2]

		40% DDGS				*P* value		
Item	Control	No added fat	Tallow	Palm oil	SE	Control vs DDGS	Fat effect	Tallow vs palm
d 0 to 36								
ADG, g	1,054	925	885	939	41	0.001	—[3]	0.14
ADFI, kg	3.05	2.80	2.61	2.65	0.10	0.002	0.07	—
G:F, g/kg	346	330	339	354	7	—	0.09	0.13
d 0 to 69								
ADG, g	1,029	925	891	934	25	0.001	—	0.13
ADFI, kg	3.34	3.13	2.88	2.90	0.09	0.001	0.006	—
G:F, g/kg	308	296	309	322	5	—	0.02	0.13
Final BW, kg	134.4	127.1	125.0	127.8	3.8	0.001	—	—
HCW, kg	97.4	88.7	88.7	89.9	3.0	0.001	—	—
Dressing, %[4]	71.9	70.0	71.1	70.4	0.4	0.04	0.07	0.14
FFLI, %[4,5]	51.1	51.4	51.6	51.6	0.3	—	—	—
Backfat thickness, mm[4]	19.4	18.6	18.2	18.3	0.5	—	—	—
Loin depth, mm[4]	56.7	56.0	53.9	55.4	1.2	—	—	—

[1] Supplied by U.S. Energy Partners, Russell, KS.

[2] A total of 112 barrows (initial weight of 63 kg) with 7 pigs/pen and 4 pens/treatment.

[3] Dashes indicate $P > 0.15$.

[4] HCW used as a covariate.

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

Table 6.6. Effects of adding beef tallow and palm oil to diets with sorghum-based distillers dried grains with solubles (DDGS)[1] on jowl fat composition[2]

		40% DDGS				*P* value		
Item[3]	Control	No added fat	Tallow	Palm oil	SE	Control vs DDGS	Fat effect	Tallow vs palm
C8:0, %	0.02	0.02	0.02	0.02	0.003	—[4]	—	—
C10:0, %	0.10	0.10	0.06	0.09	0.01	0.15	0.06	0.13
C12:0, %	0.10	0.09	0.08	0.09	0.01	—	—	—
C14:0, %	1.56	1.46	1.45	1.28	0.02	0.001	0.02	0.001
C16:0, %	23.18	21.67	20.33	21.48	0.21	0.001	0.02	0.004
C16:1, %	3.03	2.71	2.69	2.30	0.08	0.001	0.02	0.001
C17:0, %	0.60	0.66	0.83	0.50	0.04	0.13	—	0.001
C18:0, %	9.34	8.71	8.83	8.48	0.16	0.004	—	0.12
C18:1, %	45.60	43.58	44.89	44.84	0.51	0.003	0.003	—
C18:2, %	12.69	16.88	16.75	17.07	0.63	0.001	—	—
C18:3, %	0.85	1.00	1.04	0.95	0.03	0.005	—	0.08
C20:0, %	0.23	0.21	0.22	0.19	0.01	0.15	—	0.12
Other fatty acids, %	1.90	2.16	2.06	1.95	0.07	0.10	0.11	—
SFA, %[5]	35.4	33.2	32.1	32.3	0.3	0.001	0.06	—
Unsaturated fatty acids, %[6]	64.6	66.9	67.9	67.6	0.3	0.001	0.06	—
MUFA, %	50.0	47.7	49.0	48.4	0.6	0.001	0.02	—
PUFA, %	14.6	19.2	18.9	19.2	0.7	0.001	—	—
Unsaturated:saturated ratio	1.83	2.02	2.12	2.09	0.03	0.001	0.05	—
Iodine value[7]	67.0	72.5	73.5	73.4	0.8	0.001	—	—

[1] Supplied by U.S. Energy Partners, Russell, KS.

[2] A total of 112 barrows (initial weight of 63 kg) with 7 pigs/pen and 4 pens/treatment.

[3] Fatty acid profile determined by GLC (according to Sukhija and Palmquist, 1988).

[4] Dashes indicate $P > 0.15$.

[5] SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C24:0]). Brackets indicate concentration.

[6] Unsaturated fatty acids = ([C14:1] + [C15:1] + [C16:1] + [C17:1] + [C18:1] + [C18:2] + [C18:3] + [C20:1] + [C20:2] + [C20:3n6] + [C20:4n6] + [C20:5n3] + [C20:6n3] + [C22:5n3] + [C22:6n3] + [C24:1]). Brackets indicate concentration.

[7] Calculated from fatty acid profile using AOCS Official Method Cd 1c-85.

Table 6.7. Effects of adding stearic acid and coconut oil to diets with sorghum-based dried distillers grains with solubles (DDGS)[1] on growth performance and carcass characteristics in finishing pigs[2]

		40% DDGS				*P* value		
Item	Control	No added fat	Stearic	Coconut	SE	Control vs DDGS	Fat effect	Stearic vs coconut
d 0 to 30								
ADG, g	928	835	835	909	19	0.009	0.12	0.02
ADFI, kg	2.93	2.74	2.80	2.66	0.09	0.02	—[3]	0.13
G:F, g/kg	317	305	298	342	6	—	0.009	0.001
d 0 to 67								
ADG, g	840	789	804	818	22	0.09	—	—
ADFI, kg	2.86	2.75	2.88	2.60	0.08	—	—	0.02
G:F, g/kg	294	287	279	315	7	—	0.05	0.001
Final BW, kg	124.4	121.0	122.1	123.2	3.1	0.14	—	—
HCW, kg	89.6	85.3	86.0	88.1	2.3	0.05	—	—
Dressing, %[4]	71.7	70.8	70.5	71.4	0.6	—	—	—
FFLI, %[4,5]	52.6	53.0	53.0	52.2	0.4	—	—	0.09
Backfat thickness, mm[4]	16.9	16.1	16.2	17.6	0.5	—	—	0.06
Loin depth, mm[4]	57.0	55.4	56.3	57.7	1.1	—	—	—
Belly firmness score[4,6]	5.8	4.7	4.9	6.1	0.3	0.02	0.001	0.001
Tip to tip distance, mm[4]	186	145	162	239	9	—	0.001	0.001
Tip to tip distance adjusted for weight, mm[4,7]	176	159	159	239	15	—	0.006	0.001
Angle of the belly, degrees[4]	29.2	23.4	25.6	37.8	1.4	—	0.002	0.001
Angle of the belly adjusted for weight, degrees[4,7]	27.7	25.4	25.1	37.8	1.3	—	0.01	0.001

[1] Supplied by U.S. Energy Partners, Russell, KS.

[2] A total of 112 barrows (initial weight of 68 kg) with 7 pigs/pen and 4 pens/treatment.

[3] Dashes indicate $P > 0.15$.

[4] HCW used as a covariate.

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

[6] Scale of 1 = very soft to 10 = very firm.

[7] Adjusted for weight of the belly through covariate analysis.

Table 6.8. Effects of adding stearic acid and coconut oil to diets with sorghum-based distillers dried grains with solubles (DDGS)[1] on jowl fat composition[2]

		40% DDGS				*P* value		
Item[3]	Control	No added fat	Stearic	Coconut	SE	Control vs DDGS	Fat effect	Stearic vs coconut
C8:0, %	0.02	0.02	0.02	0.02	0.005	—[4]	—	—
C10:0, %	0.07	0.10	0.06	0.13	0.02	—	—	0.03
C12:0, %	0.07	0.10	0.10	1.24	0.03	0.001	0.001	0.001
C14:0, %	1.47	1.52	1.55	4.09	0.05	0.001	0.001	0.001
C16:0, %	23.03	22.31	22.22	23.23	0.17	0.05	0.08	0.003
C16:1, %	2.73	2.74	2.55	3.04	0.08	—	—	0.001
C17:0, %	0.71	0.67	0.73	0.59	0.02	0.08	—	0.002
C18:0, %	10.24	9.16	9.88	9.33	0.19	0.002	0.05	0.04
C18:1, %	44.46	42.46	42.21	39.10	0.36	0.001	0.003	0.001
C18:2, %	13.30	16.86	16.41	15.39	0.19	0.001	0.003	0.004
C18:3, %	1.01	1.15	1.12	1.09	0.02	0.002	0.12	—
C20:0, %	0.24	0.21	0.24	0.22	0.01	0.12	—	—
Other fatty acids, %	1.86	1.97	2.15	1.87	0.06	0.08	—	0.01
SFA, %[6]	36.1	34.3	35.0	39.0	0.3	—	0.001	0.001
Unsaturated fatty acids, % [6]	63.9	65.7	65.0	60.9	0.3	—	0.001	0.001
MUFA, %	48.6	46.6	46.2	43.4	0.4	0.001	0.004	0.001
PUFA, %	15.3	19.1	18.8	17.5	0.2	0.001	0.007	0.003
Unsaturated:saturated ratio	1.78	1.92	1.86	1.56	0.02	—	0.001	0.001
Iodine value [7]	67.1	71.9	70.7	66.6	0.4	0.001	0.001	0.001

[1] Supplied by U.S. Energy Partners, Russell, KS.

[2] A total of 112 barrows (initial weight of 68 kg) with 7 pigs/pen and 4 pens/treatment.

[3] Fatty acid profile determined by GLC (according to Sukhija and Palmquist, 1988).

[4] Dashes indicate $P > 0.15$.

[5] SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C21:0] + [C22:0] + [C24:0]). Brackets indicate concentration.

[6] Unsaturated fatty acids = ([C14:1] + [C15:1] + [C16:1] + [C17:1] + [C18:1] + [C18:2] + [C18:3] + [C20:1] + [C20:2] + [C20:3n6] + [C20:4n6] + [C20:5n3] + [C20:6n3] + [C22:5n3] + [C22:6n3] + [C24:1]). Brackets indicate concentration.

[7] Calculated from fatty acid profile using AOCS Official Method Cd 1c-85.