Interactive effects of distillers dried grains with solubles (DDGS) and housing system on sow performance and longevity

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Industry Summary

Background: Use of DDGS in diets for growing swine has been the focus of much research effort in the past 5 – 7 years with little attention paid to DDGS use in diets for breeding females. In fact, sows are ideal candidates for feeding DDGS because of its moderately high fiber content. Increases in reproductive performance and improved welfare have been attributed to feeding high-fiber diets to sows but long-term studies have not been conducted with DDGS to confirm or refute these perceptions. Increasing fiber content of diets could also increase slurry output which would decrease storage time in slurry collection pits but this has not been evaluated.

Objectives: The objectives of this study were to: 1. determine the long-term effects of feeding DDGS to sows on reproductive performance over three reproductive cycles; 2. determine if feeding DDGS during gestation and lactation will improve longevity and welfare of sows in two different gestation housing systems; and 3. quantify the increase in fecal and urinary output resulting from feeding DDGS to reproducing sows.

Procedures: Four hundred one sows that farrowed 904 litters over three parities were used in this experiment. Females were assigned to treatments as parity 0 (n=311) or parity 1 (n=90) sows and maintained on their assigned treatments for three reproductive cycles or until they were culled, whichever occurred earlier. Sows were assigned randomly to one of four experimental treatments in a 2 x 2 arrangement. Dietary treatments included a control diet composed of corn and soybean meal (CON) fed during gestation and lactation or similar diets containing 40% DDGS in gestation and 20% DDGS in lactation (DDGS). Within dietary treatment, sows were housed in either individual stalls or group pens (50 sows/pen) with an electronic sow feeder during gestation. Behavior of sows was recorded by video cameras for 24 hours using 40 focal sows in pens and 27 focal sows in stalls. Group-housed sows were recorded immediately after mixing in the pens. Stalled sows were recorded 7 to 10 days after placement in stalls. Total collection of feces and urine were performed on 19 gestating sows fed CON and 21 gestating sows fed DDGS to determine effects of diet on slurry output by sows.

Findings: Sows fed DDGS or CON began the experiment with equal body weight. However, at the end of the first reproductive cycle, DDGS-fed sows were 4 kg lighter than CON-fed sows and at the end of the second reproductive cycle they were 8 kg lighter than CON-fed sows. This difference in body weight stabilized (7 kg) at the end of the third reproductive cycle. These differences in body weight suggest that young sows were less able to derive energy and nutrients for body growth from DDGS diets than older sows. Live born litter size was 0.5 pigs less for DDGS-fed compared with CON-fed sows which translated into 0.4 fewer pigs per litter at weaning. The smaller litters nursing DDGS-fed sows gained less weight than litters nursing CON-fed sows. The smaller weight gain of litters from DDGS sows was most evident during the first reproductive cycle lending support to the idea that young sows had more difficulty digesting diets containing DDGS. Sows housed in pens during gestation and fed DDGS supported the lowest litter weight gain compared with sows assigned to the remaining three treatments. Daily feed intake during lactation and wean-to-estrus intervals were not influenced by diet. The percentage of sows completing three parities in this experiment (CON/stall: 71.8%; CON/pen: 56.0%; DDGS/stall: 66.0%; DDGS/pen: 55.5%) was not statistically different among diet and housing treatments. Over the entire experiment, feeding DDGS reduced the total number of pigs weaned by 0.8 while housing sows in pens of 50 sows during gestation reduced total number of pigs weaned by 2.1. Sows fed DDGS were more aggressive in pens as they were involved in longer and more aggressive fights with pen-mates compared with CON-fed sows. In contrast, DDGS-fed sows in stalls spent more time resting and less time engaged in stereotypic behaviors than sows assigned to CON which suggests sows were more satiated and content. As expected, feeding DDGS to sows did reduce dry matter digestibility of the diet but, contrary to expectations, did not affect output of slurry. This suggests that feeding DDGS to sows will not decrease residence time in slurry storage pits. Nutrient composition of slurry was not affected by inclusion of DDGS in the diet of pregnant sows.

Conclusions: It appears that feeding high levels of DDGS to reproducing sows may result in marginal depressions in production of weaned pigs. These reductions are more likely in young sows (parity 0 and 1) compared with older sows. In this study, gestation housing system had a larger effect on reproductive performance than did diet. Longevity of sows was not affected by inclusion of DDGS in the diet. Slurry output from pregnant sows and nutrient composition of slurry was not influenced by inclusion of DDGS in the diet.

Key Words: DDGS, longevity, housing, manure output, sow

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Abstract

An experiment was conducted to evaluate the interactive effects of dietary DDGS and housing system on sow and litter performance, sow longevity and welfare, and manure production and composition. Four hundred and one (n = 311 for parity 0; n = 90 for parity 1) sows were assigned randomly to one of four dietary treatments and maintained on these treatments for up to three reproductive cycles. Sows were fed either a fortified corn-soybean meal control diet (CON, n = 203) during gestation and lactation, or diets containing 40% DDGS in gestation and 20% DDGS in lactation (DDGS, n =198). Within dietary treatment, sows were housed either in individual stalls (Stall, n = 200) or group pens (Pen, n = 201) with electronic sow feeders during gestation. Sows were offered their assigned diets based on body condition during gestation and allowed *ad libitum* access to their assigned diets during lactation. *Sow and Litter performance:* Sows fed DDGS were lighter and had less backfat depth than CON sows at the end of each reproductive. Dietary DDGS did not affect total number of piglets born per litter but sows fed DDGS farrowed smaller ($P < 0.05$) number of piglets live per litter (11.0 vs. 11.6, respectively) but had larger ($P < 0.05$) number of piglets born dead per litter (0.9 vs. 0.7, respectively) than those fed CON. Feeding DDGS decreased ($P < 0.05$) both litter size after cross-fostering (10.2 vs. 10.6, respectively) and at weaning (9.8 vs. 10.2, respectively) compared with feeding CON. Litter weight was not influenced at birth but was decreased ($P < 0.05$) at weaning by inclusion of DDGS in sow diets. Weight gain was lower for litters nursing sows fed DDGS especially in the first reproductive cycle. Sows fed DDGS and housed in pens supported the lowest litter weight gain compared with sows assigned to the remaining three treatments. Diet did not affect piglet pre-weaning mortality, sow ADFI during lactation, or wean-to-estrus interval. *Sow Longevity and Welfare:* Neither diet nor housing had statistically significant effects on percentage of sows that completed the first, second, or third reproductive cycles. The percentage of sows that completed the experiment were 63.9% (Stall, 71.8%; Pen, 56%) of sows fed CON and 60.8% (Stall, 66.0%; Pen, 55.5%) of sows fed DDGS. Feeding DDGS decreased ($P < 0.03$) the number of piglets born alive (26.2 vs. 27.4) and tended ($P < 0.10$) to decrease the number of pigs weaned (23.7 vs. 24.5) for sows over three reproductive cycles compared with feeding CON. Over the entire experiment, feeding DDGS reduced the total number of pigs weaned by 0.8 while housing sows in pens of 50 sows during gestation reduced total number of pigs weaned by 2.1. Sows fed DDGS were more aggressive in pens as they were involved in longer and more aggressive fights with pen-mates compared with CON-fed sows. In contrast, DDGS-fed sows in stalls spent more time resting and less time engaged in stereotypic behaviors than sows assigned to CON which suggests sows were more satiated and content. *Slurry Production and Composition:* Total collection of feces and urine was performed for 3 d on gestating sows (wk 6 to 10) in their first or third reproductive cycle from CON (n = 9 vs. n = 10, respectively) and DDGS (n = 10 vs. n = 11, respectively) to determine apparent dry matter digestibility of diets, and output and composition of slurry. Feeding DDGS decreased ($P < 0.05$) diet dry matter digestibility compared with feeding CON (76.8% vs. 82.9%, respectively). Sows fed DDGS excreted more ($P < 0.05$) fresh feces than sows fed CON (755 vs. 561 g/d, respectively); however, slurry (feces + urine) production was not different between DDGS- and CON-fed sows. Concentration of nitrogen, phosphorus, and potassium in excreted slurry were not different between CON and DDGS. In conclusion, feeding diets containing 40% DDGS in gestation and 20% in lactation decreased number of piglets born alive and weaned per litter, and reduced litter weight gain but had no effect on sow longevity or slurry production. Feeding DDGS increased aggressive

interactions in group pens but increased resting time and decreased time spent on stereotypic behaviors in stalled sows.

Introduction

Use of DDGS in diets for growing swine has been the focus of much research effort in the last 5-7 years with little attention paid to DDGS use in diets for breeding females. In fact, sows are ideal candidates for feeding DDGS because of the moderately high-fiber content. Song et al. (2010) found sow performance was not different for sows fed 10, 20, and 30% DDGS compared to those fed a corn-soybean meal control diet. This study clearly demonstrates that DDGS can be fed successfully to lactating sows. However, long-term effects on subsequent performance were not evaluated. Wilson (2003) reported that number of pigs born alive per litter was increased marginally when sows received 50% DDGS in gestation diets for two reproductive cycles. Wilson's work at our research station suggests important benefits of DDGS on reproductive performance when fed to sows. However, these initial results need a more comprehensive, longer-term study to verify the initial findings.

Housing systems for pregnant sows has become a "top of mind" issue for pork producers throughout the U.S. Recent announcements by Smithfield Foods, Maple Leaf Foods, and other major restaurant chains that individual stalls for housing gestating sows will be phased out in favor of group pens demonstrate that consumers are having significant influences on pork production systems. As group housing systems become more prevalent, we need to know as much information as possible about management of these systems. Anil et al. (2005, 2006) reported similar sow performance when comparing individual stalls to group pens with electronic sow feeders and similar diets but sow longevity was not measured Potentially, the sows' response to diet may differ in different housing systems and influence both sow performance and longevity.

Housing system has a profound effect on behavior and welfare of gestating sows. Individual stalls offer tailored feeding for each sow and virtually eliminate aggression among sows but provide a barren environment and restrict the sow's mobility. There is evidence that limit-fed sows in a barren environment exhibit excessive stereotypic behaviors (D'Eath et al. 2009) which is considered an indicator of poor welfare. On the other hand, group housing of sows provides freedom of movement but it subjects sows to aggression, especially at mixing and feeding. The high fiber content of DDGS may influence positively the behavior and well-being of limit-fed gestating sows in both stalls and group housing. Several studies (Danielsen and Vestergaard, 2001; van der Peet-Schwering et al., 2003a) have demonstrated that high levels of fibrous feed ingredients can significantly reduce stereotypic behaviors of gestating sows in stalls. In group-housing systems, additional roughage and high dietary fiber reduce aggressive interactions among gestating sows (Brouns et al., 1994; Steward et al., 2010). In addition, de Leeuw et al. (2004) reported that high dietary fiber can stabilize glucose and insulin levels and reduce activity of limit-fed gestating sows, indicating prolonged feeling of satiety. In contrast to these reports, Holt et al. (2006) attempted unsuccessfully to ameliorate stereotypic behaviors with a high-fiber diet based on corn, soybean meal, and soybean hulls. The effects of DDGS on sow behavior and welfare in different gestation housing systems have not been quantified.

Feeding high-fiber diets to pigs may also increase manure output and change manure composition. Previous work found dry matter digestibility of DDGS diets was lower than corn-soybean meal diets in grower-finisher pigs (Xu et al., 2006). But as DDGS plays a more important role in sow feeds, very little information exists on nutrient digestibility of DDGS, output of manure, and nutrient concentration of manure when feeding diets high in DDGS to sows. Therefore, it is important to evaluate manure production and composition to provide useful information to incorporate into manure management plans.

Objectives

1. To determine the long-term effects of feeding DDGS to sows on reproductive performance over three reproductive cycles.

2. To determine if feeding DDGS to sows during gestation and lactation will improve longevity and welfare of sows housed in two different gestation housing systems.

3. To quantify the increase in fecal and urinary output resulting from feeding DDGS to reproducing sows.

Materials and Methods

The experimental protocol used in this study was approved by the Institutional Animal Care and Use Committee of the University of Minnesota.

Animals and Management

The experiment was conducted at the University of Minnesota's Southern Research and Outreach Center (SROC), Swine Research Facility, in Waseca, MN. The experiment began on May 15, 2009 and completed on August 1, 2011. Four hundred and one (n = 311 for parity 0; n = 90 for parity 1) sows (English Belle, GAP Genetics, Winnipeg, Manitoba, Canada) with an initial BW of 163 ± 22 kg were used. Sows assigned to the experiment represented 60 contemporary farrowing groups as part of the Research Center's normal production flow. All sows were assessed for incidence of lameness at breeding according to the procedures described by Bonde et al. (2004). Females with lameness scores of 1 (no signs of lameness) and 2 (stepping frequently while standing) at breeding were deemed sound and assigned to trial. Throughout gestation, sows were fed 2.04 kg daily of their assigned diet. Feeding levels were adjusted to accommodate required changes in body condition with a body condition score of 3 as a goal at farrowing. On d 109 of gestation, sows were moved into environmentally-controlled farrowing rooms and placed in individual farrowing stalls (2.13 m long x 0.97 m high x 0.66 m wide). Sows were fed 2.25 kg of their assigned lactation diet starting on day 109 of gestation until farrowing. After parturition, the amount of feed offered was gradually increased to allow for *ad libitum* access to their assigned lactation diet from day 5 until weaning at about day 19 of lactation. At weaning, sows were moved to an environmentally-controlled breeding barn and checked for signs of estrus using a mature boar daily until estrus was detected or day 21 post-weaning, whichever occurred earlier. During the post-weaning period, sows were fed 2.25 kg of their assigned gestation diets. Sows were allowed free access to water throughout the experiment and remained in the study throughout gestation and lactation for up to three reproductive cycles. Within each reproductive cycle, sows were culled only if they failed to conceive after the second post-weaning service, were anestrous longer than 21 days post-weaning, or had lameness scores of 3 or 4.

Within 24 hours of birth, piglets were cross-fostered within dietary treatment and housing system to equalize litter size across treatments as much as possible. Piglet processing procedures included iron shots, docking of tails, and disinfecting of navels within 24 hours after birth according to standard piglet management procedures of SROC. Surgical castrations were completed when all male piglets were between 5 to 9 days of age. Piglets were provided with a heat lamp for 48 hours after birth and had access to heat pads until weaning. Piglets did not receive creep feed and were weaned at about 19 days of age.

Dietary Treatment and Housing System

At breeding, sows were assigned randomly to one of four experimental treatments in a 2 x 2 factorial arrangement. Dietary treatments included a control diet composed of corn and soybean meal fortified with vitamins and minerals (CON) fed during gestation and lactation or a similar diet containing 40% DDGS in gestation and 20% DDGS in lactation (DDGS; Table 1). Distillers dried grains with solubles were obtained from a single dry-mill ethanol plant (Absolute Energy, L.L.C., Lyle, MN) throughout the study. Dietary treatments were formulated on a standardized ileal digestible (SID) amino acid basis with the ME-to-SID lysine ratio equalized across experimental diets. Calcium-to-phosphorus ratios were also similar across experimental diets. Gestating sows were fed at levels to satisfy nutrient requirements of females producing 12 total pigs per litter and gaining 30 kg maternal body weight in parity 1 and 15 to 20 kg maternal body weight in parities 2 and 3 as described by NRC (1998). Diets for lactating sows met or exceeded NRC (1998) nutrient recommendations for females with average prefarrowing body weight of 217 kg, expected litter size of 10 and expected piglet ADG of 259 g. Within dietary treatment, sows were housed either in individual stalls (0.61 m x 2.13 m) with an individual feeder or group pens (15.2 m x 7.6 m; about 50 sows/pen) with an electronic sow feeder during gestation. Both individual stalls and group pens were located on totally slotted floors and equipped with nipple waterers.

Data Collection

Nutrient Composition of Ingredients and Diets

Mycotoxin screens for vomitoxin and zearalenone were analyzed on two randomly selected lots of DDGS at a commercial laboratory (Minnesota Valley Testing Laboratories, New Ulm, MN). Contents of dry matter, crude protein, crude fat, calcium, phosphorus, ADF and amino acids for soybean meal and DDGS were analyzed at Experiment Station Chemical Laboratories (University of Missouri, Columbia, MO) and the analyzed nutrient contents were used to formulate experimental diets. Nutrient concentrations for other feed ingredients were based on NRC (1998). A sample of each batch of experimental diet was collected and frozen for subsequent nutrient analyses. A random selection of diet samples within each reproductive cycle were submitted to a commercial laboratory (Minnesota Valley Testing Laboratories, New Ulm, MN) for analyses of dry matter, crude protein, crude fat, calcium, phosphorus, and ADF.

Sow and Litter Performance

To quantify the long-term effects of feeding DDGS to sows on reproductive performance, sow body weight was recorded and last rib backfat depth of both sides was determined ultrasonically (Lean-Meater, Renco Corp., Minneapolis, MN) at breeding, on day 109 of gestation, within 24 hours after farrowing, and at weaning to assess body condition and body weight changes during gestation and lactation. In gestation, changes in feeding level were measured after any changed feeding levels were implemented. In lactation, parity of sows, farrowing date, litter size (number of piglets born, born live, after cross-fostering, and at weaning), and pre-weaning piglet deaths were recorded on farrowing crate cards. Pre-weaning mortality of piglets within litter was calculated as number of live born piglets that died before weaning divided by the number of piglets born alive. Litter weight was recorded at birth, after cross fostering, and at weaning. Litter weight gain from cross-fostering until weaning was calculated and used as an indirect measure of sow milk production. Feed was weighed and offered to sows twice daily to avoid accumulation of uneaten feed in the feeder. Orts were determined if feed was soiled and at weaning to allow calculation of average daily feed intake (ADFI) throughout lactation. Date of post-weaning estrus was noted for all sows and wean-to-estrus intervals were calculated for the first and second reproductive cycles.

Sow Longevity

Treatments and reason for treatment of sick sows were recorded. Death and cause of death for any sow were also recorded. A postmortem examination was performed by the attending veterinarian on any sow that died from causes that were not obvious. Culling date and reason, sow body weight, backfat depth, and lameness scores were recorded for all sows culled before the end of the experiment. To estimate overall productivity of the sows on the experiment, total numbers of piglets born, born alive, and weaned were summed for each sow.

Sow Behavior and Welfare

Behavioral data were collected during the second reproductive cycle after the housing and the dietary treatment were imposed. A total of 40 focal sows in the group-housing system and 27 sows in stalls from 4 breeding groups were randomly identified. Within each breeding group, focal sows were designated into the same pen or the same row of stalls. In the group-housing system, 19 focal sows were fed the control diet and 21 sows were fed the DDGS diet. In stalls, 15 and 12 focal sows were fed the control and DDGS diets, respectively. These focal sows included parity 1 and parity 2 sows. Within each housing system, the ratio of parity 1 to parity 2 was 20:20 in group-housing, and 17:12 in stalls.

Behaviors of focal sows were video-recorded for 24 hours using digital cameras (Hi-Res Bullet Cams 2505, Sony, Taiwan), which were connected to a computer with a DVR device and video-recording software (Geo Vision Multicam Digital Surveillance System V8.2; USA Vision Systems Inc, Irvine, CA). For group-housed sows, the video-recording was conducted immediately after mixing. For stalled sows, the video-recording was completed between 7 and 10 days after sows were moved into stalls at weaning. All focal sows were mated 5 to 8 days before video-recording.

The video recording for each housing system was viewed by a trained observer who was blind to the dietary treatment to eliminate subjective bias and inter-individual discrepancy. For the group-housing system, aggression involving focal sows during the entire 24 hours after mixing was analyzed by continuous observation. The frequency, duration, and outcomes (winner, loser, and unsolved) of fights were registered using the methods of Turner et al. (2006). Intensity of aggression was assessed by parallel pressing, head-to-head knocking, and head-to-body knocking according to the methods of Jensen (1980). The intensity of aggression is the highest in parallel pressing, the lowest in head-to-body knocking, and intermediate in head-to-head knocking (Jensen, 1980). Total duration, frequency, and outcomes of each aggressive interaction during daytime (0700 h to 1900 h) and nighttime (1900 h to 0700 h) were calculated for all focal sows in each pen. For stalled sows, the video-recording was analyzed by instantaneous scan sampling. Each focal sow was scanned at 5-minute intervals during daytime (0700 h to 1900 h) and nighttime (1900 h to 0700 h) to determine the behaviors of interest, including resting (lateral or ventral recumbency), stereotypies (performing oral or nasal behaviors repetitively), and others (performing neither resting nor stereotypies). These behaviors were mutually exclusive. In total, each focal sow was scanned 144 times during each period of daytime and nighttime. Behavioral time budgets for resting, stereotypies, and others were expressed by time spent on each behavior as a percentage of total observation time in each period of daytime and nighttime (Martin and Bateson, 1993).

Manure Production and Composition

To evaluate effects of feeding DDGS to sows for three reproductive cycles on nutrient digestibility, and quantity and composition of manure output, total collection of feces and urine was performed for three days on a subset of sows in their first or third reproductive cycle from sows fed CON (Cycle 1 = 9; Cycle 3 = 10) and DDGS (Cycle 1 = 10; Cycle 3 = 11) during week six to ten of gestation. Sows were housed in individual stalls during gestation. For each reproductive cycle, two contemporary farrowing groups were used. After measuring total weight of feces and total volume of urine produced, the urine to feces ratio was calculated. Feces and urine were subsampled proportionally based on excreted feces to urine ratio and then mixed to simulate slurry production. Collected fecal and feed samples were analyzed for dry matter content by forced-air oven drying at 60 ºC to allow calculation of dry matter digestibility. Composited manure samples were analyzed for nitrogen, phosphorus, and potassium by a commercial manure laboratory (AGVISE Laboratories, Inc., Benson, MN).

Statistical Analyses

For all data analyses, SAS (SAS Inst. Inc., Gary, NC) was used. Individual sow served as the experimental unit in all analyses except behavioral data collected in group pens. The PDIFF option with the Tukey-Kramer adjustment was used for means comparison. To adjust the mean, covariates were used for variables of interest. All reported means are least squares means. Treatment differences with P values < 0.05 were considered significant with P values between 0.05 and 0.10 considered a trend.

Data collected from sow and litter performance were analyzed as a 3 x 2 x 2 factorial design with repeated measurements in time and analyzed statistically using PROC Glimmix. The statistical model included fixed effects of three reproductive cycles, two dietary treatments, two housing systems, two-way interactions (reproductive cycle x dietary treatment, reproductive cycle x housing system, and dietary treatment x housing system), and the three-way interaction (reproductive cycle x dietary treatment x housing system). Farrowing group was included in the model as a random effect to account for seasonal differences that occur over the course of this experiment.

Sow longevity data were analyzed using PROC Phreg and PROC Lifetest. Days were calculated from the time sows were culled, died, or completed each reproductive cycle to the time of initial breeding. The statistical model in PROC Phreg included effects of dietary treatment, housing system, and their interaction. The statistical model in PROC Lifetest only allowed using treatment combinations (CON/Stall, CON/Pen, DDGS/Stall, and DDGS/Pen) without interaction. Therefore, *P*-values were used from the output of PROC Phreg. Total numbers of piglets born and born alive for each sow's performance over her entire period in the study were calculated as another indicator of sow lifetime productivity and was analyzed using PROC Glimmix. The statistical model included dietary treatment, housing system, and their interaction.

All behavioral data sets were tested for normal distribution using PROC Univariate. Data that were not distributed normally were transformed using logarithm transformation (X'=log10X) to achieve normal distribution. For transformed data, both actual and transformed least-square means, and statistics of transformed data are presented in the results. The Glimmix procedure of SAS was used to analyze effect of dietary treatment within each housing system. For aggression among group-housed sows, the statistical model included dietary treatment, period (daytime vs. nighttime), parity, and their interactions as fixed effects, and breeding group as a random effect, with parity nested in dietary treatment within each pen serving as the experimental unit. For behavioral time budget data, the statistical model included dietary treatment, period (daytime vs. nighttime), parity, and their interactions as fixed effects, and breeding group as a random effect, with individual sow serving as the experimental unit.

Data collected from manure production and composition were analyzed as a 2 x 2 factorial design using PROC Mixed. Reproductive cycle, dietary treatment, and their interaction were included in the model as fixed effects. Contemporary farrowing group was included as a random effect.

Results

Two lots of DDGS were screened for vomitoxin and zearalenone concentration. A concentration of 0.66 ppm and < 0.2 ppm were detected for vomitoxin and zearalenone, respectively, in the first lot. The second lot contained < 0.5 ppm and < 0.2 ppm of vomitoxin and zearalenone, respectively. Both vomitoxin and zearalenone in the DDGS used in this experiment were below levels generally recognized as safe for swine diets (Thaler and Reese, 2010).

Sow and Litter Performance

For the entire experiment, no significant three-way interactions were observed among reproductive cycle, dietary treatment, and housing system (*P*-values not shown). Consequently, the focus of the results and discussion will be on the effects of dietary DDGS on reproductive performance and the interaction between dietary DDGS and reproductive cycle to satisfy Objective #1. Where appropriate, the interaction between dietary DDGS and housing treatment will be presented to satisfy Objective #2.

Dietary treatment influenced sow body weight at breeding and this difference was present on day 109 of gestation (Table 2). Sows fed DDGS had lower ($P < 0.05$) body weight than those fed CON (breeding: 179 vs. 184 kg, respectively; d 109 of gestation: 225 vs. 231 kg, respectively). However, dietary treatment did not affect gain in body weight during gestation (DDGS, 46.6 kg vs. CON, 47.8 kg). Feeding DDGS decreased ($P < 0.01$) sow body weight at farrowing (211 vs. 216 kg) and weaning (207 vs. 214 kg) compared with feeding CON. However, dietary treatment had no effect on body weight change during lactation. An interactive effect between reproductive cycle and dietary treatment was observed for sow body weight at breeding (Table 3). Sow body weight at the start of the experiment was similar for CON and DDGS-fed sows but feeding DDGS decreased ($P < 0.05$) sow body weight at the second and third reproductive cycles compared with feeding CON. No interaction existed between reproductive cycle and dietary treatment for sow body weight on day 109, at farrowing or weight gain during gestation. Although feeding DDGS did not change sow body weight at weaning in the first reproductive cycle, body weight of sows tended to decrease ($P = 0.09$) at weaning in the second and third reproductive cycles compared with feeding CON. Sows fed DDGS lost similar body weight during lactation at the first reproductive cycle compared with those fed CON. However, sows fed DDGS diets lost more (*P* < 0.05) body weight during lactation than those fed CON in the second reproductive cycle and exhibited similar gains in body weight during lactation in the third reproductive cycle.

Feeding DDGS decreased (*P* < 0.05) sow backfat depth at breeding (14.4 vs. 15.7 mm) and day 109 of gestation (16.1 vs. 17.2 mm) compared with feeding CON (Table 2). Dietary treatment had no effect on gain of backfat depth during gestation. At farrowing and weaning, sows fed DDGS also had less backfat depth than those fed CON (farrowing: 15.5 vs. 16.8 mm; weaning: 13.2 vs. 14.6 mm). There was no dietary effect on change of backfat depth during lactation. Reproductive cycle and dietary treatment interacted to affect sow backfat depth at breeding but not on day 109 of gestation (Table 3). Sows at the beginning of the first reproductive cycle had similar backfat depth between sows fed DDGS and CON but in the second and third reproductive cycles DDGS-fed sows had less (*P* < 0.05) backfat depth than CON-fed sows at breeding. No interactions between reproductive cycle and dietary treatment were observed for backfat depth measured at any other time in the experiment.

Number of piglets born total per litter was not different between dietary treatments (Table 2). However, sows fed DDGS farrowed smaller (P < 0.05) litters of live born piglets (11.0 vs. 11.6) and tended to have a larger (P = 0.06) number of piglets born dead per litter (0.9 vs. 0.7) than those fed CON. Feeding DDGS decreased (*P* < 0.05) litter size after cross-fostering (10.2 vs. 10.6) and at weaning (9.8 vs. 10.2) compared with feeding CON. Effects of dietary treatment on litter size at farrowing were consistent across reproductive cycles because no interactions between diet and reproductive cycle were observed (Table 3). However, feeding diets containing DDGS reduced (*P* < 0.05) the number of piglets per litter after cross-fostering and at weaning in the first reproductive cycle with no differences in the second and third reproductive cycles.

There was no main effect of diet on litter weight at birth (Table 2). However, sows fed DDGS diets had lower (*P* < 0.05) litter weight at weaning than those fed CON (65.2 vs. 67.8 kg). Litters nursing CON-fed sows gained more weight than litters nursing DDGS-fed sows (49.8 vs. 47.8 kg). Diet and housing system interacted to influence litter weight at weaning and litter gain. Litters from sows fed DDGS and housed in gestation pens were lighter and gained less weight than litters from sows fed CON and housed in gestation pens. This difference between gestation housing was not apparent for litters nursing CON-fed sows. This interaction may be attributable to the differences in litter weight after cross-fostering across the treatment combinations (Table 2). For the most part, effects of diet on litter weights were consistent across reproductive cycles. However, sows fed DDGS in the first reproductive cycle supported lower (*P* < 0.05) litter weight gain compared with CON-fed sows but there were no diet effects on litter weight gain in the second and third cycles (Table 3).

Average daily feed intake of lactating sows was not different for DDGS- and CON-fed sows and this observation was consistent across all three reproductive cycles (Tables 2 and 3). Likewise, post-weaning interval to estrus was similar between sows fed DDGS and those fed CON.

Sow Longevity

No interactive effects between dietary treatment and housing system were found on percentage of sows that completed the first, second, or third reproductive cycle (Table 4). Likewise, neither dietary nor housing treatments influenced the proportion of sows that completed each successive reproductive cycle. At the end of third reproductive cycle, 63.9% (Stall, 71.8 %; Pen, 56.0%) of the CON sows and 60.8% (Stall, 66.0%; Pen, 55.5%) of the DDGS sows remained in the herd.

Effects of diet on total pigs produced during the study differed depending on housing system. For sows fed CON, total pigs born, total pigs born alive, and total pigs weaned decreased if sows were housed in group pens during gestation compared to sows housed in stalls. However when sows received diets containing DDGS, total pigs born, total pigs born alive, and total pigs weaned were not statistically different between the two housing systems. In general, feeding DDGS to sows tended to decrease ($P < 0.10$) total number of piglets born (27.9 vs. 28.9) and total number of pigs weaned (23.7 vs. 24.5) compared to feeding CON diets, and decreased ($P < 0.05$) total number of piglets born alive (26.2 vs. 27.4). Sows housed in individual stalls farrowed more ($P < 0.05$) total number of piglets (30.1 vs. 26.7), more live pigs (28.4 vs. 25.2), and weaned more pigs (25.2 vs. 23.1) compared with sows housed in group pens.

Sow Behavior

For group-housed sows, both duration ($P < 0.05$) and frequency ($P < 0.05$) of parallel pressing were increased among sows fed DDGS compared with sows fed CON (Table 6). Sows assigned to the DDGS diet also won more head-to-body knocking ($P < 0.05$) and tended to win more head-to-head knocking ($P = 0.06$) than sows assigned to the CON diet. Parity 2 sows fought more frequently and for longer periods in head-to-head knocking and parallel pressing ($P < 0.05$) compared with parity 1 sows. Parity 2 sows also won more fights of head-to-body knocking ($P < 0.01$) and head-to-head knocking ($P < 0.001$), and tended to win more fights of parallel pressing ($P = 0.07$) compared with parity 1 sows. All sows fought more frequent and for longer periods, and won more fights during daytime ($P < 0.01$) than nighttime. No interactions among dietary treatment, parity, and period were observed.

For females housed individually in stalls, sows fed the DDGS diet spent more time resting ($P < 0.05$) and tended to spend less time performing stereotypic behaviors ($P = 0.07$) than contemporaries fed the CON diet. Parity 2 sows spent less time resting ($P < 0.01$) and more time performing stereotypic behaviors ($P < 0.05$) than parity 1 sows. All sows spent less time resting ($P < 0.01$), and more time performing stereotypies ($P < 0.01$) during daytime than nighttime. Interactions between parity and period were observed for resting ($P < 0.01$) and stereotypic behaviors ($P < 0.01$), with parity 1 sows spending more time resting and less time performing stereotypic behaviors than parity 2 sows during daytime ($P < 0.05$), but not during nighttime ($P > 0.10$). There were no interactions among dietary treatment, parity and period for other behavioral variables.

Manure Production and Composition

Effects of diet on manure output and composition were consistent across cycles as indicated by the lack of interaction between diet and reproductive cycle (Table 8). Neither dietary treatment nor reproductive cycle affected ADFI of sows during the collection periods. Feeding DDGS to sows decreased ($P < 0.05$) diet DM digestibility compared with feeding CON (76.8% vs. 82.9%). Sows fed DDGS excreted more ($P < 0.05$) fresh feces than sows fed CON (755 vs. 561 g/d). Neither fecal moisture content (39.4% vs. 37.9%) nor volume of slurry (4.0 vs. 4.5 L) excreted daily differed between sows fed CON and DDGS. Quantities of nitrogen, phosphorus, or potassium excreted per 3,800 L of slurry were not different between CON and DDGS.

Discussion

Sow and Litter Performance

In the current study, we did not find any statistical difference in gestation body weight gain between dietary treatments. However, sows fed DDGS were consistently lighter throughout the experiment compared with CON sows. We also found DDGS-sows lost more body weight during lactation at the second reproductive cycle. At weaning of the first litter, DDGS-fed sows were 4 kg lighter than CON sows (Table 3). This difference grew to 8 kg at weaning in the second reproductive cycle. By the third reproductive cycle, this difference seemed to stabilize as the difference in sow body weight was 7 kg. These observations might suggest that younger sows were less able to extract energy and nutrients from the DDGS diets compared with older sows. But, as the sows aged their digestive capabilities increased such that the difference in weight was maintained rather than continue to increase and gestation gains in body weight were similar between DDGS- and CON-fed sows. Renteria-Flores (2003) previously has documented higher nutrient digestibility of high-fiber diets in old compared with young sows. In contrast to the current study, Wilson (2003) fed sows diets containing DDGS in gestation and lactation for two reproductive cycles and reported similar gestation weight gains between sows fed DDGS compared to those fed a corn-soybean meal control. Song et al. (2010) and Greiner et al. (2008) reported sows fed DDGS during lactation had similar body weight change compared with those fed CON.

We theorized that long-term dietary inclusion of DDGS, due to its high-fiber content, would increase litter size at birth based on previous findings of Wilson (2003). However, although the total number of piglets born per litter was not affected by dietary DDGS in this experiment, the number of live born pigs was reduced due to a higher stillbirth rate in DDGS-fed sows. Therefore, our results are contrary to those reported by Wilson (2003), who found sows fed DDGS in gestation had a marginal increase in number of piglets born alive per litter for the second but not the first parity. In the current study when sows received DDGS in both gestation and lactation, litter size at weaning was decreased compared to a corn-soybean meal based diet. Wilson (2003) used about 25 or less sows per dietary treatment when she reported an increase in litter size due to DDGS feeding. However, we used about 200 females for the CON and 200 females for the DDGS diets and thus have more confidence in our findings with regard to litter size.

Within 24 hours of birth, piglets were cross-fostered to keep similar litter size (about 10) within dietary treatment and housing system. Because number after cross-fostering was lower for DDGS-fed sows and pre-weaning mortality was not affected by dietary treatment, litter size at weaning was significantly lower by about 0.4 pigs. Wilson (2003) and Song et al. (2010) also reported that dietary DDGS fed to sows during lactation did not influence pre-weaning mortality of piglets. Dietary DDGS reduced litter weight gain compared to CON likely due to the lower litter size weaned for DDGS-fed sows. Litter weight gain for sows fed DDGS in cycle 1 was 3.1 kg less than for contemporary sows fed CON. However by the third cycle, this difference in litter weight gain was only 1.5 kg. Since pigs were not offered creep feed, litter weight gain is a reasonable proxy for sow milk production. This narrowing difference in litter weight gain as sows advanced through the experiment lends support to the idea that younger sows had more difficulty extracting energy and nutrients from DDGS-containing diets than did older sows. This idea is further supported by the observation that average daily feed intake of sows during lactation was not different between DDGS- and CON-fed sows. Wilson (2003) and Greiner et al. (2008) also reported no differences in voluntary feed intake of lactating sows when comparing corn-soybean meal based diets to similar diets containing DDGS. In contrast, Song et al. (2010) found a positive relationship between DDGS content of diets and voluntary feed intake of lactating sows.

Sow Longevity and Welfare

Generally, sow longevity is defined as length of productive life, which can be represented by a large number of different measures (Stalder et al., 2004). In the current study, we used the survival rate of sows in the herd to evaluate interactive effects of dietary DDGS and gestation housing system on sow longevity. Sows were only culled when they failed to become pregnant after the second post-weaning service, had a wean-to-estrus interval longer than 20 days, or exhibited lameness scores of 3 or 4. To our knowledge, this is the first study to report effects of dietary DDGS on sow longevity and lifetime productivity. Results from this experiment indicate that dietary DDGS had no effect on sow longevity during the three reproductive cycles studied in this experiment. Similarly, housing system during gestation did not influence sow longevity. However, Anil et al. (2005) found culling rate for sows housed in group pens was higher than those housed in individual stalls, and the main culling reason for both housing system was lameness.

Sow productivity over the entire experiment was influenced by diet and housing system. Feeding DDGS decreased the total number piglets born and born alive (26.2 vs. 27.4 pigs) and tended to reduce the number of pigs weaned (23.7 vs. 24.5 pigs) compared to CON. Housing system also affected the number of pigs produced with lower number of pigs weaned (25.2 vs. 28.4 pigs) from the group housing system compared with individual stalls. The effects of reduced pig production in pen housing were most noticeable when sows consumed the control diets. Interestingly, effects of housing system (difference of 2.1 pigs) were greater than effects of diet (difference of 0.8) on total number of pigs weaned. Our results suggest that sows fed DDGS exhibit decreased sow productivity over the three parities studied.

In the group-housing system, sows on DDGS diet were more aggressive at mixing than sows on control diet. Their high-intensity fights (parallel pressing) which are the most aggressive interactions and cause the most injuries (Turner et al., 2006) lasted longer than similar fights involving CON-fed sows. Sows fed DDGS won more fights involving head-to-body interactions and tended to win more fights of head-to-head knocking than sows fed the CON diet. These data indicate that sows fed the DDGS diet can be more aggressive to fight for dominant status in a group than sows fed the control diet in our group-housing system. To our knowledge, this is the first study to investigate the long-term effect of DDGS on aggression in group-housed sows. It is not clear why DDGS-fed sows were more aggressive than sows fed a corn-soybean meal based diet.

In gestation stalls, sows fed DDGS spent more time resting, and tended to spend less time performing stereotypic behaviors compared with sows fed the CON diet. Since limit-feeding induces hunger in gestating sows, hunger can be associated with increased physical activities and stereotypies (D'Eath et al., 2009). In contrast, reduced physical activities (or increased resting) and stereotypies may indicate satiety (de Leeuw et al., 2004; D'Eath et al., 2009). In this study, sows fed the DDGS diet increased time spent resting and decreased time spent performing stereotypies, which may indicate improved satiety. Several previous studies reported that feeding a large volume of roughage and high-fiber diets to fill the gut can reduce stereotypies in gestating sows (Robert et al., 1997; Danielsen and Vestergaard, 2001; van der Peet-Schwering et al., 2003b). In this study, although the DDGS diet contains more fiber than the control diet, the difference in volume of daily intake between the DDGS and the control diets was not obvious. However, there may have been a large enough difference in diet composition to elicit greater satiety in DDGS-fed sows. These results suggest that inclusion of 40% DDGS in diets can improve sow welfare by reducing feelings of hunger in gestating sows. In stalled sows, reduced feelings of hunger were associated with increased rest and reduced stereotypies.

Manure Production and Composition

We found sows fed DDGS had 6% lower DM digestibility than sows fed CON. Lower apparent total tract digestibility of dietary fiber in DDGS (Stein and Shurson, 2009) likely contributed to the lower DM digestibility of DDGS diets. Because DM digestibility was decreased, fecal output was increased as expected when feeding DDGS to sows. An increase of slurry volume might also be expected when DDGS is included because of the incremental increase in fecal excretion. However, slurry volume was not different between dietary DDGS and CON. This lack of a difference in total slurry output can be explained by the difference in ratio of excreted urine to feces for sows fed CON and DDGS. The average urine to feces ratio tended to be higher for CON-fed sows than that of DDGS-fed sows, which could result in a similar volume of slurry produced between dietary treatments. We hypothesized that the high level of crude protein in DDGS would increase the excretion of nitrogen and the high availability of phosphorus in DDGS would decrease the phosphorus excretion in slurry. However, dietary DDGS had no effect on nitrogen, phosphorus, or potassium content of slurry. In the present study, concentrations of crude protein and available phosphorus of CON and DDGS diets during gestation and lactation (Table 1) were kept consistent. Furthermore, the similar ADFI during gestation and lactation between sows fed CON and DDGS indicate sows consumed similar amounts of nitrogen and phosphorus. No studies have reported effects of dietary DDGS fed to sows on nitrogen and phosphorus excretion in manure. In grower-finisher pigs, Gralapp et al. (2002) and Xu et al. (2006) both found no difference in total nitrogen and phosphorus concentrations in manure for pigs fed corn-soybean or corn-soybean-DDGS based diets, which supports our findings with sows. When considering potassium, the third major component of crop fertilizer, there is a lack of studies showing effects of feeding DDGS to pigs on its excretion.

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Table 1. Composition and nutrient content of experimental diets in gestation and lactation (as-fed basis)

Item	Gestation		Lactation	
	Control	DDGS	Control	DDGS
Ingredient, %				
Corn	74.45	54.35	61.55	51.90
DDGS	0.00	40.00	0.00	20.00
Soybean meal (46.5%)	18.80	0.00	30.00	20.00
Choice white grease	2.00	0.50	3.70	3.00
Dicalcium phosphate	1.90	0.80	2.40	1.90
Limestone	1.40	2.30	1.30	1.80
Salt	0.35	0.35	0.35	0.35
Vitamin-mineral premix[1]	0.50	0.50	0.50	0.50
Biotin premix[2]	0.20	0.20	0.20	0.20
Choline chloride (50%)	0.10	0.20	0.00	0.10
L-Lysine-HCL (78%)	0.00	0.40	0.00	0.20
L-Tryptophan (98%)	0.05	0.10	0.00	0.05
L-Threonine (98.5%)	0.15	0.20	0.00	0.00
DL-Methionine (99%)	0.10	0.10	0.00	0.00
Nutrient content (calculated)				
ME, Kcal/kg	3,341	3,351	3,413	3,417
CP, %	14.90	15.00	19.10	18.90
Total calcium, %	1.01	1.03	1.12	1.15
Total phosphorus, %	0.69	0.61	0.82	0.79
Available phosphorus, %	0.41	0.43	0.52	0.53
Crude fat, %	5.13	7.10	6.47	7.85
ADF, %	3.10	7.16	3.34	5.35
SID Lys, %	0.65	0.66	0.94	0.92
SID Met + Cys, %	0.53	0.54	0.52	0.52
SID Thr, %	0.58	0.58	0.58	0.55
SID Trp, %	0.19	0.18	0.21	0.22

[1]Vitamin –mineral premix supplied the following per kilogram of diet: vitamin A, 11,013 IU; vitamin D, 2,753 IU; vitamin E, 55 IU; vitamin K, 4.4 mg; thiamine, 1 mg; riboflavin, 10 mg; niacin, 55 mg; pantothenic acid, 33 mg; pyridoxine, 1.7 mg; folic acid, 1.7 mg; vitamin B_{12}, 0.1 mg; I, 2.2 mg from ethylenediamine dihydriodide; Se, 0.3 mg from sodium selenite; choline, 495 mg from choline chloride; and metal polysaccharide complexes of zinc sulfate (90.3 mg of Zn), iron sulfate (54 mg of Fe), manganese sulfate (18 mg of Mn), and copper sulfate (5.4 mg of Cu).

[2]Biotin premix supplied 0.51 mg of biotin (JBS United Inc., Sheridan, IN) per kg of diet.

Table 2. Interactive effects of distillers dried grains with solubles (DDGS) and housing system on sow and litter performance over three reproductive cycles

Item	Control		DDGS		Pooled SE	*P*-value		
	Stall	Pen	Stall	Pen		Diet	Housing	Diet*Housing
No. of litters	246	213	229	216				
Sow BW, kg								
Breeding	189	179	184	175	1.67	<.01	<.01	0.69
d 109 of gestation	234	228	229	221	1.97	<.01	<.01	0.57
Gestation gain[1]	45.7	50.0	46.6	46.7	1.15	0.27	0.04	0.05
Farrowing	218	214	214	207	1.88	<.01	<.01	0.52
Weaning	216	212	209	205	1.91	<.01	0.03	0.98
Lactation change[2]	-2.3	-1.5	-4.2	-1.7	0.99	0.23	0.08	0.34
Sow backfat depth, mm								
Breeding	16.3	15.0	15.4	13.4	0.37	<.01	<.01	0.37
d 109 of gestation	17.2	17.3	16.3	16.0	0.45	0.01	0.85	0.71
Gestation gain[1]	0.8	2.3	0.9	2.5	0.28	0.64	<.01	0.79
Farrowing	16.9	16.8	15.7	15.2	0.43	<.01	0.50	0.58
Weaning	14.8	14.5	13.5	13.0	0.37	<.01	0.32	0.78
Lactation change[2]	-2.1	-2.2	-2.3	-2.2	0.16	0.36	0.91	0.39
Litter size								
Total born	12.6	11.9	12.0	11.8	0.02	0.12	0.10	0.42
Born alive	11.9	11.2	11.1	10.9	0.02	0.03	0.07	0.41
Born dead	0.7	0.7	0.9	0.9	0.10	0.06	0.74	0.83
After cross-fostering	10.7	10.4	10.4	10.0	0.01	<.01	<.01	0.46
Weaning	10.4	10.1	10.0	9.7	0.01	<.01	<.01	0.65
Litter wt, kg								
Born alive	17.8	17.6	18.1	17.1	0.40	0.77	0.11	0.30
After cross-fostering	17.6	17.9	18.3	17.2	0.32	0.90	0.14	0.02
Weaning	67.5	68.1	67.0	63.4	1.04	<.01	0.11	0.02
Gain[2]	49.7	50.0	49.1	46.6	0.71	<.01	0.09	0.03
Piglet ADG, g	268	276	274	268	3.29	0.80	0.69	0.02
Piglet pre-weaning mortality, %	9.8	8.9	8.3	9.7	0.95	0.67	0.78	0.19
Lactation ADFI, kg	6.1	6.1	6.0	5.9	0.11	0.17	0.79	0.56
Wean-to-estrus interval[3], d	5.3	5.5	5.6	5.4	0.03	0.54	0.93	0.26

[1]Gestation length was used as a covariate in the statistical model.

[2]Lactation length was used as a covariate in the statistical model.

[3]Data were collected from the first and second reproductive cycles.

Table 3. Effects of feeding diets containing distillers dried grains with solubles (DDGS) on sow and litter performance in each reproductive cycle

Item	1st Cycle		2nd Cycle		3rd Cycle		Pooled SE	P-value		
	Control	DDGS	Control	DDGS	Control	DDGS		Cycle	Diet	Cycle*Diet
No. of litters	179	178	150	147	130	120				
Sow BW, kg										
Breeding	170	170	187	182	193	185	1.46	<.01	<.01	<.01
d 109 of gestation	227	224	231	225	234	227	1.81	0.06	<.01	0.43
Gestation gain[1]	56.5	53.8	44.6	43.7	42.3	42.5	1.25	<.01	0.27	0.31
Farrowing	211	207	216	210	221	214	1.70	<.01	<.01	0.44
Weaning	204	200	214	206	223	216	1.65	<.01	<.01	0.09
Lactation change[2]	-7.0	-7.4	-0.9	-3.7	2.2	2.1	0.98	<.01	0.23	0.05
Sow backfat depth, mm										
Breeding	17.3	16.8	15.7	14.4	14.0	12.1	0.33	<.01	<.01	0.03
d 109 of gestation	19.9	18.9	16.9	15.6	15.0	13.9	0.42	<.01	0.01	0.80
Gestation gain[1]	2.4	2.2	1.2	1.1	1.0	1.7	0.33	<.01	0.64	0.33
Farrowing	19.3	18.3	16.4	15.0	14.7	13.2	0.36	<.01	<.01	0.42
Weaning	16.2	15.2	14.4	12.9	13.3	11.6	0.33	<.01	<.01	0.15
Lactation change[2]	-3.0	-3.0	-2.0	-2.2	-1.4	-1.5	0.19	<.01	0.36	0.65
Litter size										
Total born	11.8	11.5	12.2	11.9	12.9	12.2	0.03	0.05	0.12	0.74
Born alive	11.2	10.8	11.5	10.9	11.9	11.3	0.03	0.23	0.03	0.96
Born dead	0.5	0.7	0.7	1.0	1.0	1.0	0.11	0.01	0.06	0.25
After cross-fostering	10.3	9.6	10.6	10.4	10.8	10.5	0.01	<.01	<.01	<.01
Weaning	10.1	9.3	10.3	10.1	10.5	10.2	0.01	<.01	<.01	<.01
Litter wt, kg										
Born alive	17.2	16.8	18.1	17.8	17.8	18.1	0.47	0.08	0.77	0.64
After cross-fostering	17.4	16.6	18.3	18.4	17.6	18.2	0.38	<.01	0.90	0.06
Weaning	64.4	60.8	69.4	67.7	69.6	67.1	1.15	<.01	<.01	0.35
Gain[2]	47.8	44.7	51.2	49.9	50.6	49.1	0.77	<.01	<.01	0.18
Piglet ADG, g	267	272	279	273	269	269	3.34	0.03	0.80	0.03
Piglet pre-weaning mortality, %	8.7	9.7	8.3	8.1	11.0	9.0	1.07	0.29	0.67	0.18
Lactation ADFI, kg	5.4	5.1	6.3	6.2	6.6	6.5	0.11	<.01	0.17	0.62
Wean-to-estrus interval, d	5.4	5.6	5.4	5.4	-	-	0.03	0.40	0.54	0.24

[1]Gestation length was used as a covariate in the statistical model.

[2]Lactation length was used as a covariate in the statistical model.

Table 4. Interactive effects of distillers dried grains with solubles (DDGS) and housing system on sow longevity for three reproductive cycles

Item	Control		DDGS		Pooled SE	*P*-value[1]		
	Stall	Pen	Stall	Pen		Diet	Housing	Diet*Housing
No. of sows assigned	103	100	97	101				
One reproductive cycle								
No. of sows failed	14	10	9	11				
No. of sows completed	89	90	88	90				
Percent completed	86.4	90.0	90.7	89.1	NS	0.63	0.51	0.78
Two reproductive cycles[2]								
No. of sows failed	20	33	20	31				
No. of sows completed	83	67	77	70				
Percent completed	80.6	67.0	79.4	69.3	NS	0.96	0.44	0.82
Three reproductive cycles[2]								
No. of sows failed	29	44	33	45				
No. of sows completed	74	56	64	56				
Percent completed	71.8	56.0	66.0	55.5	NS	0.34	0.13	0.33

[1]Initial breeding parity was used as a covariate in the statistical model.

[2]Cumulative values.

Table 5 . Interactive effects of distillers dried grains with solubles (DDGS) and housing system on total number of piglets born, born alive, and weaned for three reproductive cycles

Item	Control		DDGS		Pooled SE	*P*-value		
	Stall	Pen	Stall	Pen		Diet	Housing	Diet*Housing
Total no. of piglets born[1]	31.6	26.2	28.6	27.1	0.02	0.09	<.01	<.01
Total no. of piglets born alive[1]	30.0	24.7	26.7	25.6	0.02	0.03	<.01	<.01
Total no. of piglets weaned[1]	26.1	22.9	24.2	23.2	0.02	0.10	<.01	0.03

[1]Initial breeding parity was used as a covariate in the statistical model.

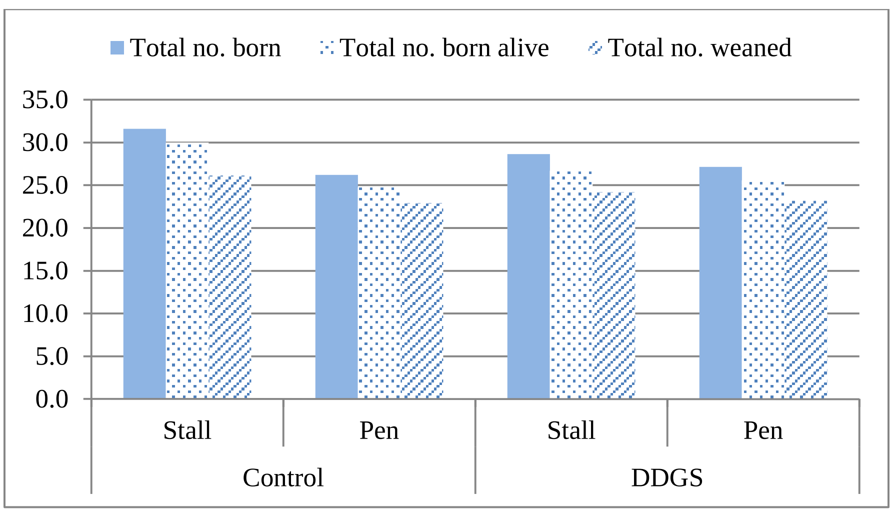

Figure 1. Interactive effects of distillers dried grains with solubles (DDGS) and housing system on total number of piglets born, born alive, and weanedfor three reproductive cycles

Table 6. Effect of DDGS on aggression among group-housed gestating sows during the first 24 h after mixing

Item	Diet treatment		Parity		Period		Pooled SE	*P*-Value[1]		
	CON	DDGS	Parity1	Parity2	Day	Night		Diet	Parity	Period
Number of focal sows	19	21	20	20	40	40				
Head-to-body knocking										
Frequency,#/sow	1.11	2.80	1.11	2.80	3.19	0.71				
Transformed data[2]	-0.44	0.17	-0.46	0.19	0.77	-1.04	0.28	0.13	0.11	<0.001
Duration, sec/sow	10.87	23.18	9.20	24.85	28.74	5.32				
Transformed data[2]	0.64	1.25	0.55	1.34	2.33	-0.43	0.57	0.35	0.22	0.001
Wins, #/sow	0.13	0.86	0.08	0.91	0.96	0.03				
Transformed data[2]	-1.81	-1.16	-1.99	-0.99	-0.83	-2.15	0.21	0.04	0.002	0.001
Head-to-head knocking										
Frequency,#/sow	2.37	5.59	2.44	5.52	6.55	1.41				
Transformed data[2]	0.56	0.74	0.14	1.16	1.44	-0.14	0.32	0.66	0.02	0.001
Duration, sec/sow	7.80	69.22	12.58	64.44	69.16	7.85				
Transformed data[2]	1.45	2.25	0.92	2.78	2.97	0.73	0.43	0.21	0.01	0.001
Wins, #/sow	0.60	2.10	0.23	2.44	2.46	0.23				
Transformed data[2]	-1.19	-0.45	-1.57	-0.06	-0.09	-1.55	0.27	0.06	0.001	0.001
Parallel pressing										
Frequency,#/sow	0.71	1.72	0.70	1.74	2.28	0.15				
Transformed data[2]	-1.04	-0.31	-1.04	-0.30	0.49	-1.83	0.24	0.02	0.01	<0.001
Duration, sec/sow	24.91	109.60	61.03	73.49	129.34	5.18				
Transformed data[2]	0.42	2.14	0.63	1.93	3.73	-1.16	0.66	0.01	0.05	<0.001
Wins, #/sow	0.28	0.56	0.21	0.62	0.81	0.02				
Transformed data[2]	-1.60	-1.20	-1.67	-1.13	-0.58	-2.21	0.20	0.17	0.07	<0.001

[1]No interactions were significant for any variables ($P > 0.05$).

[2]Data were transformed using logarithm (X'=log10 X) to achieve normal distribution.

Table 7. Effects of DDGS on behavioral time budget of gestating sows housed in stalls

Item	Diet treatment		Parity		Period		Pooled	*P*-Value[1]		
	Control	DDGS	Parity 1	Parity 2	Day	Night	SE	Diet	Parity	Period
Number of focal sows	15	12	17	10	27	27				
Behavioral time budget, %										
Resting[2]	66.4	73.1	74.2	65.4	61.1	78.5	2.70	0.02	0.01	<0.001
Stereotypies[3]	27.6	22.8	21.6	28.7	34.4	15.9	2.60	0.07	0.02	<0.001
Others[4]	5.9	4.1	4.2	5.8	4.4	5.6				
Transformed data[5]	1.557	1.189	1.26	1.486	1.095	1.651	0.13	0.04	0.20	0.01

[1]Interactions between parity and period were observed for resting and stereotypic behaviors (both $P < 0.01$), with parity 1 sows spending more time resting and less time performing stereotypic behaviors than parity 2 sows during daytime, but not during night time; and there were no interactions among dietary treatment, parity, and period for other variables (all $P > 0.10$).

[2]Sows were lying either laterally or ventrally, without oral and nasal behaviors.

[3]Sows were performing oral or nasal behaviors repetitively.

[4]Sows were performing none of above behaviors.

[5]Data were transformed using logarithm (X'=log10X) to achieve normal distribution.

Table 8. Effects of feeding diets containing high level of distillers dried grains with solubles (DDGS) to sows for three reproductive cycles on DM digestibility, and quantity and composition of manure output

Item	Control		DDGS		Pooled SE	P-value		
	1st Cycle	3rd Cycle	1st Cycle	3rd Cycle		Diet	Cycle	Diet*Cycle
No. of sows	9	10	10	11				
Gestation ADFI, kg	2.3	2.1	2.3	2.2	0.06	0.37	0.17	0.64
DM digestibility, %	80.8	85.0	73.6	79.9	3.34	0.01	0.33	0.66
Feces, g/d[1]	642	480	870	640	93.12	<.01	0.23	0.59
Fecal moisture, %	37.6	41.3	36.1	39.6	1.47	0.24	0.17	0.93
Urine, L/d	3.2	4.2	2.5	5.2	0.86	0.95	0.28	0.15
Urine to feces ratio	5.2	9.9	3.0	11.9	2.33	0.07	<.01	0.17
Slurry output, L/d	3.7	4.4	3.2	5.8	0.90	0.38	0.64	0.17
Nitrogen, kg/3,800 L	38.4	31.6	41.4	27.3	3.76	0.87	0.01	0.34
Phosphorus, kg/3,800 L	32.0	24.8	35.2	23.3	4.23	0.84	0.03	0.58
Potassium, kg/3,800 L	14.9	10.1	15.2	9.0	1.69	0.81	0.11	0.67

[1]Feces was as-collected basis.