RESEARCH REPORT

ANIMAL WELFARE

Title: Optimized Minimal Floor-space for Group-Pen System Using Feeding Stalls and Diet Strategy to Improve Well Being**, NPB #12-200**

Investigator: Janeen L. Salak-Johnson, PhD

Institution: University of Illinois

Date Submitted: 10/8/2015

Industry Summary:

Sow aggression is a common problem associated with group-housing systems especially during feeding and mixing of sows. Grouped-housed sows establish a social hierarchy upon mixing which often reduces aggressive encounters later-on, however pregnant sows often still engage in aggressive encounters at feeding time due to feed restriction, which can compromise performance, productivity, and well-being of the gestating sow. Realistically, it is not feasible to completely eliminate aggressive encounters among group-kept gestating sows, but it may be plausible to minimize the potential negative effects of aggression on group-kept gestating sows. Therefore, the main objective of this study was to assess the effects of housing small groups (n = 9 sows per pen) of gestating sows in pens at floor-space allowance of 1.7 m^2/sow equipped with feeding stall partitions that varied in length (2 ft. vs 6ft.) and fed modified high fiber diet of either 30% wheat middlings-15% soy hulls (Midds-Hulls) or 30% DDGS- 30% corn germ meal (DDGS-GM) on sow well-being. The secondary objective of this study was to more specifically assess the effects that these treatment combinations had on well-being of two lowest ranked sows (submissive) within the group. For the most part, length of feeding partitions and type of high fiber diet had minimal effects on immune, endocrine and performance and productivity, except for improved piglet weaning weight. However, sow social rank played a role in the effects of diet and length of feeding partition on well-being. Specifically, submissive sows housed in pens with long feeding partitions and fed a high fiber diet of DDGS supplemented with corn germ meal weaned the heaviest pigs and received the least number of aggressive encounters. These results imply that if group-pens are not properly designed in terms of adequate floor-space and length of feeding stall partition there are minimal effects on the overall well-being of gestating sows in terms of performance and productivity. Moreover, these data imply that well-being of socially submissive sows may be improved by housing them in pens with longer feeding stalls and feeding them a high-fiber diet. Taken together, these results imply that sow social status is an important factor that should be considered when implementing group pen systems and that housing environment and dietary strategies may be a management tool that can be used to improve at least submissive sow well-being.

Keywords: Feeding stalls, Group-pens, Social Status, Sows, Well-being

Scientific Abstract: One of the main concerns with housing gestating sows in group pens is the increased aggression at mixing and around limited resources which often results in variable body conditions scores and higher lesion and injuries. Grouped-housed sows establish a social hierarchy upon mixing which often reduces aggressive encounters later-on, however pregnant sows still engage in aggressive encounters at feeding time due to feed restriction, thus affecting sow well-being. At gestational d 37, groups of 9 multiparous sows/pen (n=144, 36/block) that were randomly assigned by BW and parity to a 2 x 2 factorial arrangement, with dietary treatments of either (**a**) soy hulls-wheat middlings (**Midds-Hulls**) or (**b**) DDGS-corn germ meal diet (**DDGS-GM**) modified gestation diets, and feeding stall length of either (**c**) 2 ft. (**SHORT**) or (**d**) 6 ft. (**LONG**). Social rank (n = 64 sows) was determined using a feed competition test to assign dominance value (**DV**) of either dominant (**DOM**) or submissive (**SUB**). Within each treatment pen a DV was calculated based on aggressive encounters during the feeding test. Sow performance, productivity, behavior, immune and endocrine status were assessed throughout gestation to determine sow well-being. Lesion scores and blood glucose along with behavior at collection were recorded every 3 d for 2-wks post mixing (Phase 1), and then again on a bi-weekly basis until gestational d 104 (Phase 2). Data were analyzed using PROC MIXED with repeated measures and PROC GLIMMIX for ordinal data (SAS). No effects of diet × feeding partition length occurred for sow- or litter-related traits. Sows fed DDGS-GM loss less BW ($P < 0.01$) from gestational d 90 through end of lactation and had greater BF depth (P =0.05) at end of lactation compared with sows fed Midds-Hulls diet. Those same sows also weaned heavier piglets than did sows fed Midds-Hulls diet ($P = 0.02$). There was no diet × feeding partition length effect on total lesion severity during phase 1 ($P > 0.05$), but there was an effect on lesion severity scores during phase 2. Sows housed in pens with SHORT feeding partitions and fed either Midds-Hulls or DDGS-GM diet had least severe total lesion scores ($P = 0.04$). Sows fed Midds-Hulls diet had lower ($P = 0.03$) total lesion severity score during phase 2. Regardless of diet, sows housed in pens with SHORT feeding partitions had less severe lesion scores during both phases ($P < 0.01$). Interactions of feeding partitions and dietary fiber with social rank affected sow performance, behavior, productivity, and immune status. Socially, SUB sows were heaviest when housed in pens with LONG feeding stalls than with SHORT (social status x stall length; $P < 0.02$), and SUB sows were also heaviest when fed Midds-Hulls diet and performed equally when compared with DOM sows (social status x diet; $P < 0.01$). Total aggressive encounters (AE; $P < 0.02$) and no. of AE towards SUB sows were lowest ($P < 0.004$) when housed in pens with LONG feeding stalls and fed DDGS-GM diet (diet x stall length). Percentage of standing and sitting was greatest ($P < 0.02$) for SUB sows fed DDGS-GM, but highest ($P < 0.004$) percentage of eating was observed when sows were fed Midds-Hulls diet. Heaviest ($P < 0.01$) adjusted litter and piglet wean BW ($P < 0.005$) was found among piglets weaned from SUB sows in pens with LONG feeding stalls and fed DDGS-GM diet (social status × diet × stall length). Based on these results, it seems plausible to increase average piglet weaning weight by feeding sows a DDGS-GM diet from gestational d 35 to 104. However, the feeding partition lengths did not affect performance and productivity of sows housed in small groups, with exception of lesion severity scores which may be reflective of either inadequate length and/or floor-space allowance. Results from this research show that socially dominant and submissive sows both perceive and cope with social stress by evoking different biological responses and a combination of housing and dietary strategies can improve submissive sows well-being, therefore social status should be considered when implementing group housing for gestating sows. These results imply that if group-pens are not properly designed in terms of adequate floor-space and length of feeding stall partition there are minimal effects on the overall well-being of gestating sows in terms of performance and productivity. Moreover, these data imply that well-being of socially submissive sows may be improved by housing them in pens with longer feeding stalls and feeding them a high-fiber diet. Taken together, these results imply that sow social status is an important factor that should be considered when implementing group pen systems and that housing environment and dietary strategies may be a management tool that can be used to improve at least submissive sow well-being.

Introduction:

Well-defined, science-based assessment of the welfare of the gestating sow is essential to the future of the entire swine industry. Overall science indicates that in terms of performance, productivity, health, and well-being that sows housed in individual stalls as compared to group-pens have similar values across measurement perspectives (McGlone et al., 2004; McGlone, 2013). No one system has been identified as being better than another based on current notions of sow welfare (McGlone et al., 2004, Rhodes et al., 2005), and there is no template for the ideal housing system in terms of improved sow well-being. Both plusses and minuses are associated with dry sows being housed either individually or in groups, therefore it seems imperative to retain the positives of each system while improving on the constraints of each system. Improvement in each system should encompass individualized care and feeding, improved quantity and quality of space for each sow, while minimizing the negative attributes of each system would be ideal. That is, a housing system should provide every breeding and pregnant animal with access to food and water, allow sows to express appropriate behaviors, while minimizing expression of undesirable behaviors that are detrimental in terms of well-being (within the constraints of the housing system), and minimize aggression and competition between sows, while maintaining or improving sow well-being.

How to keep pregnant sows is a contentious issue facing the swine industry. Group-housing systems are extremely complex, and difficulty with which to come to grips, simply because there are so many factors that must be considered and integrated. Animal accommodations are not jigsaw puzzles meaning that all the pieces do not necessarily fit together perfectly. Yes, group-pens facilitate social living and freedom of movement for gestating sows, but not without welfare consequences. The greatest welfare concerns associated with managing sows in group-pens has to do with minimizing the level of aggression (especially early on), injuries and stress for several days post-mixing as well as subordinate sows being underfed due to competition at feeding. All of these factors can also be influenced by feeding method, floor-space allowance, group size, genetics, and management procedures—just to name a few. Moreover, some of these group housing systems require more highly skilled and attentive stockmanship to successfully manage group-penned sows. When a group-keeping system fails to work well, some sows inevitably experience a poor state of wellness.

The highest level of aggression within a group-pen system occurs during mixing and around resources (e.g., water, feeding) in order to establish social hierarchy. Aggression during the structure of a social hierarchy among group-housed sows is inevitable and reduces overall aggression later on but results in sow's performance and productivity to be affected, especially by individual rank. As aggression increases in group housing, housing and dietary strategies may be the key to improve the submissive sow's well-being. Previous studies have attempted to improve sow well-being in group housing by equipping pens with feeding stalls, Andersen et al. (1999) found decreased aggression and displacements at trough in pens equipped with feeding stalls. Feeding high fiber gestation diets to sows have been shown to improve satiety, decrease aggression, and reduce stereotypic behaviors (Brouns et al., 1994; Danielsen and Vestergaard, 2001; de Leeuw et al., 2004; de Leeuw et al., 2005). Therefore, the objective of this study was to assess the well-being of gestating sows using multiple welfare metrics housed in group pens (9 sows/pen) with feeding stalls (LONG or SHORT) and feed modified gestation diets (soybean hulls-wheat middlings or DDGS-corn germ meal) and to further assess the effects of these treatments on the well-being of submissive sows.

Objectives: To assess the effects of **1)** feeding stall length (2 ft. vs. 6 ft.) and **2)** a high-fiber diet (soybean hulls-wheat middlings vs. DDGS-corn germ meal) using multiple measures of welfare including behavior, physiology and productivity traits on sow well-being (A) and more specifically the effects on well-being of submissive sows (B).

Materials and Methods

Animals, Housing, and Experimental Design

The University of Illinois Institutional Animal Care and Use Committee approved the protocol for this experiment. Crossbred primiparous (parity 0, n=46) and multiparous (parities 1 and 2, n=57; parities ≥3, n=76) sows used in this experiment. All sows were derived from Genetiporc Fertilis 25 genetic sow line kept at the University of Illinois Swine Research Center between September 2013 and June 2015 (36 sows/block). Once pregnancy was confirmed, groups of 9 sows were randomly allocated in a 2 x 2 factorial arrangement to group pens equipped with individual feeding stall lengths of either 2 ft. (**Short**) or 6 ft. (**Long**) and high-fiber gestation diets supplemented with either 30% wheat middlings-15% soy hulls (**Midds-Hulls**) or 30% DDGS-30% corn germ meal (**DDGS-GM**). Treatment diets were fed 2-d (d 35 post-breeding) prior to sows moving into assigned treatment pens. All diets were formulated to meet or exceed NRC requirements (NRC, 2012). Sows were fed 2.23 kg/d of the Midds-Hulls diet from gestational d 35 to 90, and then from d 91 to 104 sows were fed 3.57 kg/d of the diet; whereas, sows fed DDGS-GM diet were offered 2.10 kg/d from d 35 to 90 and 3.37 kg/d from d 91 to 104, respectively. All sows received 6,700 kcal ME/d from gestational d 35 to 90 and 10,720 kcal ME/d from d 91 to 104. Sows were moved to treatment group pens at gestational d 37. Sows were fed as a group and feed was added to each feeding stall space at 0630 h daily. Sows had ad libitum access to water as each feeding stall space was equipped with individual nipple waterer. The floor-space allowance within the pens was 18 ft^2/sow (1.7 m^2 /sow).

All newly bred sows were kept in individual crates prior to the start of the study. Sows were AI within 24 h after the onset of estrus, and then again 24 h later. Pregnancy was confirmed at d 27 post breeding using an EZ Preg Checker VSS700 (Veterinary Sales and Service Inc., Stuart FL.). All sows remained in their assigned treatment pens until approximately gestational d 104, when they were moved to a farrowing facility and remained until the end of lactation. All litters were weaned at 21 d of age ± 2, and sows were returned to the breeding facility. If cross-fostering was necessary, it occurred within same treatments.

Body Lesion Scores

Body lesions scores were recorded prior to sows moving into their respective treatment pens, one day after moving into pens, then every 3 days for the first two weeks post-mixing (phase 1), and then bi-weekly thereafter (phase 2). Lesion scores were recorded as previously described by Salak-Johnson et al. (2007) with minor modifications. Briefly, body regions included: head, ears, neck, breast, shoulders, side, back, udder, rear, vulva, front legs, hind legs, front hooves, and hind hooves. Scores ranged from 0 to 7 for all regions except hooves which had a possible high score of 5. Score 0 = no lesions, 1 = dehairing/callus/balding, 2 = redness/swelling, 3 = swelling and callus/abscess, 4 = scabbed over scratch, 5 = marked wound/fresh scratch, 6 = severe wound/open wound, and 7 = severe swelling. For the hooves, 0 = normal, 2 = swelling/callus, 3 = claw asymmetry, 3 = severe swelling, 4= crown/declaw wound, and 5 = sand crack. Each body region was given a score and all region scores were added to calculate total severity for each day.

Behavior

Sow behavior was captured using EverFocus EQ120/AEN colored cameras (EverFocus Co., LTD., Duarte, CA), Geovision GV-1240 (Geovision, Inc., Irvine, CA) video capture combo card, and viewed using EZViewLog (Geovision, Inc., Irvine, CA), cameras were fixed above each pen to view the entire area and lights were kept on 24 h a day. The Geovision combo card was programmed to record for the first 48 h after mixing and then again for 24 h on a bi-weekly basis. Live behavioral observations were registered during feeding at various time points including first feeding post-mixing, and then every 3-wk thereafter until sows were moved to farrowing facility to analyze aggressive behaviors that occur during feeding. Frequencies and durations of every aggressive encounter (AE) during these time periods was registered which included push, bite, fight, and threat, and for each encounter the initiating and receiving sow was registered. Behavior was registered at collection of blood glucose samples, posture and behavior for each sow was recorded to analyze possible correlations. Behaviors registered at blood glucose collection were eat, drink, sham chew, oral-nasal-facial (ONF), locomotion, stand, sit, and lay.

Social Status (objective B only)

On gestational d 37 (prior to moving into treatment pens) post-feeding, groups of sows were placed in a non-experimental pen to determine social status using a feed competition test previously described by Parent et al. (2012). The non-experimental pen (13.5 ft. x 13.5 ft.) was equipped with one feeder. The feed competition test was captured using EverFocus EQ120/AEN colored camera that was located above the pen and recorded using Geovision GVd1240 for 30 minutes. Initially, sows are acclimated to the non-experimental pen for 5-min, and then 4 kg of the assigned treatment diet was added to the feeder. All aggressive interactions were registered and both the initiator and the receiver during the aggressive encounters were identified. Behaviors registered during feeding competition test included fight, bite, push, chase, and displacement from feeder (Table 3.2). A

Dominance Value (DV) was calculated for each sow based on all aggressive interactions that occurred during the feeding competition test. The equation was:

$$DV = \frac{Aggressive\ Encounters\ Initiated}{(Aggressive\ Encounters\ Initiated + Encounters\ Received)}$$

Based on the calculated DV and number of displacements that occurred in experimental pens, 2 sows per group were identified as dominant (**DOM**) and 2 sows were identified as submissive (**SUB**). This subsample of sows was analyzed separately and used for this analysis (*n*=64; primiparous *n*=21, multiparous *n*=43). After the feed competition, all sows were simultaneously moved to their assigned experimental pen.

Blood Sample Collection and Analysis

Blood samples were collected on gestational d 30, 70, 90, 104, and again at the end of lactation (~ 15 mL) ± 1 d via jugular venipuncture using 30 mL syringes containing 2 mL heparin. Sows were snared and blood samples were obtained > 2 mins. Whole blood smears were made, fixed in methanol, stained with Hema-3 staining system (Fisher Scientific, Houston, TX) and leukocyte differential counts were determined under a light microscope. Total white blood cell counts (WBC) were determined using a Coulter Z1 particle counter (Beckman Coulter, Miami, FL) by adding 10 μL of whole blood to 10 mL of Isoflow (Beckman Coulter) and 3 drops of Zap-oglobin (Beckman Coulter) to lyse red blood cells.

For functional immune assays, 12 mL of whole blood was carefully layered over Histopaque 1077 (density = 1.077 g/mL; Sigma Aldrich, Saint Louis, MO) and 1119 (density = 1.119 g/mL; Sigma Aldrich) and centrifuged for 30 minutes at 700 x g and 25° C. Mixed lymphocyte population was aspirated from the 1077 layer and neutrophils from the 1119 layer. The lymphocyte layer was washed with Roswell Park Memorial Institute media (RPMI; Gibco, Carlsbad, CA), centrifuged for 15 minutes at 1160 x g and 4° C, the pellet was then dissolved in RPMI/5% Fetal Bovine Serum (FBS) and incubated (37°C in a 5% CO_2 humidified incubator) in a petri dish for 1 h to isolate lymphocytes. Cell concentrations were adjusted for the specific requirements of each immune assay. Plasma was collected and stored at -20° C until further analysis.

Immune Assays

To assess innate immune status of sows, natural killer cell (NK) cytotoxicity and neutrophil chemotaxis were measured. Neutrophil chemotaxis was measured using an assay previously described by Salak et al. (1993) and Sutherland et al. (2005). Briefly, neutrophils were used at a concentration of 3 x 10^6 cells/mL, assay medium (RPMI) as a control and recombinant human complement-5a (10^{-5} M; Sigma Aldrich) was used as a chemoattractant. NK cell cytotoxicity was measured using a commercially available nonradioactive cytotoxicity detection kit (Roche Diagnostics, Indianapolis, IN), following the manufacture's protocol and as described by Sutherland et al. (2005) with modifications. Briefly, lymphocytes were used as effector cells and K-562 chronic human myelogenous leukemia cells (American Tissue Type Culture Collection, Manassas, VA) were used as target cells. Lymphocytes were adjusted to concentration of 1 x 10^7 cells/mL, K-562 cells were adjusted to a constant 10,000 cells/well, samples were run in triplicate at effector (lymphocytes) to target cell (K-562) ratios of 12.5:1, 25:1, 50:1, and 100:1. Plates were read using a microplate reader (Thermo Scientific Instruments, Waltham, MA) at a wavelength of 490 nm and reference wavelength of 690 nm. Percent cytotoxicity was calculated as described by Lumpkin and McGlone (1992), and an assay was considered valid if maximum release divided by spontaneous release was ≤ 30%.

To assess adaptive immune status of sows, mitogen induced lymphocyte proliferation assay was performed. Briefly, in triplicate, 100 µL of lymphocytes at a concentration of 5 x 10^6 cells/mL were added to a 96-well flat bottom plate. Concanavalin A (ConA; Sigma Aldrich) and lipopolysaccharide (LPS; Sigma Aldrich) were used as mitogens (ConA: 0, 2, and 20 µg/mL; LPS: 0, 5, and 50 µg/mL) to stimulate T and B cells, respectively. Plates were incubated for 48 h at 37°C in a 5% CO_2 humidified incubator, then 100 µL from each well was removed and 100 µL of RPMI/10% FBS was added, plates were then incubated for 18 h. After 18 h incubation 20 µL of 3-[4, 5-dimethylthiazol-2-yl]-2, 5-diphenyltetrazolium bromide (MTT; Sigma Aldrich) was added to each well, and the plates were incubated for 4 h. Acidified isopropanol (100 µL of 0.1 N HCL in anhydrous isopropanol) was added to each well and plates were read within an hour using a microplate reader (Thermo Scientific Instruments) at a wavelength of 600 nm. The results are expressed as a proliferation index: Optical density of stimulated cells ÷ Optical density of nonstimulated cells.

Plasma Analysis

Total plasma cortisol was measured on d 30 (baseline) and d 90 of gestation using a commercially available RIA cortisol kit, following the manufacturer's protocol with exception of standards made in stripped porcine plasma (MP Biomedicals, Santa Ana, CA). Briefly, in duplicate, 25 µL of sample or standard were added to antibody-coated tubes. 1 mL of radiolabeled (I^{125}) cortisol was added to tubes, vortex, and incubated for 45 min in water bath at 37°C. The liquid phase was aspirated and radioactivity was counted with a gamma counter. A standard curve based on 0, 8, 16, 32, 62.5, 125, and 250 ng/µL was used. Intra- and interassay CV were 9.1% and 8.3% respectively, and sensitivity of 3 pg. Plasma IL-12 was measured on d 30 (baseline) and d 90 of gestation using a commercially available ELISA nonradioactive kit, following the manufacturer's protocol (R&D Systems, Minneapolis, MN). Briefly, in duplicates, 100 µL of diluted sample or standard and 50 µL of assay diluent was added to 96-well microplate coated with a monoclonal antibody specific for porcine IL-12/IL-23 p40. Plates were incubated for 2 h at room temperature on a horizontal orbital microplate shaker and then each well was aspirated and washed five times with wash buffer. Conjugate solution (200 µL) was added to each well and incubated for another 2 h on the shaker. Each well was aspirated and washed five times, then 120 µL of substrate solution was added to each well and incubated for 30 min on the benchtop protected from light. After 30-min incubation, the reaction was stopped with 120 µL of stop solution to each well, and plates were read using a microplate reader (Thermo Scientific Instruments) at a wavelength 450 nm. A standard curve based on 0, 47, 94, 188, 375, 750, 1500, and 3000 pg/mL was used.

Blood Glucose Collection

Blood glucose levels were measured 2 d prior and after treatment diets were fed, then every 3 d for the first two weeks post-mixing, and then again on a biweekly basis until sows were moved into farrowing crates. Blood glucose was measured 30 min prior to feeding and 30, 60, 90, and 120 min post feeding at each measurement day. The Precision Xtra monitor was used in combination with Precision Xtra strips (Abbott, Alameda, CA) to immediately determine the glucose level in a drop of blood as previously described by de Leeuw et al. (2005). A drop of blood was obtained from the ear vein using a small needle (20 gauge, 1 in.; Excel International). Samples that were not obtained within 5 min were excluded from the analysis.

Performance and Productivity Traits and Lesions Scores

Sow BW was taken on gestational d 30, 70, 90, 104, and end of lactation (~ d 131), ± 1 d. Sow backfat depth (BF) and body condition score (BCS) were taken on gestational d 30, 90, 104 and end of lactation ± 1 d. Sow BF depth was measured using a longitudinal imaging ultrasound scan cranial to the last rib using an Aloka-500V ultrasound machine (Hitachi Aloka, Wallingford, CT). Sow BCS was determined using visual-appraisal (sow's rear aspect) method (1= emancipated to 5= obese) described by Coffey et al. (1999) and DeDecker et al. (2014). Body lesions scores were taken prior to moving into treatment pen day 0, 1 d after mixing, every 3 d for the first two weeks post-mixing (phase 1), then bi-weekly until gestational d 104, and again at the end of lactation (phase 2). Body lesion scores included hair coat condition, dung freedom, lameness, and various body regions. Body regions (Fig. 3.1) used to assess lesion scores included the head, ears, neck, chest/breast, shoulders, back, udder, rear, vulva, legs and hooves. Lesion scores were based on the presence or absence of an apparently new or old lesion in conjunction with severity of the wound (0 = normal/no lesions; 1 = dehairing, callus, balding; 2 = redness, swelling; 3 = swelling plus callus, abscess; 4 = moderate wound, scabbed over scratch; 5 = marked wound, fresh scratch; 6 = severe wound, open wound; and 7 = severe swelling). Averaging all scores from each body location for each sow resulted in a total body lesion severity score. Litter-related traits included total number of piglets born and born alive, and numbers of females, males, stillborn, mummified, laid on, euthanized, and total mortality (no. stillborn + no. mummified + no. laid on + no. euthanized), and piglets weaned. Calculated litter traits included litter BW at birth, adjusted litter BW at birth (adjusted by number of piglets born), litter wean BW, adjusted litter wean BW (adjusted by number of piglets weaned), and mean piglet weaning BW.

Statistical Analysis

All data were analyzed with the mixed models procedure of SAS (SAS Inst. Inc., Cary, NC), with repeated measures. All traits were tested for departures from normal distribution, and transformations were applied to traits deviating from normal distribution, estimates were shown from original data. A linear mixed-effects model was used to analyze measurements, the model included all possible 2- and 3-way interactions of the fixed effects of diet (MID-HULLS or DDGS-CM), feeding stall length (short or long), and sow social status (DOM or SUB). A random effect of replicate was included in the model to account for potential environmental and management differences across groups. The model for physiological measures also included day of measurement (levels varies depending on measurement). The model for behavior of observations during feedings and blood glucose also included day post treatment (dietary or stall length treatment), which varied depending on measurement. Lesion scores being an ordinal variable required analysis with PROC GLIMMIX (SAS Inst. Inc., Cary, NC) to determine the means with a response distribution of Gaussian. Due to significant differences in BF at gestational d 30, that day was used as a covariate to analyze BF. The GLIMMIX procedure of SAS was used to analyze the number of stillborn, mummified, laid-on, mortality, and cross foster as well as BCS and body lesion scores. Least square means were generated and separated statistically with pairwise *t* tests (PDIFF option). Significance was set at $P \leq 0.05$, whereas trends were discussed at $P \leq 0.10$.

Results

<u>Objective 1:</u>

Sow- and litter-related traits. No diet × feeding partition length interaction occurred for or feeding partition length for any sow-related performance traits ($P > 0.05$; Table 2); however, there were main effects of diet on several sow-related performance traits (Table 2). Dietary treatment had no effect on sow mean BW throughout gestation except for at the end of lactation sows fed DDGS-GM tended to be heavier than sows fed Midds-Hulls diet ($P = 0.09$; Table 2). Conversely, sow BW change was affected by dietary treatment, specifically those sows fed DDGS-GM diet gained more BW between gestational d 30 and end of lactation than did sows fed Midds-Hulls ($P < 0.01$; Table 2), with the exception of BW gain from gestational d 70 to 104, those sows fed Midds-Hulls diet gained more BW (P < 0.01; Table 2). Sows fed Midds-Hulls diet loss more BW from gestational d 90 to end of lactation ($P < 0.01$; Table 2). At end of lactation, sows fed DDGS-GM diet had deeper mean BF ($P = 0.05$) and tended to have deeper BF at gestational d 90 ($P = 0.09$) than did sows fed Midds-Hulls diet (Table 2).

There were no effects of dietary treatment × feeding partition length or main effects of feeding partition length on any litter-related traits ($P > 0.05$; Table 3). Only average piglet weaning weight was affected by diet; sows fed DDGS-Germ Meal diet weaned heavier piglets (7.09 ± 0.2 kg) compared to sows fed Midds-Hulls diet (6.75 ± 0.2 kg; $P = 0.02$). Sows fed DDGS-Germ Meal diet tended to have less stillborn piglets per litter compared to sows fed Midds-Hulls diet, 1.29 ± 0.2 versus 1.86 ± 0.2, respectively ($P = 0.08$). There were no effects on all other litter-related traits.

Sow Body Lesion Scores. There was a diet × feeding partition length interaction for sow body lesion scores (Table 4). During phase 1 (time of mixing till 2-wks post), sows fed DDGS-GM diet and housed in pens with SHORT feeding partitions had the greatest lesion score at the ears ($P < 0.01$), while sows fed the same diet, but housed in pens with LONG feeding partitions had more severe lesions at the udder and vulva ($P \leq 0.01$). During phase 2 (bi-weekly till d 104), sows housed in pens with SHORT partitions and fed either diet had the lowest total lesion severity score, while sows fed DDGS-GM and housed in pens with LONG partitions had the highest lesion score ($P = 0.04$). Sows fed DDGS-GM diet and housed in pens with LONG feeding partitions had more severe lesions at the ears than did sows in other treatments ($P < 0.01$).

Lesion scores at all body regions were not different between sows fed Midds-Hulls diet and sows fed DDGS-GM diet, except for lesions at the udder and front hooves (Table 5). Sows fed Midds-Hulls diet had lowest udder lesion score ($P = 0.02$) and those fed DDGS-GM diet had less severe lesions at the front hooves (P < 0.001). Furthermore, there was a tendency for sows fed DDGS-GM diet to have least severe neck lesion score compared to sows fed Midds-Hulls diet ($P = 0.06$). There was also a dietary treatment effect on lesion scores during phase 2 (Table 5). Sows fed Midds-Hulls diet had lowest total lesion severity ($P = 0.03$) and least severe lesions at the ears ($P =0.03$) and back ($P < 0.01$). Sows fed DDGS-GM diet had least severe vulva lesion score ($P = 0.04$).

There was a feeding partition length effect on total lesion severity score (Table 5). Sows housed in pens with SHORT partitions had lower total severity scores during both phases ($P < 0.01$). Moreover, lesions at the neck, back, rear, vulva, and hind legs among these sows were less severe during both phases (all $P < 0.01$). Head lesion scores (phase 1) were lower among sows housed in pens with SHORT feeding partitions ($P < 0.01$). During phase 1, sow ear lesion scores were less severe for sows housed in pens with LONG feeding partitions, but during the phase 2 sows housed in pens with SHORT feeding partitions had lowest ear lesion scores (both $P = 0.01$).

Immunology and Endocrine traits. Interactive effect of dietary treatment × feeding partition length occurred for neutrophil counts on gestational d 104 ($P = 0.02$). Sows housed in pens with SHORT partitions and fed Midds-Hulls diet had higher neutrophil counts compared to sows in all other treatments, but mean neutrophil counts were similar. All other measures were not different among treatments. There were main dietary effects on several descriptive immune traits. Sows fed DDGS-GM diet had greater ($P = 0.03$) total WBC counts than did sow fed Midds-Hulls diet (7.22 vs. 6.77, 10^7/mL), but sows fed Midds-Hulls had greater ($P = 0.02$) total neutrophils than did sows fed DDGS-GM (2.1 vs. 1.9, 10^6/mL). All other descriptive immune traits were not different between sows fed either diet.

There were dietary treatment effects on percentages of lymphocytes, monocytes, and neutrophils (Table 6). Sows fed DDGS-GM diet had greater percentages of lymphocytes and monocytes than did sows fed other diet (*P* < 0.01 and *P* = 0.02, respectively). Sows fed Midds-Hulls had greater percentage of neutrophils and neutrophil-to-lymphocyte ratio (both *P* < 0.01) than did sows fed other diet. There were no dietary treatment × feeding partition length interaction occurred for LPS- or ConA-induced lymphocyte proliferation (*P* > 0.05). Sows fed DDGS-GM diet had more stimulated B-cell but less stimulated T-cell response at gestation day 90 than did sow fed Midds-Hulls diet (P < 0.05). There were no main effects of diet or feeding partition length on cortisol or IL-12 concentrations, but there was a tendency for sows housed in pens with long partitions to have higher IL-12 concentrations (*P* = 0.07).

Aggressive Encounters. No diet × feeding partition length interaction or main effects of diet occurred for aggressive behavior (*P* > 0.05). Sows housed in pens with short feeding partitions (*P* < 0.01) had shorter bouts of aggression than did sows in pens with long (Table 7). Sows housed in pens with short feeding partitions had more non-physical encounters (*P* = 0.02) and more social interactions in the pen area (*P* = 0.02) than did sows in pens with long. The frequencies of aggressive encounters and other interactions were not different between sows in pens with either feeding partition length.

<u>Objective 2:</u>

Social status × feeding partition length and social status × dietary treatment occurred for several performance traits including sow mean BW, BW gain and loss, BF depth and few litter-related traits (Table 8). Socially, DOM sows were heaviest and gained the most BW from gestational d 30 to 70 when housed in pens with SHORT partitions (social status × partition length). Socially, DOM sows fed DDGS-GM diet were heaviest, while SUB sows were heaviest when fed Midds-Hulls diet. Sow BF depth tended to be greater among DOM sows fed DDGS-GM diet, but SUB sows had similar BF regardless of diet.

Both, DOM and SUB sows had most severe lesion scores when housed in pens with LONG feeding stalls than in pens with SHORT (social status x stall length; Table 9). Social status × diet interactions occurred for lesions scores at head (*P* < 0.002), ears (*P* < 0.08), side (*P* < 0.002), back (*P* < 0.07), and vulva (*P* < 0.06). Total severity scores were lowest (*P* < 0.003) for sows in pens with SHORT feeding stalls and fed DDGS-GM diet, regardless of social status (Table 9). Productivity measures were not different regardless of social status and dietary treatment.

A 3-way interaction occurred and interactive effect of social status × feeding stall length occurred for productivity traits. Piglets weaned from socially, SUB sows housed in pens with LONG feeding stalls and fed DDGS-GM diet had the heaviest adjusted litter (*P* < 0.01; Fig. 1) and piglet wean BW (*P* < 0.005; Fig. 2). Socially, SUB sows housed in pens with SHORT feeding stalls had heaviest piglet wean BW and had similar piglet weaned BW as DOM sows (Fig 3).

Total WBC, percentage of lymphocytes, monocytes, and immature (banded) neutrophils showed a tendency (*P* < 0.10) in a social status x feeding stall length interaction. Socially, DOM sows had the lowest (*P* <

0.07) glucose level and percentage of monocytes ($P < 0.03$) when fed DDGS-GM diet, and SUB sows had similar levels regardless of diet and were similar to DOM sows that were fed Midds-Hulls. Percentage of lymphocytes ($P < 0.08$), cortisol concentration ($P < 0.08$), and neutrophil: lymphocyte ratio (N:L; $P < 0.04$) were all affected by social status × diet × stall length interaction. The N:L ratio was greatest for DOM sows housed in pens with SHORT feeding stalls and fed Midds-Hulls diet and SUB sows housed in pens with LONG feeding stalls and fed the same diet had the lowest ratio. Socially, SUB sows housed in pens with LONG feeding stalls had greater blood glucose levels than sows in other treatment combinations (social status x stall length; Fig. 4).

Total aggressive encounters (AE; $P < 0.02$) and no. of AE towards SUB sows were lowest ($P < 0.004$) when housed in pens with LONG feeding stalls and fed DDGS-GM diet while the lowest AE:Displacement ratio ($P < 0.01$) occurred among those housed in pens with SHORT feeding stalls regardless of diet (diet x stall length; Table 10). The AE during feeding for feeding stall length x day post stall treatment interaction were significant for all measures except total displacements ($P < 0.15$) and no. of displacements towards SUB sows ($P < 0.13$; Table 11). Percentages of displacement of SUB sows was calculated by no. AE by DOM towards SUB sows ($P < 0.002$) and no. of displacements by DOM towards SUB sows ($P < 0.09$), which showed SUB sows experienced the lowest percentage displaced when housed in pens equipped with LONG stalls throughout gestation. The AE among sows during feedings for diet x day post stall treatment interaction were similar for all behaviors.

Discussion

Previous studies have reported contradictory findings on the effects of high-fiber diets on sow BF depth and BW loss, while most reported minimal to no effects on litter-related traits (McGlone and Fullwood, 2001; Danielsen and Vestergaard, 2001; Guillemet et al., 2006; Holt et al., 2006). In the present study, these data imply that sows fed DDGS-Germ Meal diet during gestation had greater BF depth at the end of lactation, loss less BW during lactation, and weaned heavier piglets than sows fed Midds-Hulls diet. McGlone and Fullwood (2001) found gilts were heavier at farrowing when fed a beet pulp fiber diet compared to gilts that were fed a control diet, but BW change during lactation was not different regardless of diet. In the present study, sows were not weighed at farrowing, but based on the last BW recorded prior to farrowing was at gestational d 104 (one-wk prior to farrowing), and on that day sow BW was not different among sows fed either diet. Since there was no difference in litter birth weight, we speculate that the difference in BW change from d 104 to end of lactation is most likely reflective of the BW loss during lactation. It is plausible that those sows fed Midds-Hulls diet used more energy resources (indicated by the greater BW and BF depth loss) to produce milk compared to sows fed the DDGS-Germ Meal diet. We speculate that sows fed Midds-Hulls diet may have diverted some nutrients in order to cope with stress, hence more loss in BF depth and BW. Sows fed the Midds-Hulls diet had a higher neutrophil-to-lymphocyte ratio indicating that these sows may have been more stress responsive to stimuli than those sows fed DDGS-Germ Meal diet.

The most common stressor in group-housing is aggression, however sows fed the Midds-Hulls had less severe lesions than sows fed the DDGS-Germ Meal diet suggesting that there was less aggression among sows fed the former diet. Another common stressor in group housing is not enough feed intake, it has been shown that food deprivation can cause stress (Anderson, 1975; Tsuma et al., 1996; Mburu et al., 1998). In the present study sows were simultaneously fed which could have led to some sows eating more and others eating less feed. Perhaps sows fed the Midds-Hulls diet did not provide enough satiety compared to sows fed DDGS-Germ Meal diet. Sows fed the Midds-Hulls diet had more severe lesions at the vulva which may indicate that they tried to displace each other more than sows fed the DDGS-Germ Meal diet. Both competing for feed and eating less than their allotted feed may have led to the stress experienced by sows fed the Midds-Hulls diet. As a result, they gained less BW and loss more BF depth. Furthermore, the effects of stress during gestation could have impacted sows during lactation, for instance sows fed the Midds-Hulls diet could have had less energy reserves leading to less milk production thus weaning lighter piglets.

Feeding partitions were used in an attempt to reduce sow aggression, it was hypothesized that the LONG feeding partitions would provide more protection and thus result in less body lesions since the stalls were long enough to protect the entire body. Surprisingly, sows housed in pens with LONG feeding partitions had more severe lesions during both phases, especially at the neck, back, rear, and hind legs. During phase 1, sows housed in pens with LONG feeding partitions had more lesions at the back and rear, 1.37 and 1.76 difference, respectively. Similarly during phase 2, sows housed in pens with LONG feeding partitions had higher lesion scores at the neck, back, rear, and hind legs (differences were 0.98, 0.92, 1.79, and 1.41 respectively). We speculate that the pen design may partially explain higher scores among these sows. The LONG feeding partitions were essentially standard gestation stalls with backs removed and the feeding partition floor-space was included in the total floor-space allowance per sow. We speculate that sows ability to easily leave the long feeding partition space was hindered by restricted-space and the hinges that were left on once the gestation stall back gates were removed. Furthermore, lesion on the rear and hind legs were a lot more severe on sows housed in pens with LONG feeding partitions which may have been due to sows trying to displace one another but not having adequate space to leave or enter the feeding stall space. Since most of the sow's body was protected with the LONG feeding partitions it would have been more difficult for sows to displace one another thus sow displacement would have taken longer and thus the greater duration of aggressive encounters. In addition, the space between the end of the LONG feeding partitions and the end of the pen was a lot smaller than the space between the SHORT feeding partitions and the end of the pen so the minimal space in the former pen could have forced sows to hit the fences with their rears and hind legs.

In an early study by Barnett et al. (1992) there was no difference in the number and length of lesions between gilts housed in pens with feeding partitions and gilts housed in pens without any feeding partitions. Barnett et al. (1992) compared the number and length of lesions as oppose to the present study, were scores were given based on the presence or absence of lesions and severity. Furthermore, Barnett et al. (1992) only used gilts while the present study used gilts and multiparous sows which can contribute to the different findings. In a similar study, Andersen et al. (1999) compared the use of body and shoulder feeding partitions along with feeding wet or dry feed to sows. Sows housed in pens with body feeding partitions and fed a dry diet received less bites at the head, shoulder, and body. In addition, total aggressive behaviors and displacements at the trough were reduced in sows housed in pens with body feeding partitions compared to sows housed in pens with shoulder feeding partitions or with no partitions at all. These results are contrary to what was found in the present study, where sows housed in pens with LONG feeding partitions had higher total severity scores and more lesions at the head (phase 1). Unlike in Andersen et al. (1999) in this study there were no differences in shoulder lesions and the sow body was categorized into different regions. Lesions on the side were not different but sows housed in pens with LONG feeding partitions had more severe lesions on the back. Andersen et al. (1999) found more vulva bites in sows housed in pens with body partitions and the same was found in the present study, sows housed in pens with LONG feeding partitions had more severe lesions at the vulva. Krause et al. (1997) found that most of the aggression between gilts housed in groups was towards the head instead of the side or rear, but in the present study more lesions were seen on the shoulder, side, and hind legs than in the head. This may partly be explained by the observation that during feeding, when most aggression occurred, the head of the sow was in the feeding trough and protected by the feeding partitions while the side and hind legs were exposed. Sows could have squeezed between the sow and the feeding partition and attacked the side.

Despite the differences in body lesions due to the different feeding partition treatments sow performance and productivity was not compromised. Sows housed in LONG feeding partitions had more severe lesions, yet they did not have different BW, BF, BCS, and litter traits as sows housed in SHORT feeding partitions. This suggests that sows housed in LONG feeding partitions were able to cope with their environment without compromising their well-being in terms of performance and productivity. Based on these results, average piglet weaning weight can be increased by feeding sows a high fiber, high energy diet from gestational d 35 to 104, however the feeding partition lengths used in this study at the floor space of 1.7 m^2 had no effect on performance and productivity of sows housed but 0.6 m feeding partitions resulted in less severe body lesion scores. More research needs to be done on the effects of high energy diets by comparing it with a control diet. Feeding partitions could be further studied but differences in structure should be minimized. Despite sows being able to cope with different environmental challenges different well-being measures should be used to determine which environment is best.

Aggression among group-housed gestating sows can lead to an increase in lesion scores, injuries and reduced productivity. Most aggression occurs upon mixing and at feeding, especially around resources (e.g. feed and water). At mixing, sows engage in aggressive encounters to establish a social hierarchy, once social stability is achieved sows tend to engage in these conflicts around resources. If a competitive feeding system is used in a group-housing system, this increases the opportunity for the more-dominant sows within the group to displace lower ranked sows from their feeding space before they have time to consume their daily allotment of feed, thus some sows consume more feed while others consume less feed. Social status and feeding systems are important factors that need to be considered when managing sows in group-pens, especially the submissive sows. Submissive sows receive more aggression and are displaced more often from the feeder, especially in pens with competitive type feeding systems (Andersen et al., 1999; O'Connell et al., 2003).

Social status has been shown to influence sow performance as socially dominant sows gain more BW (O'Connell et al., 2003; Zhao et al., 2013) and have greater productivity than socially submissive sows (Tuchscherer et al., 1998; Hoy et al., 2009). However, in this study when submissive sows were fed Midds-Hulls diet had similar BW gain as dominant sows and when they were in pens with LONG feeding stalls they were subjected to less aggressive encounters throughout gestation. This suggests the severe lesion scores that were seen for both socially DOM and SUB sows when housed in group pens equipped with LONG feeding stalls than with SHORT feeding stalls was due to the experimental design of the pen and not aggression.

When assessing the effects of influence of feeding system on individual social rank, previous studies have shown submissive sows benefit from simultaneous and protective feeders against other sows rather than sequential and non-protective feeders (Andersen et al., 1999; Chapinal et al., 2010). In this study, submissive sows seemed to benefit most when housed in pens with LONG feeding stalls and fed DDGS-GM diet. They experience the least number of aggressive encounters and had heavier litter weaning BW and average piglet wean BW especially when compared with submissive sows in other treatment combinations. It is plausible that submissive sows differentially divert energy toward other biological resources than do dominant sows in group housing systems. Socially, submissive sows feed the DDGS-GM diet may have had more energy stores during lactation as they avoided conflicts (Beilharz and Cox, 1967) during gestation and were fed a higher energy diet thus diverted more energy into storage per se than into conflicts. Conversely, dominant sows were the aggressors and more than likely had to expand energy during aggressive interactions and maintaining social status which may have also partly explain the differences in piglet BW. Although, dominant sows spent a greater percentage of their time lying than did submissive sows in the same treatment environment, the dominant sows SUB sows, the recovery of its energy cost from aggressive encounters may not have been possible for the DOM sows.

Taken together, these findings imply that housing gestating sows in group pens with long feeding stalls and feeding them a high-fiber diet may improve the well-being of socially submissive sows, but improper design of group pens with feeding partitions and fed high-fiber diet has little to no effect on sow well-being. Therefore, combining housing and dietary management strategies can impact sow well-being based on social rank in a competitive feeding system.

Table 1: Composition of modified gestational diets used in the experiment.

Item	Wheat middlings-soybean hulls (**Midds-Hulls**)	DDGS-corn germ meal (**DDGS-GM**)
Ingredients, %		
Corn	38.90	33.65
Soybean meal, 48%	12.50	2.50
Soybean hulls	15.00	-
Wheat middlings	30.00	-
DDGS	-	30.00
Corn germ meal	-	30.00
Soybean oil	1.00	1.00
Limestone	1.30	1.60
Dicalcium phosphate	0.60	0.55
Salt	0.40	0.40
Vitamin mineral premix	0.30	0.30
Total	100.00	100.00
Energy and nutrients		
Energy, Kcal ME/kg	2,999	3,177
Crude protein, %	13.78	18.96
Calcium, %	0.78	0.78
Phosphorus, %	0.61	0.66
Phosphorus, digestible, %	0.34	0.34
Acid detergent fiber, %	9.81	7.93
Neutral detergent fiber, %	23.97	25.75
Amino Acids		
Arginine, %	0.90	0.83
Histidine, %	0.35	0.52
Isoleucine, %	0.59	0.49
Leucine, %	1.05	1.34
Lysine, %	0.61	0.61
Methionine, %	0.21	0.45
Methionine + cysteine, %	0.46	0.66
Phenylalanine, %	0.60	0.58
Threonine, %	0.43	0.51
Tryptophan, %	0.15	0.23
Valine, %	0.59	0.59

Table 2: Effects of treatments on sow performance (least-squares means ± SE).

Performance trait	Midds-Hulls	DDGS-GM	Diet P-value	SHORT	LONG	P-value	Diet × Stall[1]
Mean BW, kg	233.4 ± 5.6	234.4 ± 5.6	0.67	235.0 ± 5.6	232.8 ± 5.6	0.33	0.59
BW, kg (d30)	219.7 ± 5.7	221.6 ± 5.7	0.65	221.8 ± 5.7	219.5 ± 5.7	0.58	0.74
BW, kg (d70)	227.2 ± 3.5	223.0 ± 3.5	0.40	224. 6 ± 3.5	225.6 ± 3.6	0.85	0.79
BW, kg (d90)	235.4 ± 6.4	236.4 ± 6.4	0.88	238.4 ± 6.4	233.7 ± 6.4	0.29	0.79
BW, kg (d104)	256.5 ± 6.5	255.0 ± 6.5	0.75	257.6 ± 6.5	253.9 ± 6.5	0.43	0.97
BW, kg (end of lactation)	223.8 ± 8.1	233.5 ± 8.0	0.09	230.4 ± 8.0	226.9 ± 8.1	0.55	0.78
BW, kg (d 30 to 70)	10.0 ± 1.4	8.19 ± 1.4	0.29	9.25 ± 1.4	8.95 ± 1.4	0.86	0.76
BW, kg (d 30 to 90)	14.8 ± 1.8	14.0 ± 1.8	0.68	15.0 ± 1.8	13.8 ± 1.8	0.54	0.80
BW, kg (d30 to 104)	34.0 ± 1.8	31.7 ± 1.8	0.28	33.0 ± 1.8	32.8 ± 1.8	0.93	0.62
BW, kg (d30 to end of lactation)	1.11 ± 2.2[a]	9.22 ± 2.1[b]	< 0.01	3.74 ± 2.1	6.59 ± 2.1	0.22	0.54
BW, kg (d70 to 90)	5.23 ± 1.0	3.74 ± 1.0	0.08	4.89 ± 1.0	4.08 ± 1.0	0.35	0.95
BW, kg (d70 to 104)	25.6 ± 1.2[a]	20.6 ± 1.2[b]	< 0.01	23.2 ± 1.2	23.0 ± 1.2	0.86	0.36
BW, kg (d70 to end of lactation)	-6.41 ± 4.7	-2.94 ± 4.7	0.11	-5.93 ± 4.7	-3.42 ± 4.7	0.25	0.68
BW, kg (d90 to 104)	20.9 ± 0.7[a]	17.3 ± 0.7[b]	< 0.01	18.7 ± 0.7	19.4 ± 0.7	0.35	0.77
BW, kg (d90 to end of lactation)	-13.2 ± 3.7[a]	-5.99 ± 3.7[b]	< 0.01	-11.1 ± 3.7	-8.12 ± 3.7	0.16	0.25
BW, kg (d104 to end of lactation)	-32.8 ± 3.7[a]	-23.0 ± 3.6[b]	< 0.01	-28.7 ± 3.6	-27.0 ± 3.6	0.44	0.19
Mean BF, cm	1.86 ± 0.03	1.92 ± 0.03	< 0.01	1.89 ± 0.03	1.89 ± 0.03	0.75	0.62
BF, cm (d30)	1.97 ± 0.06	1.83 ± 0.06	0.04	1.91 ± 0.06	1.89 ± 0.06	0.68	0.25
BF, cm (d90)	1.87 ± 0.05	1.96 ± 0.05	0.09	1.89 ± 0.05	1.94 ± 0.05	0.65	0.96
BF, cm (d104)	1.91 ± 0.05	1.99 ± 0.05	0.18	1.96 ± 0.05	1.93 ± 0.05	0.56	0.94
BF, cm (end of lactation)	1.69 ± 0.04	1.83 ± 0.04	0.05	1.75 ± 0.04	1.76 ± 0.04	0.91	0.93
Mean BCS	2.99 ± 0.02	2.98 ± 0.02	0.75	2.98 ± 0.02	2.98 ± 0.02	0.90	0.06
BCS, d37	2.99 ± 0.03	3.01 ± 0.03	0.57	3.01 ± 0.03	2.99 ± 0.03	0.57	0.34
BCS, d90	2.99 ± 0.04	2.96 ± 0.04	0.53	2.98 ± 0.04	2.96 ± 0.04	0.78	0.36
BCS, d104	3.07 ± 0.04	3.01 ± 0.04	0.23	3.03 ± 0.04	3.05 ± 0.04	0.59	0.63
BCS, end of lactation	2.90 ± 0.07	2.93 ± 0.07	0.50	2.90 ± 0.07	2.92 ± 0.07	0.64	0.15

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

[1] Probability value for the diet x feeding partition length interaction.

Table 3: Effects of treatments on litter-related traits (least-squares means ± SE).

Litter trait	Midds-Hulls	DDGS-GM	Diet P-value	SHORT	LONG	Length P-value	Diet × Partition[1]
Litter birth weight (kg)	19.7 ± 1.1	20.0 ± 1.1	0.68	19.7 ± 1.1	20.0 ± 1.1	0.75	0.34
Total born (No./litter)	14.3 ± 0.6	13.7 ± 0.6	0.23	14.2 ± 0.6	13.8 ± 0.6	0.41	0.48
Total born alive (No./litter)	12.3 ± 0.6	12.3 ± 0.6	0.93	12.5 ± 0.6	12.0 ± 0.6	0.32	0.80
Males (No./litter)	5.73 ± 0.3	6.07 ± 0.3	0.33	6.13 ± 0.3	5.67 ± 0.3	0.18	0.42
Females (No./litter)	5.82 ± 0.3	5.55 ± 0.3	0.48	5.52 ± 0.3	5.85 ± 0.3	0.38	0.24
Stillborn (No./litter)	1.86 ± 0.2	1.29 ± 0.2	0.08	1.56 ± 0.2	1.59 ± 0.2	0.93	0.45
Mummified (No./litter)	0.14 ± 0.07	0.16 ± 0.07	0.69	0.15 ± 0.07	0.16 ± 0.07	0.90	0.66
Laid-on (No./litter)	0.88 ± 0.1	0.88 ± 0.1	0.97	0.84 ± 0.1	0.92 ± 0.1	0.67	0.47
Other dead (No./litter)	0.80 ± 0.3	1.08 ± 0.3	0.17	0.91 ± 0.3	0.96 ± 0.3	0.81	0.83
Pre-weaning mortality (No./litter)	3.51 ± 0.4	3.26 ± 0.3	0.59	3.29 ± 0.4	3.48 ± 0.4	0.69	0.48
Total piglets weaned (No./litter)	10.9 ± 0.3	10.5 ± 0.3	0.11	10.8 ± 0.3	10.6 ± 0.3	0.42	0.90
Litter weaning weight (kg)	72.9 ± 2.4	73.0 ± 2.3	0.97	73.4 ± 2.3	72.4 ± 2.4	0.64	0.68
Avg. piglet weaning weight (kg)	6.75 ± 0.2[a]	7.09 ± 0.2[b]	0.02	7.00 ± 0.2	6.84 ± 0.2	0.28	0.94
Cross-foster (No./litter)	-0.20 ± 0.2	-0.10 ± 0.1	0.79	-0.08 ± 0.3	-0.22 ± 0.3	0.72	0.14

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

[1] Probability value for the diet x feeding partition length interaction.

Table 4: Effects of dietary treatment × feeding partition length on sow body lesion scores (least-squares means ± SE).

Item	Midds-Hulls		DDGS-GM		P-value[1]
	SHORT	LONG	SHORT	LONG	
Phase 1					
Total Severity	25.5 ± 1.5	30.4 ± 1.5	25.9 ± 1.5	30.8 ± 1.5	0.97
Head	1.72 ± 0.2	2.11 ± 0.2	1.53 ± 0.2	2.14 ± 0.2	0.45
Ears	1.45 ± 0.3[a]	1.45 ± 0.3[a]	1.94 ± 0.3[b]	1.28 ± 0.3[a]	< 0.01
Neck	4.19 ± 0.2	4.54± 0.2	3.75 ± 0.2	4.35 ± 0.2	0.47
Chest	0.05 ± 0.02	0.03 ± 0.02	0.01 ± 0.02	0.04 ± 0.02	0.20
Breast	< 0.00 ± 0.02	0.04 ± 0.02	0.03 ± 0.02	< 0.0001 ± 0.02	0.09
Shoulders	4.62 ± 0.3	4.37 ± 0.3	4.86 ± 0.3	4.58 ± 0.3	0.93
Side	4.51 ± 0.4	4.66 ± 0.4	4.93 ± 0.4	4.75 ± 0.4	0.35
Back	1.34 ± 0.3	2.86 ± 0.3	1.57 ± 0.3	2.78 ± 0.3	0.30
Udder	0.48 ± 0.1[a]	0.37 ± 0.1[a]	0.46 ± 0.1[a]	0.76 ± 0.1[b]	< 0.01
Rear	1.31 ± 0.2	3.24 ± 0.2	1.55 ± 0.2	3.13 ± 0.2	0.26
Vulva	0.29 ± 0.01[a]	0.47 ± 0.01[b]	0.10 ± 0.1[a]	0.64 ± 0.1[c]	0.01
Front Legs	0.94 ± 0.2	1.35 ± 0.2	0.76 ± 0.2	1.21 ± 0.2	0.85
Hind Legs	4.49 ± 0.4	5.06 ± 0.4	4.37 ± 0.4	5.14 ± 0.4	0.59
Front Hooves	0.01 ± 0.01	0.04 ± 0.01	< 0.0001 ± 0.01	< 0.0001 ± 0.01	0.36
Hind Hooves	0.08 ± 0.1	0.18 ± 0.1	< 0.0001 ± 0.1	0.03 ± 0.1	0.65
Phase 2					
Total Severity	20.0 ± 1.1[a]	24.4 ± 1.1[b]	20.2 ± 1.1[a]	27.8 ± 1.1[c]	0.04
Head	1.86 ± 0.2	1.69 ± 0.2	1.62 ± 0.2	1.70 ± 0.2	0.50
Ears	1.05 ± 0.2[a]	1.01 ± 0.2[a]	0.97 ± 0.2[a]	1.73 ± 0.2[b]	< 0.01
Neck	2.45 ± 0.3	3.31 ± 0.3	2.47 ± 0.3	3.57 ± 0.3	0.54
Chest	0.02 ± 0.02	0.02 ± 0.02	0.02 ± 0.02	0.02 ± 0.02	0.86
Breast	--	--	--	--	--
Shoulders	3.68 ± 0.2	3.60 ± 0.2	3.63 ± 0.2	4.01 ± 0.2	0.22
Side	3.77 ± 0.3	3.62 ± 0.3	3.75 ± 0.3	4.12 ± 0.3	0.20
Back	0.89 ± 0.4	1.60 ± 0.4	1.14 ± 0.4	2.29 ± 0.4	0.17
Udder	1.15 ± 0.3	1.18 ± 0.3	1.18 ± 0.3	1.55 ± 0.3	0.27
Rear	1.02 ± 0.2	2.78 ± 0.2	1.31 ± 0.2	3.13 ± 0.2	0.87
Vulva	0.49 ± 0.1	0.69 ± 0.1	0.17 ± 0.1	0.53 ± 0.1	0.49
Front Legs	0.81 ± 2.8	0.75 ± 2.7	0.66 ± 2.8	6.16 ± 2.7	0.31
Hind Legs	2.79 ± 0.3	4.16 ± 0.3	3.13 ± 0.3	4.58 ± 0.3	0.84
Front Hooves	< 0.0001 ± 0.03	0.03 ± 0.03	0.05 ± 0.03	0.01 ± 0.03	0.13
Hind Hooves	0.05 ± 0.4	< 0.0001 ± 0.4	0.06 ± 0.4	0.83 ± 0.4	0.31

[a–c] Within a row, means without a common superscript letter differ ($P \leq 0.05$).

[1]Probability value for the diet x feeding partition length interaction.

Table 5: Main effects of dietary treatment and feeding partition length on body lesion scores (least-squares means ± SE).

Body Region	Midds-Hulls	DDGS-Germ Meal	P-value	SHORT Partitions	LONG Partitions	P-value
Phase 1						
Total Severity	27.9 ± 1.4	28.4 ± 1.4	0.56	25.7 ± 1.4[a]	30.6 ± 1.4[b]	< 0.01
Head	1.91 ± 0.12	1.84 ± 0.12	0.59	1.63 ± 0.11[a]	2.13 ± 0.12[b]	< 0.01
Ears	1.45 ± 0.24	1.61 ± 0.24	0.21	1.69 ± 0.24[a]	1.37 ± 0.24[b]	0.01
Neck	4.37 ± 0.18	4.05 ± 0.18	0.06	3.97 ± 0.18[a]	4.44 ± 0.18[b]	< 0.01
Chest	0.04 ± 0.02	0.03 ± 0.02	0.57	0.03 ± 0.02	0.04 ± 0.02	0.90
Breast	0.02 ± 0.02	0.02 ± 0.02	0.80	0.02 ± 0.02	0.02 ± 0.02	0.80
Shoulders	4.49 ± 0.29	4.72 ± 0.29	0.16	4.74 ± 0.29	4.48 ± 0.29	0.11
Side	4.59 ± 0.35	4.84 ± 0.35	0.16	4.72 ± 0.35	4.71 ± 0.35	0.93
Back	2.10 ± 0.32	2.17 ± 0.32	0.63	1.45 ± 0.32[a]	2.82 ± 0.32[b]	< 0.01
Udder	0.42 ± 0.08[a]	0.61 ± 0.08[b]	0.02	0.47 ± 0.08	0.56 ± 0.08	0.24
Rear	2.27 ± 0.12	2.34 ± 0.12	0.66	1.43 ± 0.12[a]	3.19 ± 0.12[b]	< 0.01
Vulva	0.38 ± 0.09	0.37 ± 0.09	0.91	0.19 ± 0.09[a]	0.56 ± 0.09[b]	< 0.01
Front Legs	1.15 ± 0.13	0.98 ± 0.13	0.14	0.86 ± 0.13[a]	1.28 ± 0.13[b]	< 0.01
Hind Legs	4.78 ± 0.38	4.75 ± 0.38	0.91	4.43 ± 0.38[a]	5.11 ± 0.38[b]	< 0.01
Front Hooves	0.03 ± 0.01[a]	< 0.001±0.01[b]	0.05	0.007 ± 0.01	0.02 ± 0.01	0.36
Hind Hooves	0.13 ± 0.06	0.01 ± 0.06	0.16	0.04 ± 0.06	0.11 ± 0.06	0.42
Phase 2						
Total Severity	22.2 ± 1.0[a]	24.0 ± 1.0[b]	0.03	20.1 ± 1.0[a]	26.1 ± 1.0[b]	< 0.01
Head	1.77 ± 0.19	1.66 ± 0.19	0.53	1.74 ± 0.19	1.69 ± 0.19	0.78
Ears	1.03 ± 0.16[a]	1.35 ± 0.16[b]	0.03	1.01 ± 0.16[a]	1.37 ± 0.16[b]	0.01
Neck	2.88 ± 0.21	3.02 ± 0.22	0.49	2.46 ± 0.21[a]	3.44 ± 0.22[b]	< 0.01
Chest	0.02 ± 0.02	0.02 ± 0.02	0.91	0.02 ± 0.02	0.02 ± 0.02	0.91
Breast	--	--	--	--	--	--
Shoulders	3.64 ± 0.19	3.82 ± 0.19	0.34	3.65 ± 0.19	3.80 ± 0.19	0.44
Side	3.69 ± 0.29	3.93 ± 0.29	0.23	3.76 ± 0.29	3.87 ± 0.29	0.58
Back	1.24 ± 0.37[a]	1.71 ± 0.37[b]	< 0.01	1.02 ± 0.37[a]	1.94 ± 0.37[b]	< 0.01
Udder	1.16 ± 0.24	1.37 ± 0.24	0.18	1.16 ± 0.24	1.36 ± 0.24	0.19
Rear	1.90 ± 0.19	2.22 ± 0.19	0.07	1.16 ± 0.19[a]	2.95 ± 0.19[b]	< 0.01
Vulva	0.59 ± 0.10[a]	0.35 ± 0.10[b]	0.04	0.33 ± 0.10[a]	0.61 ± 0.10[b]	0.02
Front Legs	0.78 ± 1.94	3.41 ± 1.95	0.34	0.73 ± 1.94	3.46 ± 1.95	0.32
Hind Legs	3.48 ± 0.21	3.86 ± 0.22	0.08	2.96 ± 0.21[a]	4.37 ± 0.22[b]	< 0.01
Front Hooves	0.02 ± 0.02	0.03 ± 0.02	0.58	0.02 ± 0.02	0.02 ± 0.02	0.93
Hind Hooves	0.02 ± 0.28	0.04 ± 0.29	0.29	0.05 ± 0.28	0.41 ± 0.29	0.37

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

Table 6: Main effects of diet on differentials (least-squares means ± SE)

Immune trait	Midds-Hulls	DDGS-Germ Meal	P-value
Mean lymphocytes (%)	42.1 ± 2.2[a]	44.9 ± 2.2[b]	< 0.01
Mean neutrophils (%)	48.2 ± 1.8[a]	45.3 ± 1.8[b]	< 0.01
Mean eosinophils (%)	5.24 ± 0.2	5.24 ± 0.2	1.00
Mean monocytes (%)	3.09 ± 0.9[a]	3.73 ± 0.9[b]	0.02
Mean other (%)	0.73 ± 0.4	1.00 ± 0.4	0.09
Mean neutrophil: lymphocyte	1.60 ± 0.2[a]	1.30 ± 0.2[b]	< 0.01

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

Table 7: Main effect of feeding partition length on aggressive encounters (least-squares means ± SE)

Item	SHORT	LONG	P-value
Mean duration, sec.	2.94 ± 0.3[a]	7.23 ± 0.4[b]	< 0.01
Frequency, No./24 hrs	130.0 ± 28.8	87.5 ± 28.8	0.36
Physical encounters, No./24 hrs	94.3 ± 26.3	78.0 ± 26.3	0.68
Non-physical encounters, No./24 hrs	25.3 ± 3.3[a]	6.75 ± 3.3[b]	0.02
Encounters in pens, No./24 hrs	116.5 ± 18.9[a]	36.5 ± 18.9[b]	0.04
Encounters in feeding partitions, No./24 hrs	13.5 ± 13.1	51.0 ± 13.1	0.11

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

Table 8. Interactive effects of social status with stall length or dietary treatments on performance (Least Square Means)

	Social Status*Feeding Stall Length						Social Status*Diet					
	DOM		SUB				DOM		SUB			
Item	Long	Short	Long	Short	SE	P-value	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
BW d 30, kg	242.81^{a}	223.44^{b}	183.44^{c}	192.81^{c}	4.38	0.002	235.16	231.09	190.31	185.94	4.38	0.97
BW d 70, kg	223.83	227.37	218.49	212.15	3.32	0.10	223.38^{a}	227.83^{a}	218.74^{ab}	211.91^{b}	3.29	0.04
BW d 90, kg	226.62	233.46	224.89	219.51	3.95	0.09	227.13^{ab}	232.95^{a}	227.28^{a}	217.11^{b}	3.89	0.02
BW d 104, kg	247.09	251.98	241.79	235.76	4.85	0.22	247.39^{a}	251.68^{a}	246.27^{a}	231.28^{b}	4.78	0.02
BW d 135, kg	217.04	224.76	215.59	212.03	4.36	0.15	216.21	225.59	215.21	212.41	4.35	0.10
BW Mean, kg	227.37	231.49	224.11	220.22	2.92	0.14	227.43^{a}	231.42^{a}	226.20^{a}	218.13^{b}	2.88	0.01
BW Gain 1 (d 30 to 70), kg	10.16^{ab}	15.78^{a}	11.25^{ab}	3.97^{b}	2.71	0.02	10.53^{ab}	15.41^{a}	10.75^{ab}	4.47^{b}	2.71	0.04
BW Gain 2 (d 70 to 90), kg	2.95	4.29	5.03	4.19	1.31	0.41	3.73	3.51	6.19	3.03	1.31	0.27
BW Gain 3 (d 90 to 104), kg	19.86	18.29	17.44	16.56	1.34	0.80	19.80	18.36	19.37	14.63	1.34	0.22
BW Total Gain, kg	32.91	39.86	33.72	26.50	3.95	0.08	34.00^{a}	38.76^{a}	37.42^{a}	22.81^{b}	3.95	0.02
BW Loss, kg	-29.79	-28.95	-26.05	-24.21	3.95	0.90	-32.23	-26.51	-30.13	-20.13	4.11	0.58
BF Mean, cm	1.89	1.88	1.74	1.64	0.04	0.26	1.82	1.95	1.70	1.68	0.04	0.06
BCS, 1-5	3.05	2.99	2.96	2.97	3.60	0.43	3.05	2.98	2.95	2.98	3.60	0.18

$^{a\text{-}c}$ Means within a row with different superscripts differ ($P \leq 0.05$).

Table 9. Interactive effects of social status with stall length or dietary treatment on body lesion scores (Least Square Means)

	Social Status*Feeding Stall Length						Social Status*Diet					
	DOM		SUB				DOM		SUB			
Item	Long	Short	Long	Short	SE	P-value	Midds-Hulls	DDGS-GM	Midds-Hulls	DDGS-GM	SE	P-value
Total Severity	28.84[a]	22.32[c]	29.46[a]	25.74[b]	0.77	0.03	25.48	25.68	27.82	27.38	0.77	0.62
Head, 0-7	2.10	1.63	1.69	1.53	0.19	0.36	2.10[a]	1.63[ab]	1.34[b]	1.88[ab]	0.19	0.002
Ears, 0-7	1.07	1.14	1.59	1.63	0.17	0.92	0.86	1.35	1.62	1.60	0.17	0.08
Neck, 0-7	4.34	3.32	4.00	3.36	0.22	0.31	3.87	3.79	3.91	3.44	0.22	0.31
Shoulders, 0-7	4.60	4.48	4.56	4.31	0.22	0.73	4.42	4.66	4.42	4.45	0.22	0.57
Side, 0-7	4.87[a]	4.16[b]	4.24[ab]	4.51[ab]	0.22	0.01	4.75[a]	4.27[ab]	4.04[b]	4.71[ab]	0.22	0.002
Back, 0-7	2.92	1.08	2.31	1.11	0.20	0.06	1.87	2.13	1.88	1.54	0.20	0.07
Udder, 0-7	1.20	0.93	0.69	0.57	0.14	0.54	1.08	1.04	0.58	0.69	0.14	0.53
Rear, 0-7	3.23	1.38	3.07	1.27	0.21	0.87	2.26	2.35	2.17	2.17	0.21	0.78
Vulva, 0-7	0.51	0.24	0.52	0.30	0.11	0.80	0.61	0.15	0.46	0.35	0.11	0.06
Front Legs, 0-7	1.18	0.77	1.03	0.81	0.16	0.48	1.13	0.82	1.11	0.74	0.16	0.79
Hind Legs, 0-7	5.54[a]	3.77[c]	4.52[b]	3.95[bc]	0.23	0.002	4.80	4.51	4.26	4.21	0.23	0.51

[a-c] Means within a row with different superscripts differ ($P \leq 0.05$).

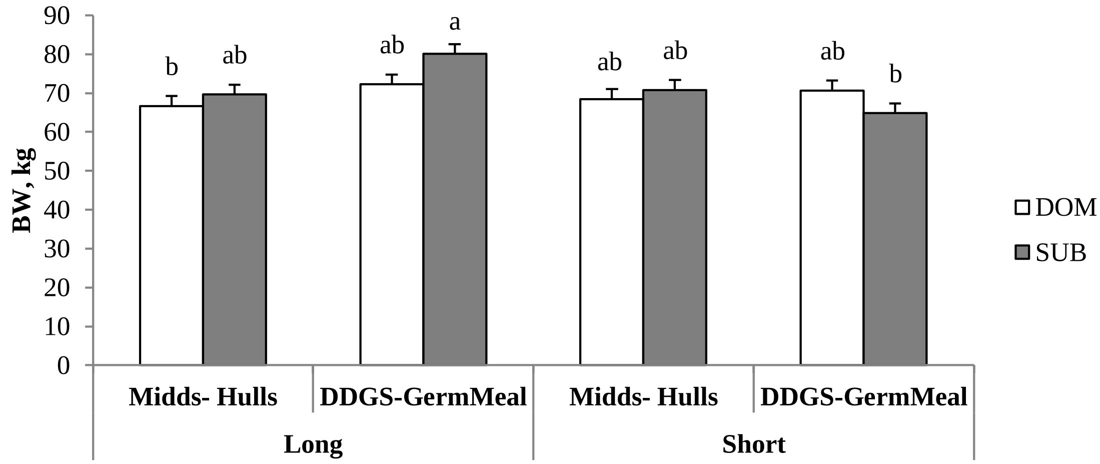

Figure 1. Social status × diet × feeding stall length on adjusted litter wean BW (*P*=0.01)

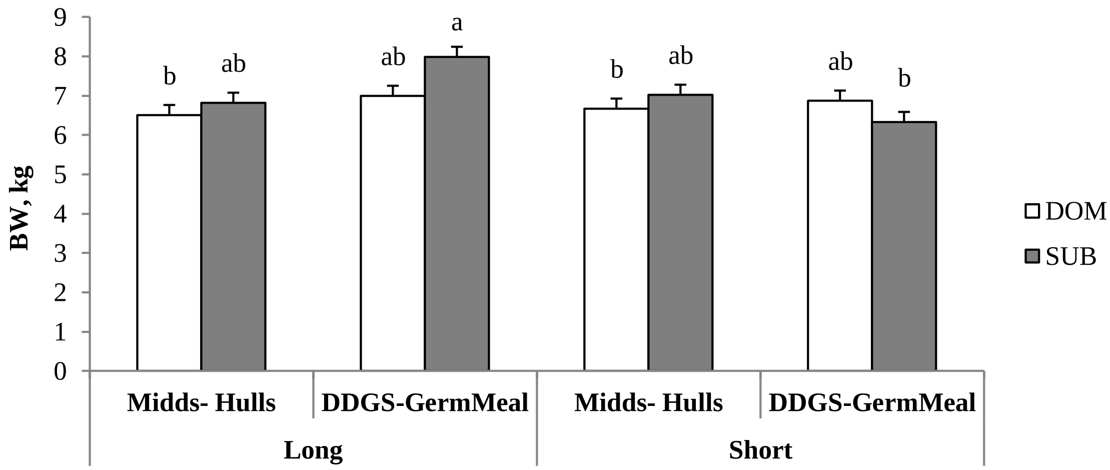

Figure 2. Social status × diet × feeding stall length on average piglet wean BW (*P*=0.005)

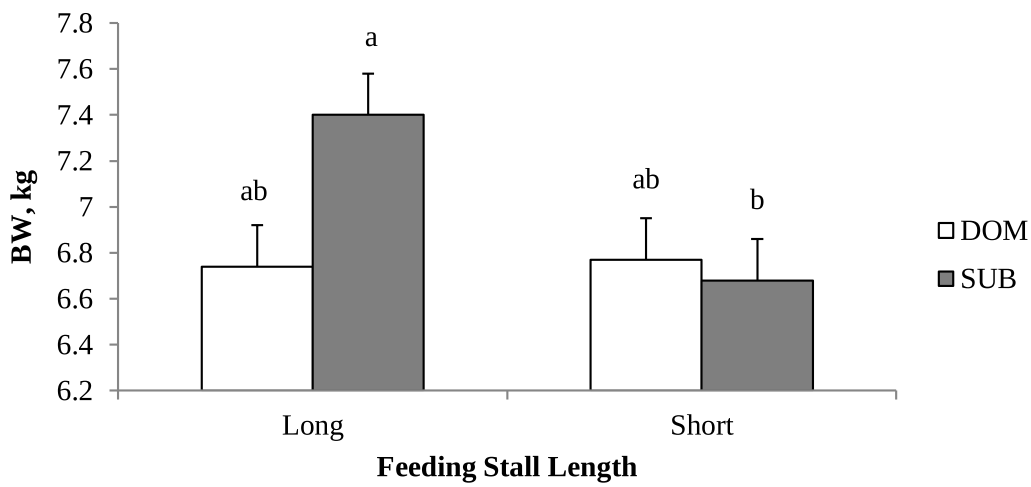

Figure 3. Social status × feeding stall length on average piglet wean BW (*P=0.05)*

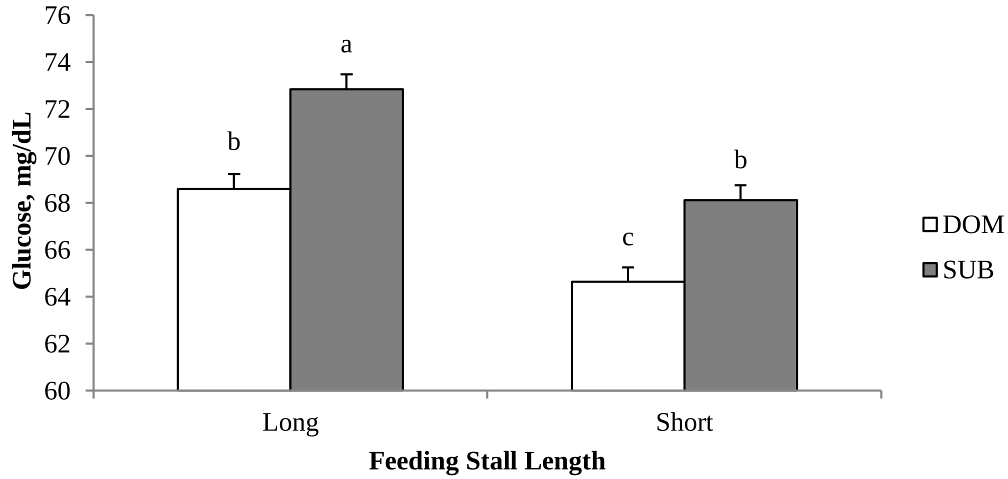

Figure 4. Social status × feeding stall length on blood glucose (*P*=0.04)

Table 10. Main effect of diet and feeding stall interaction on behaviors during feedings (Least Square Means)

	Diet*Feeding Stall Length					
	Midds- Hulls		DDGS-GM			
Behavior	Long	Short	Long	Short	SE	P-value
Total Aggressive Encounters	17.69^{b}	22.06^{ab}	11.69^{b}	29.56^{a}	2.84	0.02
Total Displacements	1.88	13.50	2.94	21.44	2.13	0.58
AE:Disp	8.45^{a}	1.69^{b}	4.19^{b}	1.62^{b}	0.79	0.01
No. AE to SUB	8.50^{a}	6.56^{ab}	2.81^{b}	7.75^{a}	1.14	0.004
No. Displacements to SUB	1.50	4.25	0.63	5.19	0.85	0.19
No. AE by DOM	7.44	10.50	5.81	13.44	1.58	0.16
No. Displacements by DOM	1.00	8.44	1.19	11.06	1.16	0.30
No. AE by DOM to SUB	3.94	3.38	1.81	3.31	0.72	0.23
No. Disp by DOM to SUB	0.94	2.56	0.31	2.19	0.51	0.81

$^{a\text{-}b}$ Means within a row with different superscripts differ ($P \leq 0.05$).

Table 11. Main effect of feeding stall length interaction with day post treatment on behaviors during feedings (Least Square Means)

	Day Post Stall Treatment*Feeding Stall Length									
	1		22		43		64			
Behavior	Long	Short	Long	Short	Long	Short	Long	Short	SE	P-value
Total Aggressive Encounters	22.38^{ab}	15.13^{ab}	15.75^{ab}	30.88^{a}	12.25^{b}	32.25^{a}	8.38^{b}	25.00^{ab}	4.01	0.003
Total Displacements	1.63	5.88	3.38	21.13	2.25	22.50	2.38	20.38	3.02	0.15
AE:Disp	10.92^{a}	2.27^{bc}	7.23^{ab}	1.58^{c}	4.09^{bc}	1.52^{c}	3.04^{bc}	1.25^{c}	1.12	0.04
No. AE to SUB	10.13^{a}	3.13^{b}	4.50^{ab}	8.13^{ab}	5.00^{ab}	9.88^{a}	3.00^{b}	7.50^{ab}	1.61	0.001
No. Displacements to SUB	1.00	1.38	1.00	4.88	1.00	6.50	1.25	6.13	1.20	0.13
No. AE by DOM	11.75^{ab}	6.38^{bc}	5.88^{bc}	13.88^{a}	4.25^{c}	14.25^{a}	4.63^{c}	13.38^{a}	2.24	0.004
No. Displacements by DOM	1.50^{c}	3.88^{bc}	1.00^{c}	11.13^{ab}	0.75^{c}	11.75^{a}	1.13^{c}	12.25^{a}	1.64	0.03
No. AE by DOM to SUB	6.13^{a}	1.25^{b}	1.63^{ab}	3.63^{ab}	2.00^{ab}	5.38^{ab}	1.75^{ab}	3.13^{ab}	1.02	0.002
No. Disp by DOM to SUB	0.88	0.75	0.50	2.13	0.25	3.88	0.88	2.75	0.71	0.09

$^{a\text{-}c}$ Means within a row with different superscripts differ ($P \leq 0.05$).