Effects of distillers' dried grains with solubles on behavior of sows kept in a group-housed system with electronic sow feeders or individual stalls

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Li, Y. Z., Phillips, C. E., Wang, L. H., Xie, X. L., Baidoo, S. K., Shurson, G. C. and Johnston, L. J. 2013. **Effects of distillers' dried grains with solubles on behavior of sows kept in a group-housed system with electronic sow feeders or individual stalls**. Can. J. Anim. Sci. **93**: 57–66. A study was conducted to investigate the effects of diets that contained distillers' dried grains with solubles (DDGS) on stereotypic behaviors of gestating sows housed in stalls and aggression in a group-housed system. Sows were fed corn–soybean-based control (CON) or treatment (DDGS) diets starting from their previous breeding cycle (40% and 20% DDGS as-fed basis during gestation and lactation, respectively). Group-housed sows were mixed in pens with an electronic sow feeder within 1 wk after mating. Behaviors of focal sows ($n = 27$ in stalls, $n = 40$ in pens) were video-recorded for a period of 24 h between 4 and 8 d after mating. Salivary cortisol levels were measured on 32 focal sows ($n = 16$ in stalls, $n = 16$ in pens) during the week before mating (week 0), 1 wk and 12 wk after mating. In pens, DDGS sows fought for longer periods ($P = 0.05$), tended to fight more frequently ($P = 0.06$), and had greater cortisol concentrations ($P < 0.001$) at mixing compared with CON sows. In stalls, DDGS sows spent more time resting ($P = 0.02$), less time performing stereotypies ($P = 0.05$), and had lower cortisol concentrations ($P = 0.03$) in week 12 compared with CON sows. These results indicate that DDGS diets may compromise the welfare of sows in pens, but improve the welfare of sows in stalls.

Key words: Behavior, distillers' dried grains with solubles, sow housing

Li, Y. Z., Phillips, C. E., Wang, L. H., Xie, X. L., Baidoo, S. K., Shurson, G. C. et Johnston, L. J. 2013. **Incidence des DDGS sur le comportement des truies logées en groupes dans des porcheries pourvues de nourrisseurs électroniques ou de stalles individuelles**. Can. J. Anim. Sci. **93**: 57–66. Une étude a été effectuée pour approfondir les effets des rations contenant des drèches sèches de distillerie avec solubles (DDGS) sur le comportement stéréotypé des truies en gestation logées dans des stalles et sur le comportement d'agression de celles élevées dans en groupes. Les animaux ont reçu la ration témoin à base de maïs et de soja (CON) ou la ration expérimentale (DDGS) dès le début de leur cycle de reproduction (40 % et 20 % de DDGS servies en l'état pendant la gestation et la lactation, respectivement). Les truies logées en groupe ont été rassemblées dans des enclos dotés d'un nourrisseur électronique une semaine après l'accouplement. Le comportement des sujets ($n = 27$ dans les stalles, $n = 40$ dans les enclos) a été filmé pendant 24 h, quatre à huit jours après la saillie. La concentration de cortisol dans la salive a été mesurée chez 32 truies ($n = 16$ dans les stalles, $n = 16$ dans les enclos) la semaine précédant l'accouplement (semaine 0), puis une et douze semaines après la saillie. Dans les enclos, les truies nourries de DDGS se sont battues plus longtemps ($P = 0{,}05$), avaient tendance à se battre plus souvent ($P = 0{,}06$) et affichaient une plus grande concentration de cortisol ($P < 0{,}001$) que les truies du groupe CON lors de leur rassemblement. Dans les stalles, les truies recevant des DDGS se sont reposées plus longtemps ($P = 0{,}02$), ont démontré des comportements stéréotypés moins longtemps ($P = 0{,}05$) et présentaient un taux de cortisol plus faible ($P = 0{,}03$) que celles du groupe CON la douzième semaine. Ces résultats laissent croire que les rations contenant des DDGS pourraient nuire au bien-être des truies élevées en enclos et rehausser celui des sujets gardés dans des stalles.

Mots clés: Comportement, drèches sèches de distillerie avec solubles, logement des truies

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Housing systems have a profound impact 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 (Mendl et al. 1993). Gestating sows in individual stalls may exhibit stereotypic behaviors (D'Eath et al. 2009), which are considered an indicator of poor welfare. On the other hand, sows in group housing have freedom of movement, but are subject to aggression, especially at mixing and feeding (Arey and Edwards 1998). Intense aggression at mixing can cause injuries, which impair both the welfare and performance of sows (Strawford et al. 2008; Spoolder et al. 2009). Limit-feeding makes the housing system for gestating sows even more challenging. Limit-fed sows exhibit more stereotypic behaviors in stalls (Bergeron and Gonyou 1997; Bergeron et al. 2000) and more aggressive interactions in groups (Arey and Edwards 1998) compared with sows allowed ad libitum access to feed. However, ad libitum feeding can cause excessive gains in weight during pregnancy, which is detrimental to both health and reproductive performance of sows. To tackle the dilemma, high-fiber diets are recommended (European Commission Council 2001; Spoolder et al. 2003) to control weight gain and reduce undesired behaviors of gestating sows. Several studies (van der Peet-Schwering et al. 1998; Bergeron et al. 2000) have demonstrated that high-fiber diets can reduce stereotypic behaviors of gestating sows in stalls. For group-housed sows, roughage and high-fiber diets tended to reduce aggressive interactions in the long-term (Brouns et al. 1994; Spoolder et al. 1997; Stewart et al. 2010). In addition, de Leeuw et al. (2004, 2005) reported that diets high in fermentable fiber can stabilize glucose and insulin levels in the blood and reduce physical activities of limit-fed gestating sows, which indicated that sows were experiencing prolonged feelings of satiety.

The emergence of the ethanol industry to generate renewable energy has made the by-product, distillers' dried grains with solubles (DDGS), readily available and widely used as a feed ingredient for farm animals. The high fiber content of DDGS may affect the behavior and well-being of limit-fed gestating sows, both in stalls and group-housed systems. This study was conducted to investigate the effects of diets containing DDGS on stereotypic behaviors of gestating sows housed in individual stalls and aggressive interactions at mixing among sows housed in a group-housed system with electronic sow feeders.

MATERIALS AND METHODS

Animals, Housing and Management

This study was conducted at the University of Minnesota's Southern Research and Outreach Center in Waseca, Minnesota between February and April 2010. The center operated an 800-sow unit with an equal number of sows housed in stalls and groups. At entry to the breeding herd, gilts were assigned randomly to one of the two housing systems. Once assigned, breeding females remained in their gestation housing system for the rest of their production period. The group-housed system had four pens (15.2 m × 7.6 m) on fully slatted concrete floors. Each pen was equipped with six bowl drinkers and an electronic sow feeder (Osborne Industries, Osborne, KS), which controlled individual feeding by means of radio-frequency identification. Each pen accommodated about 50 sows with a floor space allowance of 2.2 m^2 per sow excluding the space occupied by the feeding station. Sows assigned to this system were managed in dynamic groups. Every 8 wk, a group of 20 to 25 sows was removed for farrowing, and a recently bred (4 to 8 d after mating) group of 25 multiparous sows (parity 1 to 10) was added to the pen, which was referred to as "mixing". After being introduced into a pen, all sows had continuous individual access to the electronic feeding station. The gestation stall (2.1 m × 0.6 m, Crystal Spring Hog Equipment, Ste. Agathe, MB) was equipped with an individual feeder and a nipple drinker on fully slatted floors. Sows in stalls were fed once daily starting at 0630. Sows in both housing systems were provided 2.25 kg of their assigned diet daily (see dietary treatment). If necessary, feeding level was adjusted during gestation to achieve or maintain an individual body condition score of 3 (Coffey et al. 1999). The composition of sow parity was consistent across the two housing systems. Each contemporary breeding group consisted of approximately 18% parity 1, 18% parity 2, and 64% parity 3 or greater. Both housing systems provided similar thermal environments. Room temperature was controlled by a heating system and exhaust fans in the range of 15 to 23°C. Lights in each room were on for 10 h starting at 0600.

Dietary Treatment

At commencement of this study, gilts and parity 1 sows within each housing system from one contemporary breeding group were allocated randomly to one of two dietary treatments. These females remained on their dietary treatment through three gestation and lactation periods within each housing system. The control diets (CON, Table 1) were corn–soybean-meal-based diets fed in mash form and formulated according to Nutritional Requirement Council (1998) nutritional requirements of gestating and lactating sows. The treatment diets (DDGS) were nutritionally similar to CON but included 40% DDGS during gestation and 20% DDGS during lactation. Each feeding station (group-housed) and individual feeder (stalls) had two feeder lines to provide either CON or DDGS diet based on the dietary treatment to which each sow was assigned. Sows within a breeding group were allocated randomly into individual stalls, regardless of dietary treatment. Similarly in the group-housed system, sows fed CON and DDGS diets in a breeding group were mixed into the same pen.

This study was conducted during the second gestation period after the dietary and housing treatments had been imposed. All sows were weaned into stalls for mating. A week (4 to 8 d) after mating, group-housed sows were moved to pens and stalled sows remained in stalls. Forty focal sows each in the group-housed system and stalls from four contemporary breeding groups were

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

	Gestation[z]		Lactation[z]	
Item	CON	DDGS	CON	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[y]	0.50	0.50	0.50	0.50
Biotin premix[x]	0.20	0.20	0.20	0.20
Choline chloride (50%)	0.10	0.20	0.00	0.10
L-Lys-HCL (78%)	0.00	0.40	0.00	0.20
L-Trp (98%)	0.05	0.10	0.00	0.05
L-Thr (98.5%)	0.15	0.20	0.00	0.00
DL-Met (99%)	0.10	0.10	0.00	0.00
Nutrient content (calculated)				
ME (Kcal kg^{-1})	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

[z]CON stands for control diets, which were corn–soybean-meal-based diets formulated according to NRC (1998) recommendations, and DDGS diets contained distillers' dried grains with solubles (DDGS).
[y]Vitamin-mineral premix supplied the following per kilogram of diet: vitamin A, 11 013 IU; vitamin D, 2753 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).
[x]Biotin premix supplied 0.51 mg of biotin (JBS United Inc., Sheridan, IN) per kilogram of diet.

identified for data collection. An effort was made to balance the parity of focal sows for dietary treatment within each housing system. However, among the 40 focal sows in stalls, we were only able to record the behaviors of 27 sows due to technical difficulties. Consequently, data were collected on 40 sows in group-housed system and 27 sows in stalls. In the group-housed system, 17 focal sows (9 in parity 1 and 8 in parity 2) were fed CON and 23 sows (12 in parity 1 and 11 in parity 2) were fed DDGS. In stalls, 15 (9 in parity 1 and 6 in parity 2) and 12 (7 in parity 1 and 5 in parity 2) focal sows were fed CON and DDGS, respectively.

Data Collection

Behaviors

For behavioral observation, focal sows were identified for dietary treatment and parity with simple paint markings on their backs. Behaviors of focal sows were video-recorded at the speed of 6 frames per second for a period of 24 h 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). Video-recordings occurred at the same time in the two housing systems. In the group-housed system, newly bred sows were moved into an existing group between 1000 and 1100. The video-recording was conducted immediately after mixing. Two cameras were used for each pen to cover the entire pen area. In stalls, the video-recording occurred on the same day as in the group-housed system, which was 10 d after the sows were moved into the stalls. In both housing systems, all focal sows were mated 4 to 8 d before video-recording. Lights remained on for 24 h to facilitate video-recording behaviors of sows in both housing systems.

All video recordings in each housing system were viewed by one trained observer to avoid inter-individual discrepancy. The observer was blind to dietary treatments to eliminate subjective bias. For the group-housed system, aggression involving focal sows within the pen during the entire 24 h after mixing was registered by the continuous observation method (Martin and Bateson 1993). Intensity of aggression was assessed by parallel pressing, head-to-head knocking, and head-to-body knocking according to the methods of Jensen (1980). Parallel pressing was defined as sows that stand side by side and push hard with the shoulders against each other, generally performed with frequent bites. Head-to-head knocking was defined as a sow delivering rapid knocks with the snout against the head, neck, or ears of the receiver, generally performed with bites as accessory features. Head-to-body knocking was defined as a sow delivering rapid knocks with the snout against any parts of the body behind the ears of the receiver, generally performed with bites as accessory features. 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). The frequency, duration, and outcomes (winner) of fights were registered using the methods of Turner et al. (2006). The winner, as an indicator of aggressiveness, was defined as the sow which pursued a retreating pig, followed by any form of submissive behavior performed by the opponent, and the winner did not receive renewed aggression from the loser for 5 s or longer (Turner et al. 2006). Total duration, frequency, and winner for each aggressive interaction and total aggressive interactions during daytime (0600 to 1800) and nighttime (1800 to 0600) were calculated for all focal sows in each pen.

Total aggressive interactions were calculated by adding head-to-body knocking, head-to-head knocking and parallel pressing together. For sows in stalls, the video-recording was analyzed by instantaneous scan sampling. Each focal sow was scanned at 5-min intervals for 24 h to determine behaviors of interest, which included resting (lateral or sternal recumbency), eating (head in feeder after feed delivery), stereotypies (performing oral, nasal or facial behaviors repetitively during non-feeding periods), and others (performing none of the above behaviors). These behaviors were mutually exclusive. The stereotypic behaviors were defined according to Bergeron et al. (2000) and included activities such as object-biting (biting or chewing any part of the stall, feeder, or drinker), vacuum-chewing (chewing without any substrate in the mouth), and nose-rubbing (rubbing the floor, feeder, or stall). In total, each sow was scanned 144 times during each period of daytime and nighttime. Behavioral time budgets for resting, eating, stereotypies, and others were expressed by time spent on each behavior as a percentage of total observation time during each period (Martin and Bateson 1993).

Salivary Cortisol

Among the focal sows involved in behavioral data collection, 32 sows from the four contemporary breeding groups were identified for collecting salivary samples. These sows were selected based on their housing, dietary treatment, and parity, with two sows in each combination of the three factors as arranged by $2 \times 2 \times 2$ (housing $\times$ diet $\times$ parity). Salivary samples were collected between 1300 and 1400 for 3 d, with 1 d in each of the following weeks: before breeding (week 0), 1 wk (week 1) and 12 wk (week 12) after breeding. Salivary samples were collected on the same days in the two housing systems. For group-housed sows, salivary samples for week 0 were collected in individual stalls before the sows were mixed, and the samples for week 1 were collected 48 h after the sows were mixed in pens. Saliva samples were obtained using absorbent cotton swabs with minimal disturbance to the sows. In both housing systems, salivary samples were collected in the sow's home pen or stall. The sampler approached the focal sow quietly and placed an absorbent cotton swab in the sow's mouth. The swab remained in the sow's mouth until it was saturated with saliva. To avoid cortisol level being elevated by handling stress, each saliva sample was collected within 2 min of approaching the sow. Saliva was removed by centrifugation, and frozen at -20°C for subsequent analysis. Cortisol concentration was determined by radioimmunoassay according to the methods of Cook et al. (1997).

Bulkiness of Diets

To evaluate whether inclusion of DDGS affects bulkiness of the diet, the volume per unit weight of diets was measured. Samples of all diets fed to each of the breeding groups were collected during the study. Three samples of each diet for one breeding group were selected randomly for measuring bulkiness. To measure bulkiness of each diet, a 500-mL beaker was filled with the diet, and the excess amount of the diet was removed. The weight of the diet in the beaker was recorded as test weight in 500 mL. Each sample was analyzed in triplicates, and the average bulkiness was calculated as the volume per unit weight (L kg^{-1}).

Data Analysis

All data were tested for normal distribution using the Univariate Procedure of SAS software (SAS Institute, Inc, Cary, NC). Data that were not distributed normally were transformed using logarithm transformation ($X' = \log 10(X) + 0.1$) to achieve normal distribution (Zar 1999). For transformed data, both actual and transformed least-square means, and statistics of transformed data are presented in the results. Since different behaviors were measured in each housing system, comparison in behavioral data between the two housing systems is not possible. So, behavioral data were analyzed for each housing system separately. The Glimmix procedure of SAS was used to analyze the effect of dietary treatment on behaviors within each housing system. Within the Glimmix procedure, the Poisson regression model was used for analysis of count data, and the Gaussian Model was used for analysis of continuous data. For aggression among group-housed sows, the statistical model included dietary treatment, parity, period (daytime vs. nighttime), and their two-way interactions as fixed effects. The contemporary breeding group served as a random effect, with dietary treatment and parity nested within each pen serving as the experimental unit. The model used to analyze the time budget of sows in stalls included dietary treatment, parity, period (daytime vs. nighttime), and their two-way interactions as fixed effects. The contemporary breeding group was the random effect and individual sows were the experimental unit. The same model was used for the analysis of eating time budget, except that the period effect was not included because eating behavior was only observed during daytime (after feed delivery at 0630). The Mixed model with repeated measures was used for the analysis of cortisol data, with housing, dietary treatment, period of sampling (week 0, week 1 and week 12), and their two-way interactions as fixed effects. The breeding group served as the random effect, with individual sows serving as the experimental unit. Due to the small sample size and the balanced parity of sows, the effect of parity was not included in the statistical model for cortisol data analysis. In all cases, differences between the means were tested by PDIFF with the Tukey adjustment for multiple comparisons. Significant differences were identified at $P < 0.05$ and trends at $P < 0.10$.

RESULTS

Behaviors

For group-housed sows, no interactions for aggression between dietary treatment and parity ($P > 0.10$), dietary treatment and period ($P > 0.10$), or parity and period ($P > 0.10$) were observed. Therefore, data are presented for main effects only where appropriate. Sows fed DDGS were more aggressive than CON sows, with increased frequency ($P = 0.05$; Table 2) of head-to-body knocking, increased duration ($P = 0.04$) of head-to-head knocking, and increased frequency ($P = 0.02$) and duration ($P = 0.01$) of parallel pressing fights. When all aggressive interactions were added together, sows fed DDGS tended to fight more frequently ($P = 0.06$) and fought for longer periods ($P = 0.02$) compared with CON sows. Sows fed DDGS also tended to win more fights of head-to-body knocking ($P = 0.06$) than CON sows. Parity 2 sows fought more frequently ($P < 0.05$; Table 2), and won more fights of head-to-body knocking ($P = 0.01$) and head-to-head knocking ($P = 0.001$) than parity 1 sows. Parity 2 sows also fought for longer periods in head-to-head knocking fights ($P = 0.01$) and tended to fight for longer periods in parallel pressing fights ($P = 0.07$) compared with parity 1 sows. For all aggressive interactions, parity 2 sows fought more frequently ($P = 0.01$), tended to fight for longer periods ($P = 0.06$), and won more fights ($P = 0.001$) compared with parity 1 sows. Focal sows fought more frequently and for longer periods, and won more fights during the daytime ($P < 0.05$; Table 2) than the nighttime.

In stalls, sows fed DDGS spent more time resting ($P = 0.02$; Table 3) and less time performing stereotypic behaviors ($P = 0.05$) compared with CON sows. Parity 2 sows spent less time resting ($P = 0.01$; Table 3), and more time performing stereotypic ($P = 0.01$) and other behaviors ($P = 0.01$) than parity 1 sows. All sows spent less time resting ($P < 0.001$), and more time performing stereotypies ($P < 0.001$; Table 3) during the daytime than the nighttime. Interactions between parity and period were observed for resting ($P = 0.01$) and stereotypic behaviors ($P = 0.01$), with parity 2 sows spending less time resting and more time performing stereotypic behaviors than parity 1 sows during the daytime ($P < 0.05$), but not during the nighttime ($P > 0.10$; data not shown). There were no interactions among dietary treatment, parity and period for other variables ($P > 0.10$; data not shown). Time spent eating was not affected by either dietary treatment or parity ($P > 0.10$; Table 3).

Salivary Cortisol

Sows in the group-housed system had higher cortisol concentrations compared with sows in stalls (10.9 vs. 6.4 ng mL^{-1}, SE = 0.697; $P < 0.001$; Fig. 1). Dietary treatment did not affect cortisol concentrations ($P = 0.28$). A trend of interactions ($P = 0.06$) between housing and dietary treatment was observed, with DDGS sows in the group-housed system having higher cortisol concentrations than in stalls.

Interactions between dietary treatment and sampling period were noticed in both housing systems ($P < 0.05$; Fig. 2A and Fig. 2B). In the group-housed system, DDGS sows had higher cortisol concentrations than CON sows in week 1 (21.1 vs. 9.8 ng mL^{-1}, SE = 1.63; $P < 0.001$; Fig. 2A), but not in week 0 or week 12. In contrast, in stalls, DDGS sows had lower cortisol concentrations than CON sows in week 12 (5.5 vs. 9.3 ng mL^{-1}, SE = 0.75; $P = 0.03$; Fig. 2B), but not in week 0 or week 1.

Bulkiness of Diets

For gestation diets, the volume per unit weight of the DDGS diet was 1.486 ($\pm$0.041) L kg^{-1}, which was 11.3% greater than the CON diet (1.335 $\pm$ 0.041 L kg^{-1}). For lactation diets, the volume per unit weight of the DDGS diet was 1.420 ($\pm$0.053) L kg^{-1}, which was 6.5% greater than the CON diet (1.333 $\pm$ 0.031 L kg^{-1}).

DISCUSSION

In this study, one of the major findings was that DDGS sows were more aggressive than CON sows at mixing in the group-housed system. Sows fed DDGS fought more frequently and for longer periods in parallel pressing fights, which are the most intense and aggressive interaction and cause most injuries in sows (Turner et al. 2006; Li et al. 2011). To our knowledge, this is the first published study to investigate the effect of dietary DDGS on aggression among group-housed sows. Due to the higher fiber content and the greater volume per unit weight of DDGS relative to corn and soybean meal, we expected that sows fed DDGS might experience greater satiety and be less aggressive at mixing than CON sows. Some earlier studies (Edwards et al. 1994; Arey and Edwards 1998) suggest that sows fed high-fiber diets ad libitum were less aggressive at mixing compared with sows limit-fed with conventional diets. In addition, Barnett et al. (1994) demonstrated that ad libitum feeding for 48 h reduced aggression among sows at mixing compared with sows fed ad libitum for 24 h. However, recent studies (Spoolder et al. 2009) indicated that feed intake or satiety has limited effects on aggression among gestating sows at mixing. O'Connell (2007) noted that free access to grass silage had no effect on aggression among sows at mixing. More recently, Stewart et al. (2011) reported that neither a bulky high-fiber diet nor access to straw in racks affected aggression among sows at mixing, which agrees with results of the current study to a certain degree. The inclusion of 40% DDGS in gestation diets in the current study increased the volume per unit weight of the diet by 11%. This can be translated to a 0.3 L increase in bulkiness of daily rations (2.25 kg) for DDGS sows compared with CON sows. Compared with other studies (Spoolder et al. 2009; Stewart et al. 2010) of feeding bulky high-fiber diets to reduce aggression among sows, the

Table 2. Effect of dietary DDGS on aggressive interactions among group-housed gestating sows during the first 24 h after mixing

	Dietary treatment[z]		Parity of sows		Period of day[y]			*P* value[x]		
Item	CON	DDGS	1	2	Day	Night	SEM	Diet	Parity	Period
Number of focal sows	17	23	18	22	40	40	–	–	–	–
Average weight (kg)	175.5 ± 3.5	172.5 ± 3.1	166.9 ± 3.4	181.1 ± 3.2	–	–	–	0.45	0.001	–
Aggressive interactions at mixing										
Head-to-body knocking										
Frequency (fights sow^{-1} h^{-1})	0.10	0.23	0.09	0.23	0.27	0.06	–	–	–	–
Transformed data[w]	−1.75	−1.41	−1.75	−1.41	−1.20	−1.96	0.134	0.05	0.05	< 0.001
Duration (s sow^{-1} h^{-1})	0.96	1.88	0.77	2.07	2.40	0.44	–	–	–	–
Transformed data[w]	−0.88	−0.51	−0.96	−0.44	0.14	−1.54	0.401	0.36	0.20	0.001
Wins (% of fights)	8.5	18.6	4.9	22.2	20.8	6.3	–	–	–	–
Transformed data[w]	−0.86	0.63	−1.26	1.03	1.30	−1.53	0.545	0.06	0.01	0.001
Head-to-head knocking										
Frequency (fights sow^{-1} h^{-1})	0.21	0.45	0.20	0.46	0.55	0.12	–	–	–	–
Transformed data[w]	−1.30	−1.03	−1.41	−0.92	−0.68	−1.65	0.156	0.18	0.02	< 0.001
Duration (s sow^{-1} h^{-1})	0.92	5.50	1.05	5.37	5.76	0.66	–	–	–	–
Transformed data[w]	−0.58	0.30	−0.75	0.47	0.73	−1.01	0.284	0.04	0.01	0.001
Wins (% of fights)	16.3	25.6	6.8	35.1	25.1	16.8	–	–	–	–
Transformed data[w]	0.52	1.58	−0.42	2.52	1.88	0.22	0.589	0.21	0.001	0.05
Parallel pressing										
Frequency (fights sow^{-1} h^{-1})	0.06	0.14	0.06	0.15	0.19	0.01	–	–	–	–
Transformed data[w]	−1.93	−1.65	−1.94	−1.63	−1.37	−2.20	0.085	0.02	0.02	< 0.001
Duration (s sow^{-1} h^{-1})	2.10	9.11	5.09	6.12	10.78	0.43	–	–	–	–
Transformed data[w]	−0.72	0.45	−0.53	0.25	1.44	−1.71	0.436	0.01	0.07	< 0.001
Wins (% of fights)	14.3	18.7	12.0	21.0	29.9	3.1	–	–	–	–
Transformed data[w]	−0.39	0.60	−0.45	0.67	2.13	−1.91	0.529	0.19	0.15	< 0.001
Total frequency of fights (fights sow^{-1} h^{-1})	0.37	0.82	0.36	0.84	1.01	0.19	–	–	–	–
Transformed data[w]	−0.96	−0.59	−1.03	−0.52	−0.13	−1.42	0.136	0.06	0.01	< 0.001
Total duration of fighting (s sow^{-1} h^{-1})	3.98	16.49	6.90	13.57	18.94	1.53	–	–	–	–
Transformed data[w]	0.40	1.42	0.51	1.32	2.25	−0.43	0.391	0.02	0.06	< 0.001
Win (% of total fights)	13.0	20.9	7.9	26.1	25.3	8.7	–	–	–	–
Transformed data[w]	0.69	1.78	−0.08	2.54	2.54	−0.08	0.469	0.11	0.001	0.001

[z]CON stands for control diets, which were corn–soybean-meal-based diets formulated according to NRC (1998) recommendations, and DDGS diets contained 40% distillers' dried grains with solubles (DDGS) in the gestation diet and 20% DDGS in the lactation diet.
[y]Daytime was between 0600 and 1800, and nighttime was between 1800 and 0600.
[x]No interactions were significant for any variables ($P > 0.10$).
[w]Data were transformed using logarithm ($X' = \mathrm{Log10}(X) + 0.1$) to achieve normal distribution.

Table 3. Effects of DDGS on behavioral time budget of gestating sows housed in individual stalls

	Diet treatment[z]		Parity of sows		Period of day[y]		*P* value[x]		
Item	CON	DDGS	1	2	Day	Night	Diet	Parity	Period
Number of focal sows	15	12	17	10	27	27	–	–	–
Average weight (kg)	180.1±4.4	171.8±5.1	176.7±4.1	175.2±5.4	–	–	0.23	0.82	–
Behavioral time budget (%)									
Resting[w]	66.4±2.3	73.1±2.7	74.2±2.2	65.4±2.9	61.1±2.5	78.5±2.5	0.02	0.01	<0.001
Stereotypies[v]	28.5±2.3	23.3±2.6	22.0±2.2	29.9±2.8	31.8±2.5	20.0±2.5	0.05	0.01	<0.001
Eating[u]	2.9	2.3	2.7	2.6	5.3	0.0	–	–	–
Transformed data[t]	1.72±0.19	1.46±0.20	1.60±0.18	1.57±0.21	1.60±0.19	–	0.11	0.83	–
Others[s]	2.0	1.2	1.2	2.0	1.7	1.5	–	–	–
Transformed data[t]	0.64±0.13	0.39±0.17	0.21±0.12	0.82±0.18	0.55±0.15	0.48±0.15	0.27	0.01	0.74

[z]CON stands for control diets, which were corn–soybean-meal-based diets formulated according to NRC (1998) recommendations, and DDGS diets contained 40% distillers' dried grains with solubles (DDGS) in the gestation diet and 20% DDGS in the lactation diet.
[y]Daytime was between 0600 and 1800, and nighttime was between 1800 and 0600.
[x]Interactions between parity and period were observed for resting and stereotypic behaviors ($P = 0.01$).
[w]Sows were lying either laterally or sternally, without any oral and nasal behaviors.
[v]Sows were performing oral and nasal behaviors without ingesting feed.
[u]Sows were eating with head in the feeder after feed delivery.
[t]Data were transformed using logarithm ($X' = \text{Log10}(X) + 0.1$) to achieve normal distribution.
[s]Sows were performing none of the above behaviors.

increase in bulkiness of DDGS diets in the current study was subtle. For example, in Stewart et al. (2010)'s study, the treatment diet contained 15% crude fiber and the control diet contained 5% crude fiber. To provide the same digestible energy to the animals, the sows in treatment groups were fed 2.85 kg d^{-1}, which was a 30% increase in weight compared with the ration (2.2 kg) for control sows. This can be a substantial increase in bulkiness compared with our DDGS diet, which was formulated to contain the same digestible energy and fed the same weight as the CON diet. In group-housed systems, sows fight to establish dominance hierarchies at mixing (Spoolder et al. 2009). Aggression among sows to develop dominance

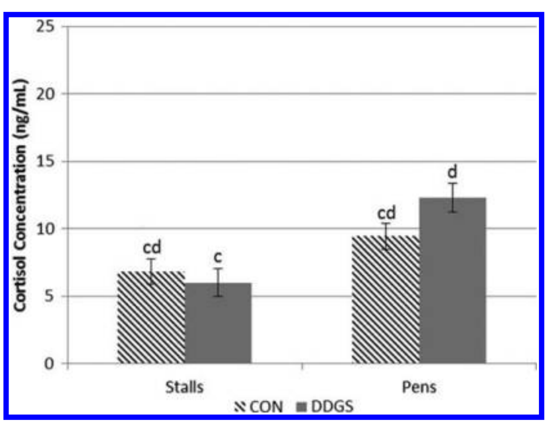

Fig. 1. Effects of housing and DDGS on salivary cortisol concentrations of sows. CON stands for control diets; DDGS stands for treatment diets which contained 40% distillers' dried grains with solubles (DDGS) in the gestation diet and 20% DDGS in the lactation diet. c, d Means without a common letter tend to differ ($P < 0.10$).

hierarchies seems unavoidable (Stewart et al. 2011), and the initial aggression is necessary to establish stable dominance hierarchies and consequently, to achieve group stability (Broom et al. 1995). It is possible that the motivation to fight for a higher rank was so great that the subtle increase in bulkiness of DDGS could not suppress aggression among sows at mixing in the current study. However, we did not expect that feeding DDGS would increase aggression among sows at mixing. An explanation for DDGS induced aggression awaits further investigation.

Parity 2 sows were more aggressive, fought more frequently, tended to fight for longer periods, and won more fights at mixing compared with parity 1 sows. These results are consistent with previous studies in which older sows were more aggressive at mixing compared with younger sows (Strawford et al. 2008; Li et al. 2011). Since focal sows were young (in parity 1 and 2) in the group, focal sows won few fights (ranged between 26 and 8% of total fights) in which they were involved, which agrees with results of previous studies that younger sows won few fights compared with older sows (Krauss and Hoy 2011; Li et al. 2012). Focal sows were also less aggressive during nighttime than daytime, as reported previously (Arey and Edwards 1998; Li et al. 2011).

In stalls, sows fed DDGS spent more time resting and less time performing stereotypic behaviors compared with CON sows. The incidence of stereotypic behaviors observed in the current study was similar to results of previous studies (Dailey and McGlone 1997; Bergeron et al. 2000; Holt et al. 2006). Stereotypic behaviors have been considered an indicator of poor welfare, especially for gestating sows housed in individual stalls (Mendl et al. 1993). These stereotypies may

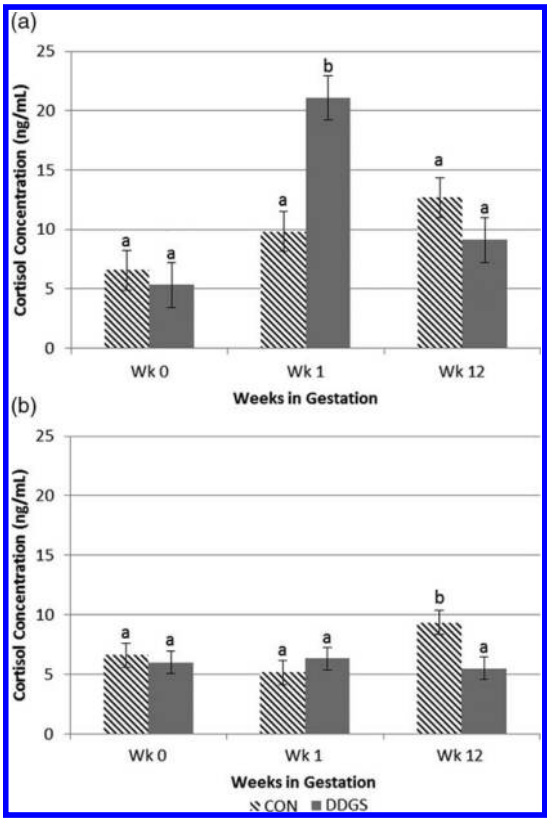

Fig. 2. (A) Effects of DDGS on salivary cortisol concentrations of group-housed sows. Week 0 was defined as the week before breeding, and week 1 and week 12 were defined as 1 wk and 12 wk after breeding, respectively. a, b Means without a common letter differ ($P<0.05$). (B) Effects of DDGS on salivary cortisol concentrations of sows in stalls. a, b Means without a common letter differ ($P<0.05$).

be associated with hunger and restricted eating or foraging behavior (Lawrence and Terlouw 1993; D'Eath et al. 2009). D'Eath et al. (2009) and de Leeuw et al. (2004) reported that hunger was associated with an increase in physical activities and stereotypies, so in contrast, increased resting and reduced stereotypies indicated satiety in gestating sows. Some earlier studies (Robert et al. 1997; van der Peet-Schwering et al. 1998; Bergeron et al. 2000) reported that feeding a large volume of roughage and high-fiber diets to fill the gut can reduce stereotypies in gestating sows. In addition, de Leeuw et al. (2004) demonstrated that fermentable fibers can stabilize glucose and insulin levels in plasma during postprandial periods, reduce physical activities, and increase resting, which indicates prolonged feelings of satiety. In the current study, the increased bulkiness of DDGS was subtle compared with bulky high-fiber diets used in other studies to reduce stereotypic behaviors in sows (Bergeron et al. 2000). So, the effects of DDGS on physical activities and stereotypies were unlikely to be associated with the bulky volume of the diet. Instead, the fiber fermentation of DDGS in sows might play a role. Although most fiber in DDGS is insoluble (Stein and Shurson 2009), about 25% of dietary fiber in DDGS is fermentable in the hindgut of swine (Urriola et al. 2010). It is possible that sows fed DDGS experienced prolonged satiety as a result of the fiber fermentation in the hindgut, which contributes to less stereotypic and more resting behavior. This is similar to the results of de Leeuw et al. (2004, 2005) for sows limit-fed with high-fiber diets.

The reduced stereotypic behaviors of sows fed DDGS was not associated with eating behavior because eating behavior was not influenced by dietary treatment. Lawrence and Terlouw (1993) suggested that stereotypic behaviors in gestating sows can be caused by restricted eating and foraging behaviors. However, several studies (Robert et al. 1997; Whittaker et al. 1999; Zonderland et al. 2004) demonstrated that sows spent more time ingesting bulky diets that contained high fiber concentrations with no effect on stereotypic behaviors, which suggests that stereotypic behaviors are not associated with eating behavior. Recent research suggests that stereotypic behaviors in gestating sows can be associated more with hunger than with eating or foraging behavior (D'Eath et al. 2009). The current study provides evidence that stereotypic behaviors of gestating sows housed in individual stalls are not associated with eating behavior.

On average, sows assigned to both dietary treatments spent 2.6% of total time eating in individual stalls. Due to limit-feeding, sows appeared to eat their portion of the diet continuously after feed delivery because all eating events were observed within 1 h after feed delivery in the current study. Our results that inclusion of 40% DDGS in gestation diets for two consecutive reproductive cycles did not affect eating behaviors of gestating sows further suggest that the difference in the bulky volume between the two diets were negligible.

Parity 2 sows spent less time resting and more time performing stereotypic behaviors compared with parity 1 sows in stalls. Similar results were reported in earlier studies (Mendl et al. 1993) where older sows performed more stereotypic behaviors. Furthermore, we observed interactions between parity and time period of the day for stereotypic behaviors, with parity 2 sows performing more stereotypic behaviors than parity 1 sows during the daytime but not during the nighttime. In fact, all sows performed more stereotypic behaviors during the daytime than nighttime. The interactions between parity and time period suggest that the daytime is a better time for observing stereotypic behaviors in gestating sows housed in individual stalls than nighttime.

In the current study, cortisol concentrations were used as another indicator to evaluate effects of dietary treatment on sow welfare in the two housing systems. In general, the cortisol concentrations of sows were higher in the group-housed system than in stalls, which may contribute to the social stress of group-housed sows. One contributor to the social stress in group-housed sows was mixing. In the current study, mixing resulted in an elevation of cortisol concentrations in DDGS sows, but not in CON sows compared with before mixing (week 0). These results were consistent with the difference in aggression at mixing between DDGS and CON sows. Compared with CON sows, DDGS sows were more aggressive at mixing. Previous studies (Strawford et al. 2008; Li et al. 2011) demonstrated that mixing-induced aggression increased cortisol concentrations in gestating sows. The elevated aggression and cortisol concentrations in DDGS sows at mixing suggest that feeding DDGS might compromise the welfare of gestating sows in group-housed systems. In stalls, however, the cortisol concentrations of DDGS sows in week 12 was lower compared with CON sows. Furthermore, behavioral data showed that DDGS sows spent more time resting and less time performing stereotypic behaviors compared with CON sows in stalls. The results of reduced stereotypic behaviors, increased resting behavior, and reduced cortisol concentrations suggest that feeding DDGS may improve welfare of gestating sows in stalls.

In conclusion, the effect of DDGS diet on behavior and welfare of gestating sows appears to be dependent on the housing system. In the group-housed system, inclusion of 40% DDGS in the gestation diet increased aggression and cortisol concentrations in sows at mixing, and consequently, may compromise the welfare of sows. However, sows fed DDGS and housed in individual stalls spent more time resting and less time performing stereotypic behaviors, and had lower cortisol concentrations which suggest improved welfare of sows.

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