Title: Impact of group size and diet on behavior and physiology of sows **(07-105)**

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Industry Summary

A major public issue on a global scale is farm animal welfare; with the most critical issue facing the swine industry being how the pregnant sow should be kept in commercial pork production. Despite the successful passing of state-by-state referendum by HSUS, that keeping sows in group-pens is a welfare-friendly practice and state, the reality is that group-penned sows experience "new problems" that adversely affect their welfare. Therefore, the objectives of this study were to evaluate the effects of feeding dietary-fiber to gestating sows kept in group-pens (10 sows per pen) at different floor-space allowances on sow performance, productivity, immune and endocrine status, and behavior. In this study, 240 sows were allotted to a **dietary treatment** of either **a)** standard diet (control) or **b)** standard diet supplemented with high-fiber (treatment) and a floor-space allowance treatment of either 1.7 m^2 or 2.3 m^2 per sow. The high-fiber diet used in this study consisted of 15% wheat middlings and 30% soy hulls. Performance measures included sow body weight, backfat (10^{th} rib), and body condition and lesion severity scores were assessed throughout gestation. Sow productivity was assessed using "standard" farrowing measures. Sow well-being was further assessed using various welfare measures which encompassed immune, endocrine and behavior traits, these measures were taken throughout gestation. Data were analyzed using Proc MIXED with repeated measures and Chi-square analysis (SAS).

Both diet and floor-space allowance had an impact on sow well-being, and there were diet x floor-space interaction for some of these measures. In short, sows fed high-fiber diet performed better than did sows fed control diet; sows fed high-fiber diet gained more body weight, were heavier overall, and had greater body conditions scores throughout gestation than did sows fed control diet. Sows fed control diet tended to retain more piglets than did sows fed a high-fiber diet. In some cases, immune status for sows fed high-fiber diet was enhanced compared with sows fed control diet, with one exception, neutrophil phagocytosis. Neutrophil phagocytosis and plasma cortisol were greater for sows fed control diet. Diet had an impact on sow behavior; with those sows being fed a control diet having longer and more stand bouts and more oral-nasal-facial bouts compared with those sows fed high-fiber diet. In general, sows fed control diet were more active. Frequencies of eat and drink bouts were greater amongst sows fed high-fiber diet. Floor-space allowance affected sow lesion scores and other behaviors. Sows kept in pens at 1.7 m^2 had greater lesion severity scores than did sows kept in pens at 2.3 m^2; while aggression, sham-chew, and drink behaviors were all greater amongst sows kept in pens at 2.3 m^2 compared to sows kept in pens at 1.7 m^2. However, stand behavior and overall activity were greater amongst sows kept in pens at 1.7 m^2 than for sows kept at 2.3 m^2. Sows fed high-fiber diet and kept in pens at 2.3 m^2 performed less oral-nasal-facial behaviors compared with all other treatment groups. Sows fed control diet and kept at 2.3 m^2 floor-space had heavier litters than did sows from other treatment groups.

Taken together these data imply that both type of diet and floor-space allowance can positively impact sow performance, behavior and immune status during gestation, but this group system and management scheme are not optimized due to some apparent “negative” affects on sow welfare that still are apparent within this system, thus others factors still need to be assessed and optimized. For example, aggressive encounters were common within this system especially around feeding time, and thus this may have diluted the “positive” effects and/or contributed to the ‘negative” effects found within this housing environment based on animal welfare. Thus, it is speculated that reducing aggressive encounters by providing protection during feeding (e.g., feeding stall) may further improve well-being, especially by reducing lesion severity scores within this system. When implementing a group-pen system and using floor-feeding, feeding sows a high-fiber diet can improve sow performance (body weight, body weight gain and body condition scores) and motivate sows to utilize their natural sequence of important maintenance behaviors such as the eat-drink-eat sequence. However, type of diet and floor-space allowance are not the only components of a group-housing system that must be considered but group-size can also impact the well-being of the gestating sow. For example, floor-space allowance can impact lesion severity and maintenance behaviors, but the floor-spaces used in this study did not necessarily improve sow well-being nor negatively impact sow well-being. However, we have shown that 1.7 m^2 of floor-space is not detrimental to sow well-being and in fact, if other components are considered this may be more ideal than 2.3 m^2 of floor-space. Results herein indicate that individual components of a sow housing system (such as diet) can impact sow well-being and therefore these factors and others should be assessed further in order to determine an optimized system that truly improves sow well-being.

Keywords: Behavior, Floor-space, Fiber, Gestation, Immune, Lesion, Productivity, Sow, Well-being

Abstract

A major public issue on a global scale is farm animal welfare with the most critical issue facing the swine industry is how the dry sow should be kept in commercial pork production. The public approval for sow housing has serious societal and economic implications for domestic and international pork production and trade. Currently, emotions and public opinion are driving potential legislation that will dictate which housing system provides optimum sow welfare. Unfortunately, public opinion and "potential" resulting legislation, is not based on scientifically-sound measures of animal welfare, thus resulting in unwittingly compromising sow welfare and negatively impacting the future of animal agriculture. Despite the successful passing of state-by-state referendum by HSUS and the misconception that keeping sows in groups is a welfare-friendly practice and state, the reality is that group-penned sows experience "new problems" that adversely affect their welfare. Therefore, the objectives of this study were to evaluate the effects of feeding dietary-fiber to gestating sows kept in group-pens of 10 sows at different floor-space allowances on sow performance, productivity, immune and endocrine status, and behavior. Two-hundred and forty sows over time were allotted to a dietary treatment [standard diet (control) or standard diet supplemented with high-fiber (treatment)] and floor-space allowance of either 1.7 m^2/sow or 2.3 m^2/sow while keeping group size constant. On days 34 (prior to group-pen) and 90 blood samples were collected to determine sow immune and endocrine statuses (N=40 sow/treatment). Immune traits assessed were: total white blood cell count (WBC), neutrophil and lymphocyte count, leukocyte cell type populations, induced lymphocyte proliferation, neutrophil phagocytosis and chemotaxis and cortisol. Sow behavior was recorded and registered using EZViewlog by Geovision for 24 h on d 44, 76, and 104 of gestation. Behaviorwas registered and analyzed using continuous-sampling included: drink, eat, lay (next to wall, next to con-specific, next to gate), stand, sit, oral-nasal-facial (ONF), sham-chew, and aggressive encounters. Both duration and frequency of each behavior were analyzed. Data were analyzed using Proc MIXED with repeated measures and Chi-square analysis (SAS). There were diet × floor-space interactions for several welfare measures. Lesion severity scores were less amongst sows fed a high-fiber diet and kept in group-pens at 2.3 m^2/sow compared with all other treatment groups ($P < 0.05$). Live litter weight was greatest amongst those piglets that were born to sows kept at 2.3 m^2/sow of floor-space and fed the control diet compared with sows kept in pens at 2.3 m^2/sow and fed high-fiber diet ($P < 0.05$). Duration of eat bouts were greater amongst sows kept at 1.7 m^2 of floor-space than for those sows kept at 2.3 m^2/sow. Dietary treatment impacted measures of well-being ($P < 0.05$); sows fed a high-fiber diet had greater BW, BCS ($P< 0.05$), and BW gain ($P < 0.10$) throughout gestation than did sows fed control diet. Number of piglets retained tended to be greater amongst sows fed control diet compared with sows fed high-fiber diet ($P < 0.10$). Lymphocyte proliferation was greater ($P < 0.05$) amongst sows fed high-fiber diet than for those sows fed control diet; however, neutrophil phagocytosis was greater ($P < 0.05$) amongst sows fed control diet. Stand and ONF behaviors were greatest ($P < 0.05$) amongst sows fed control diet and these sows were more active than sows fed high-fiber diet. Frequencies of eat and drink bouts were greater ($P < 0.05$) amongst sows fed high-fiber diet than sows fed control diet. Floor-space allowance had an impact on sow lesion scores and behavior. Lesion severity scores were greater ($P < 0.05$) amongst sows kept in group-pens at 1.7 m^2 floor-space allowance compared with sows kept at 2.3 m^2 of floor-space. Sows kept in pens at 1.7 m^2 of floor-space were more ($P < 0.05$) active than were sows kept in group-pens at 2.3 m^2. Sham-chew, drink, and aggression bouts were greater ($P < 0.05$) amongst sows kept in pens at 2.3 m^2 floor-space than for sows kept at 1.7 m^2. Results reported herein indicate that supplementing a standard gestation diet with high-fiber can improve sow performance and natural sequence of eat-drink-eat, while floor-space allowance did not negatively impact measures of sow well-being. Therefore, these data strongly support that individual components within a housing system can influence sow well-being and should be used to determine an optimal alternative housing system.

Introduction

A major public issue of global scale is farm animal welfare, more specifically, how to keep dry sows. Swine producers can choose from a number of housing choices but most do not equate to safeguarding sow welfare or sustaining animal agriculture. Why? Because public opinion is driving potential legislation as to the type of housing system that provides optimum sow welfare, not scientifically-sound measures of welfare, this may have serious societal and economic implications for the future of animal agriculture. Based on past research, there are plusses and minuses associated with all housing systems but not one has been identified that improves sow well-being. Thus it is incumbent upon us to develop welfare-friendly systems based on scientific-assessments of sow welfare to avoid unwittingly compromising well-being. We must thoroughly understand the positive and negative attributes of each housing system based sow well-being so that we can ultimately safeguard animal welfare.

It is apparent that there are both advantages and disadvantages associated with sows either kept individually and in groups during gestation, and that no keeping system has been identified, developed, or optimized such that it ultimately improves and sustains the well-being of the gestating sow. (McGlone et al., 2004; Rhodes et al., 2005; Curtis et al., 2009; Salak-Johnson et al., 2007). However, most studies have not taken a holistic approach to assessing multiple measures of welfare, as well as that most studies have compared so-called "systems" but have not considered all of the features of these respective systems that may influence how an animal responds and interacts with her environment. Features within group pens such as floor space allowance as well as diet strategy, high source of fiber, have shown to have an influence on a few measures such as sow behavior and lesions, while little is known about the impact that floor space allowance, high fiber, and the combination of both have on sow well-being. (Meunier-Salaun et al., 2001; Salak-Johnson et al., 2007; Curtis et al., 2009; Salak-Johnson et al., submitted).

Objective

Objective of this study was to evaluate the effects of high-fiber diet and floor-space allowance on performance and productivity, immune and endocrine status, and behavior of group- kept gestating sows.

Materials and Methods

All sows were artificially inseminated within 24 h after estrus onset and again 24 h later. All newly bred sows were kept in individual turn-around stalls until day 34 of gestation. Pregnancy was detected on day 28 ± 2 post-breeding using an Aloka-500V ultrasound machine for transabdominal examinations, and then pregnant sows were allocated to their respective treatments based on sow body weight and parity (parity 1-10). Sows remained in their respective gestation treatment group until ~d110 when they were moved to farrowing stalls.

In this 2 x 2 factorial design, 6 blocks of 40 sows per block (10 sows per treatment; total 240 sows) were allotted to diet [standard gestation diet (control) or standard gestation diet supplemented with high-fiber (treatment)] and floor-space allowance [1.7 m^2 per sow or 2.3 m^2 per sow]. Control diet was a typical corn and soybean based gestation diet which contained 13.6% crude protein and provided 3,348 kcal ME per kg. The

ADF and NDF concentrations in this diet were 3.06 and 9.08 %, respectively. The high fiber diet was based on corn, soybean meal, wheat middlings (15%), and soybean hulls (30%) and contained 13.2% crude protein and 2,885 kcal ME per kg. The diet also contained 16.6 and 28.3 % ADF and NDF, respectively. All nutrients were present in both diets at concentrations that are at or above current requirement estimates (NRC, 1998). All sows were fed 6,700 kcal ME per day during the initial 90 days of gestation and 10,720 kcal ME per day during the remaining gestation period. These levels of energy correspond to 2 and 3.2 kg per day of control diet and 2.3 and 3.7 kg per day of the high-fiber diet. Sows had free access to one nipple water per pen throughout the experiment.

Table 1: Composition of low and high fiber diets.

Item	Low fiber diet	High fiber diet
Ingredients, %		
Corn	81.15	45.15
Soybean meal, 48%	14.50	6.00
Wheat middlings	-	15.00
Soybean hulls	-	30.00
Soybean oil	1.00	1.00
Limestone	0.65	0.40
Dicalcium phosphate	2.00	1.65
Salt	0.40	0.40
Vitamin mineral premix	0.30	0.30
Total	100.00	100.00
Energy and nutrients		
Energy, Kcal ME/kg	3,348	2,885
Crude protein, %	13.6	13.2
Calcium, %	0.75	0.75
Phosphorus, %	0.70	0.66
Phosphorus, digestible, %	0.35	0.35
Acid detergent fiber, %	3.06	16.6
Neutral detergent fiber, %	9.08	28.3
Arginine, %	0.81	0.74
Histidine, %	0.37	0.37
Isoleucine, %	0.54	0.50
Leucine, %	1.33	1.10
Lysine, %	0.65	0.65
Methionine, %	0.24	0.20
Methionine + cysteine, %	0.50	0.46
Phenylalanine, %	0.66	0.61
Threonine, %	0.50	0.43
Tryptophan, %	0.14	0.14
Valine, %	0.65	0.61

Performance and Productivity Measures.

Sow body weight, back fat (10^{th} rib), and body condition scores were all recorded on d 34, 65, 90, and 110 of gestation. Additionally, lesion scores were recorded on d 34 of gestation , and every 2 days for the first 14 days (phase 1), and then thereafter, lesion scores were recorded on a bi-weekly basis throughout gestation (phase 2). Lesions were scored on each of the following body regions: head, ears, neck, chest/breast, shoulders, back, udder, rear, vulva, perineum, legs, and hooves. Lesion score scale: 0 = normal (no lesions), 1 = dehairing, callus, balding; 2 = redness, swelling; 3 = swelling + callus, abscess; 4 = moderate wound, scabbed over scratch; 5 = marked wound, fresh scratch; and 6 = severe wound, open wound. Thus, a sow could receive a score ranging from 0 (normal, no lesions) to 6 (severe wound, open wound) for any location on any particular day. Sows also could be assigned combined scores for a given location. For example, a sow may have had: dehairing (1), redness + swelling (2), swelling + callus (3), and marked wound/fresh scratch (5), for a total combined lesion score of 11. Standard litter traits were recorded: litter weight, live weight, number of males and females, number born and born alive, number retained, stillborn, or mummies, number weaned, and weaning weight.

Physiological Measures.

Blood samples were collected on d 34 and 90 of gestation for sows in the blocks 1 through 4 (n=40 sows/treatment) via veni-puncture using Vacutainers. Samples were processed and analyzed for total WBC counts, leukocyte populations, neutrophil and lymphocyte counts, neutrophil phagocytosis and chemotaxis, lymphocyte proliferation and natural killer cell cytotoxicity using methodology previously describe by Salak-Johnson et al., 1993, 1996; Sutherland et al., 2005; and Niekamp et al., 2006. Plasma cortisol was measured using a validated commercially available radioimmunoassay (Coat-A-Count®, Los Angeles, CA).

Behavioral Measures.

Sow behavior was recorded using Geovision GV-1240 video capture combo card and viewed using EZViewlog in real-time. Behavior was observed and registered for 10 hours on days 44, 76, and 104 of gestation during block 2 and for 10 hours during late gestation (~ d 90) for block 1, Totaling 40 h of continuous observation. The behaviors registered and analyzed using continuous-sampling include: drink, eat, lay (next to wall, next to gate, next to con-specific), stand, sit, oral-nasal-facial, sham-chew, and agonistic encounters. Both duration and frequency were assessed for each behavior.

Results

There were diet × floor-space allowance, diet × day of gestation, floor-space allowance × day of gestation interactions for performance, physiological and behavioral traits. Diet × floor-space allowance occurred for sow back-fat depth, litter weight, live litter weight (**Fig. 1**), piglets retained, mummified piglets, piglets weaned, total lymphocyte count, and behavior (ONF, sham-chew, eat, drink, lay with wall, stand, and agonistic encounters) (**Fig. 2**). Sows kept at 2.3 m^2 and fed high-fiber diet tended to have lower back-fat depth than did sows in any other treatment group ($P < 0.10$). Sows kept in pens at a floor-space allowance of 2.3 m^2 and fed high-fiber diet produced piglets with lower live litter weights than did sows kept at same floor-space but fed a control diet (**Fig. 1**) and sows kept at 1.7 m^2 floor-space and fed high-fiber diet had heavier live litter weights ($P < 0.05$). Sows kept in pens at a floor-space allowance of 2.3 m^2 had greater number of piglets retained and mummified than did sows kept at the same floor-space and fed control diet and more than did sows kept at 1.7 m^2 and fed high-fiber diet ($P < 0.05$). Number of piglets weaned was greater amongst sows kept at 1.7 m^2 and fed high-fiber diet than sows kept at 2.3 m^2 and fed fiber-diet ($P < 0.05$). Total lymphocyte count tended to be greater for sows fed high-fiber diet and kept in pens at 1.7 m^2 floor-space per sow compared with sows in any other treatment group ($P < 0.10$). Percentage of lay in contact with wall was greater for sows kept at 1.7 m^2 floor-space and fed control diet than for sows in any other treatment ($P < 0.05$). Sows kept in pens at 2.3 m^2 and fed high-fiber diet had a greater percentage of stand behavior than did sows fed same diet and kept at 1.7 m^2. Sows kept in 2.3 m^2 and fed control diet stood less ($P < 0.001$) compared with sows at same floor-space and fed fiber-diet. Duration of sham-chew was greater for sows fed control diet and kept in pens at 2.3 m^2 compared with sows in all other treatments ($P < 0.01$). Conversely, frequency of sham-chew was greatest amongst sows kept in pens at 1.7 m^2 floor-space allowance and fed control diet than sows in all other treatmenst ($P < 0.001$); while sows kept at either floo- space allowance and fed high-fiber diet had a greater percentage of sham-chew bouts

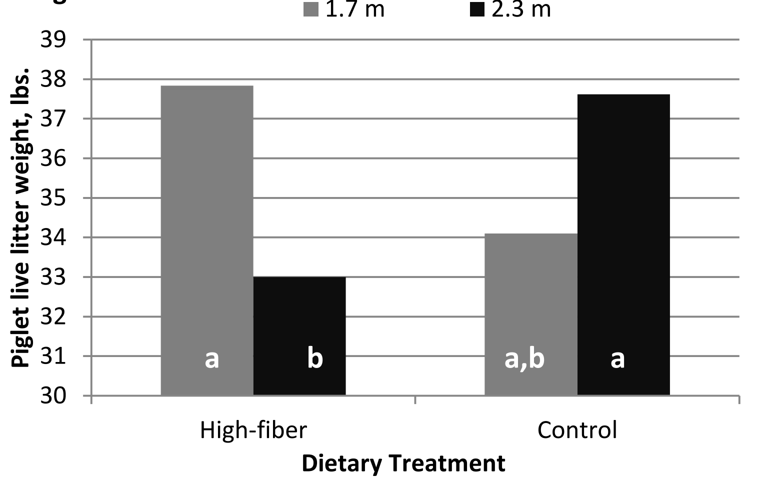
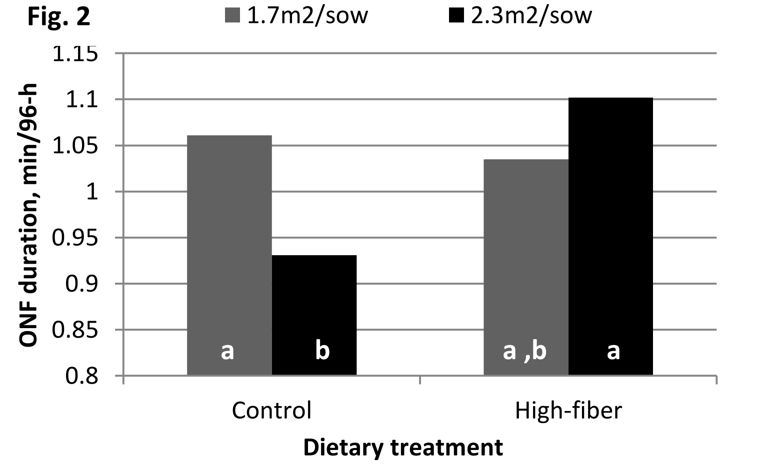
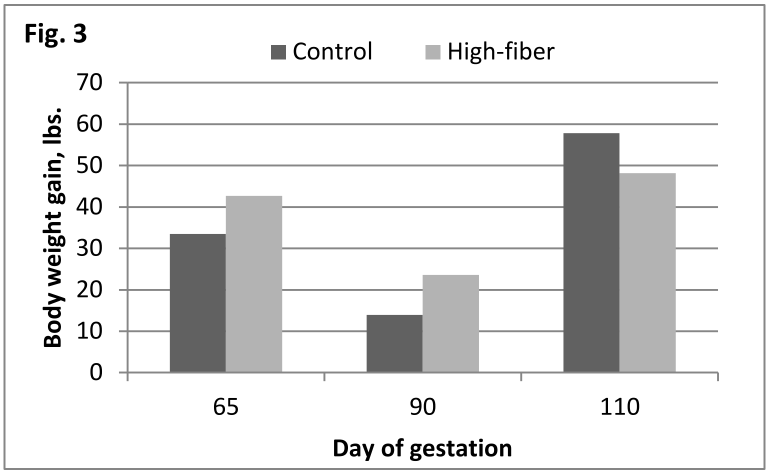
Fig. 1


Fig. 2




than did sows kept in pens at 2.3 m^2 and fed control diet ($P < 0.001$). Duration of eat bouts was greater for sows fed high-fiber diet when kept at 1.7 m^2 floor-space than all other treatment groups ($P < 0.05$). Percentage of eat bouts was greatest for sows kept at 2.3 m^2 and fed high-fiber diet than all other treatment groups ($P < 0.01$) and sows kept at 1.7 m^2 and fed high-fiber diet had greater percentage of eat bouts than sows at either floor-space allowance and fed control diet ($P < 0.001$). In contrast, duration of ONF (**Fig. 2**) and percentage of ONF bouts were greater for sows kept in pens at 2.3 m^2 and fed high-fiber diet and sows kept at 1.7 m^2 and fed control diet than sows kept at 1.7 m^2 and fed high-fiber diet ($P < 0.001$).

There were diet × day of gestation interaction for sow body weight gain (**Fig. 3**), average daily gain (ADG), and multiple immune traits. Thus, ADG was greater on d 65, 90, and 110 of gestation for sows fed a high-fiber diet than for sows fed control diet ($P < 0.001$). Neutrophil phagocytosis was influenced by diet and day of gestation; percentage of beads engulfed by neutrophils was greater on d 90 of gestation for sows fed control diet than for sows fed high-fiber diet ($P < 0.05$). But sows fed high-fiber diet on d 90 of gestation had greater conconavalin-A induced lymphocyte proliferation than did sows fed control diet ($P < 0.01$).

Dietary effects on sow performance and productivity

Table 1 shows the main effects of diet on sow performance. Feeding sows high-fiber diet during gestation had an effect on sow performance, body condition score ($P < 0.10$), and back-fat depth ($P < 0.05$).

Table 1. Effect of dietary treatment on sow performance

Measure	Control diet	High-fiber diet	P-value
Body wt, lbs	468.12±3.0	472.34±3.0	0.215
Body wt gain, lbs	33.9±1.3	35.8±1.3	0.344
ADG, lbs.	1.61±0.05	1.67±0.05	0.393
Lesion Severity, (0-7)	27.1±0.16	26.9±0.16	0.391
Back fat depth, mm	**15.6±0.24[a]**	**14.8±0.24[b]**	**0.029**
BCS, (1-5)	**2.89 ±0.02[c]**	**2.85 ±0.02[d]**	**0.098**

[ab]within row, means with different superscript differ at ($P < 0.05$) and [cd] differ at ($P < 0.10$).

Table 2 shows the main effects of diet on sow productivity. Dietary treatment had no influence on litter characteristics ($P > 0.10$).

Table 2. Effect of dietary treatment on sow productivity

Measure	Control diet	High-fiber diet	P-value
Litter weight, lbs.	39.9±0.99	38.5±0.99	0.300
Live weight, lbs.	35.8±1.00	35.4±1.00	0.765
No. Male piglets	6.3±0.24	6.1±0.24	0.442
No. Female piglets	5.6±0.23	5.6±0.23	0.926
No. Born	12.1±0.30	11.8±0.30	0.505
No. Born alive	10.6±0.33	10.5±0.33	0.822
No. Retained	0.04±0.03	0.05±0.03	0.898
No. Mummys	0.19±0.05	0.23±0.05	0.585
No. Weaned	8.9±0.20	9.0±0.20	0.826
Litter wean weight, lbs.	115.6±3.5	113.7±3.5	0.709

[cd]within a row, means with different superscript differ at ($P < 0.10$).

Dietary effects on sow immune status

Table 3 shows the effects of dietary treatment on sow immune status and plasma cortisol. Multiple immune traits were affected by feeding group-penned sows a high-fiber diet during gestation. Lymphocyte proliferation was greater amongst sows fed a high-fiber diet ($P < 0.05$; **Table 3**).

Table 3. Effects of dietary fiber on immune and endocrine traits

Measure	Control Diet	High-fiber Diet	P-value
Cortisol, ng/ml	**28.1±2.5[a]**	**23.64±2.5[b]**	**0.007**
Total WBC, 10^7	2.6±0.13	2.6±0.13	0.656
Lymphocyte, 10^7	2.9±0.31	2.9±0.31	0.429
Neutrophil, 10^7	5.7±0.53	5.8±0.53	0.731

Lymphocytes, %	45.9±6.5	51.6±6.2	0.161
Monocytes, %	2.4±0.30	2.1±0.30	0.142
Eosinophils, %	3.7±0.59	4.1±0.56	0.266
Segmented neutrophils, %	46.6±2.1	44.9±2.1	0.203
Banded neutrophils, %	1.4±0.35	1.4±0.35	0.743
Neutrophil-to-lymphocyte ratio	1.2±0.20	1.2±0.20	0.673
LPS proliferation 0.2	**1.17±0.27[d]**	**1.89±0.27[c]**	**0.060**
ConA proliferation, 0.2	**1.18±0.10[b]**	**1.73±0.11[a]**	**0.001**
Phagocytosis, %	**51.5±3.9[a]**	**43.7±3.8[b]**	**0.002**
Chemotaxis, C5a	144.6±43	130.4±39	0.696
Chemotaxis, IL8	209±51	204±48	0.888

[ab]within a row, means with different superscript differ at (P < 0.05) and [cd] differ at (P < 0.10)

Sows fed control diet had greater neutrophil phagocytosis than did sows fed high-fiber diet (P<0.01). Plamsa cortisol was statistically greater amonst sows fed the control diet than sows fed the high-fiber diet (P < 0.01). All other immune measures were similar regardless of diet treatment.

Dietary effects on sow behavior

Fig 4.

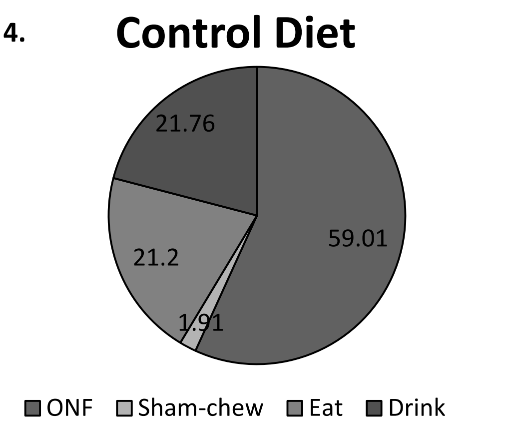
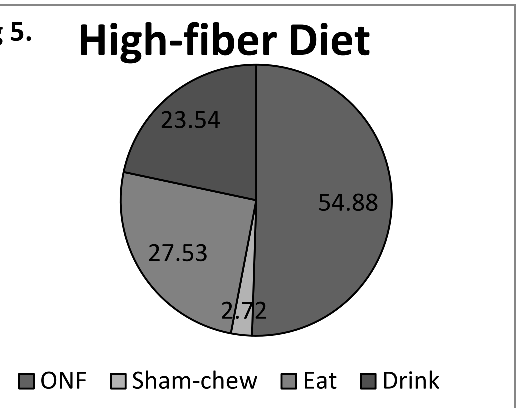


Fig 5.



Feeding sows high-fiber during gestation had an effect on various sow behaviors (P < 0.05). For example percentage of stereotypic and maintenance behaviors by sows was influenced by the diet sows consumed during gestation. Shown in figures 4 and 5 (P < 0.05); sows fed high-fiber (2.72%) had greater bouts of sham-chew than sows fed control diet (1.91%; P < 0.05). Conversely sows fed control diet had greater duration of sham-chew than sows fed high-fiber diet (P < 0.05). Sows fed control diet (59.01 %) had greater ONF bouts than sows fed high-fiber diet (54.88 %; P < 0.05). Maintenance behavior such as eat and drink bouts were also incluenced by dietary treatment; sow fed high-fiber diet performed more eat and drink bouts than sows fed control diet (P < 0.05). Duration of behaviors performed by sow in either dietary treatment is represented in Table 4. Sows fed control diet performed longer bouts of sham-chew and stand than sows fed high-fiber diet (P<0.05). All other behaviors were similar (P > 0.10)

Table 4. Effect of dietary treatment on duration of behavior

Measure, min/40-h	Control diet	High-fiber diet	P-value
Lay with wall, min	1.35±0.13	1.32±0.13	0.808

Lay with North gate, min	1.19±0.07	1.22±0.07	0.713
Lay with South gate, min	1.45±0.09	1.38±0.09	0.583
Lay with con-specific, min	1.38±0.07	1.36±0.07	0.871
Stand, min	**0.87±0.03[a]**	**0.76±0.03[b]**	**0.010**
Sit, min	0.63±0.05	0.66±0.05	0.771
Eat, min	0.87±0.25	0.94±0.25	0.189
Drink, min	0.63±0.04	0.64±0.04	0.8427
ONF, min	1.07±0.35	0.99±0.04	0.1252
Sham-chew, min	**4.8±1.1[a]**	**2.3±0.47[b]**	**0.0230**
Agonistic encounter, %	13.36	14.20	0.1537

[ab]within a row, means without a common superscript differ (P < 0.05)

Floor-space allowance effects on sow performance and productivity

Table 6 shows the main effects of floor-space allowance on sow performance. Lesions were influenced by floor space (P < 0.05). Sows kept in pens at 1.7 m^2 had greater vulva, perineum, front legs, and front hoove lesion severity scores than sows kept at 2.3 m^2 (P < 0.05). Hind leg and hoove lesion severity scores were greater amongst sows kept at 2.3 m^2 than sows kept in pens at 1.7 m^2 (P < 0.05). All other performance measures were similar regardless of floor-space allowance (P > 0.10).

Table 6. Effect of floor space allowance on sow performance

Measure	1.7 m^2/sow	2.3 m^2/sow	P-value
Body weight, lbs.	482.4±3.0	483.2±3.0	0.8525
Body weight gain, lbs.	36.7±1.3	36.5±1.3	0.9010
ADG, lbs.	1.62±0.05	1.66±0.05	0.6462
Back fat depth, mm	15.1±0.25	14.9±0.25	0.6406
BCS, (1-5)	2.83±0.02	2.88 ±0.02	0.1407
Vulva lesion, 0-7	**0.42±0.03[a]**	**0.25±0.03[b]**	**0.0003**
Perineum lesion, 0-7	**0.24±0.02[a]**	**0.14±0.02[b]**	**0.0056**
Front Legs lesion, 0-7	**1.52±0.04[a]**	**1.42±0.04[b]**	**0.0408**
Hind Legs lesion, 0-7	**1.30±0.05[b]**	**1.51±0.05[a]**	**0.0053**
Front Hooves lesion, 0-5	**0.59±0.01[a]**	**0.03±0.01[b]**	**0.0272**
Hind Hooves lesion, 0-5	**0.07±0.02[b]**	**0.17±0.02[a]**	**0.0004**
Getting up ability, 0-3	**0.14±0.01[a]**	**0.10±0.01[b]**	**0.0070**

[ab]within a row, means without a common superscript differ (P < 0.05)

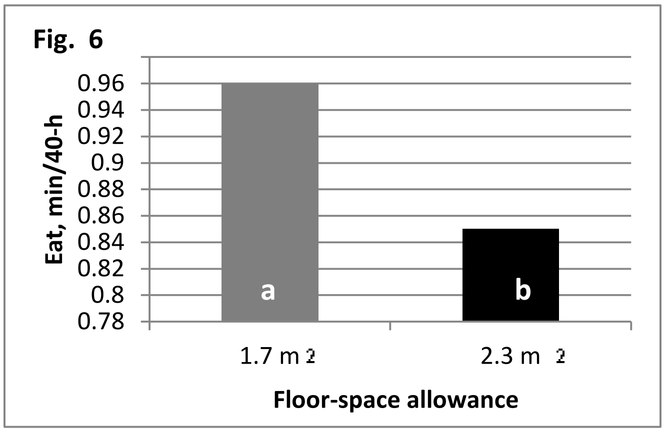
Floor-space allowance effects on sow endocrine and immune statuses

Floor-space allowance had minimal impact on sow physiology (**Table 7**). Numbers of neutrophils tended to be greater amongst sows kept in pens at 1.7 m^2/sow than for sows kept at 2.3 m^2/sow (P < 0.10). Sows kept in pens at 1.7 m^2 had greater lymphocyte counts than sows kept at a floor-space allowance of 2.3 m^2 (P < 0.05). ConA induced lymphocyte proliferation had a tendency to be greater amongst sows kept in pens at 2.3 m^2 than sows kept at 1.7 m^2 (P < 0.10). All other measures were similar, regardless of floor-space treatment.

Table. 7 Effect of floor space allowance on sow endocrine and immune traits

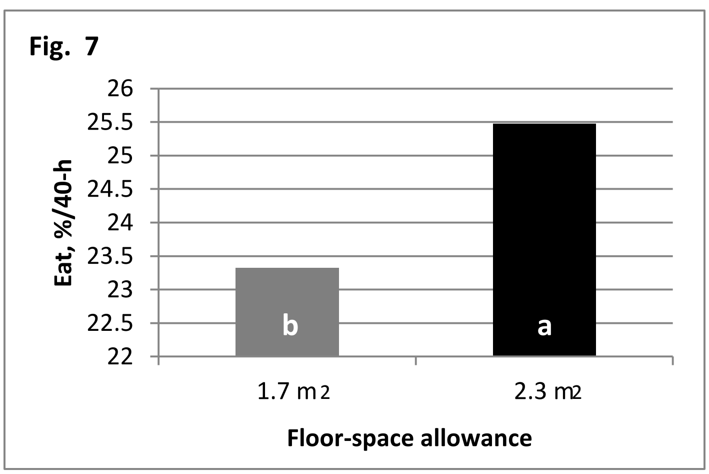
Measure	1.7 m^2/sow	2.3 m^2/sow	P-value
Cortisol, ng/ml	25.47±1.07	25.66±1.07	0.900
Total WBC, 10^7	2.76±0.06	2.68±0.06	0.370
Lymphocyte, 10^7	**3.07±0.30[a]**	**2.66±0.30[b]**	**0.047**
Neutrophil, 10^7	**6.01±0.52[c]**	**5.43±0.52[d]**	**0.093**
Lymphocytes, %	49.02±2.6	51.90±2.6	0.437
Monocytes, %	1.92±0.13	1.75±0.13	0.374
Banded neutrophils, %	1.59±0.14	1.63±0.14	0.878
Neutrophil-to-lymphocyte ratio	1.08±0.09	1.19±0.09	0.426
LPS-induced proliferation 2.0	1.96±0.38	1.68±0.38	0.607
ConA-induced proliferation 2.0	**1.31±0.11[d]**	**1.61±0.11[c]**	**0.053**
Phagocytosis, %	51.91±1.66	52.67±1.66	0.745

[cd]within a row, means without a common superscript differ (P < 0.10)



Floor-space allowance effects on duration and frequency of behaviors

Floor-space allowance affected both frequency and duration of maintenance, postural, and stereotypic behaviors for sows that gestated in group-pens (P < 0.05). Shown in figures 6, 7, and 8 and Table 8 are the main effects of floor-space allowance on sow behavior. Duration of eat behavior was greater for those sows that were kept at 1.7 m^2 of floor-space compared with those kept at 2.3 m^2 (**Fig 6**; P < 0.05); whereas frequency of eat behavior was greater for sows kept at 2.3 m^2 (**Fig 7**; P < 0.01).



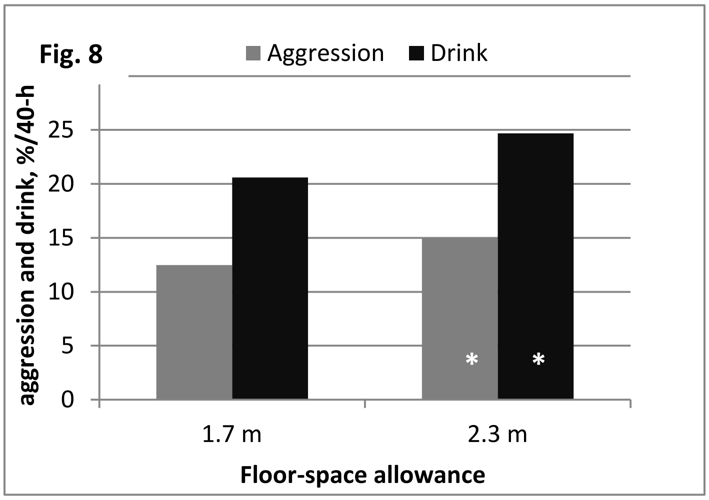
Sows kept at 1.7 m^2 of floor-space during gestation stood less (P < 0.0001) but tended to sit more (P = 0.07) than did those sows kept at 2.3 m^2 of floor-space (**Table 8**). Moreover, sows kept at 2.3 m^2 of floor-space sham-chew more than sows kept at 1.7 m^2 of floor-space (P < 0.0001; **Table 8**).

Table 8. Effect of floor space allowance on duration of behaviors performed

Measure, min/40-h	1.7 m^2/sow	2.3 m^2/sow	P-value
Lay with wall, min	1.42±0.13	1.24±0.13	0.133
Lay with North gate, min	1.21±0.07	2.20±0.07	0.917
Lay with South gate, min	1.46±0.09	1.37±0.09	0.474
Lay with con-specific, min	1.35±0.07	1.40±0.07	0.607
Stand, min	**0.86±0.03[a]**	**0.76±0.03[b]**	**0.0001**
Sit, min	**0.58±0.05[d]**	**0.71±0.05[c]**	**0.077**

Drink, min	0.45±0.03	0.48±0.03	0.498
ONF, min	0.92±0.04	0.86±0.04	0.207
Sham-chew, min	**1.41±0.32[b]**	**8.31±0.32[a]**	**0.0001**

[ab]within a row, means without a common superscript differ (P < 0.05)
[cd]within a row, means without a common superscript differ (P < 0.10)



Both aggression and drink behaviors were both affected by floor-space allowance (**Fig 8;** P < 0.001); with aggression and drink behavior being greater for sows kept at 2.3 m^2 compared with sows kept at 1.7 m^2 of floor-space.

Effects of day of gestation on well-being

Day of gestation influenced sow body lesion scores, immune status, and behavior (P<0.05). As day of gestation increased, lesion severity scores decreased (P< 0.05) and other physiological traits were altered due to the natural stress associated with pregnancy. From d 34 to d 90, all sows had an increase in neutrophil-to-lymphocyte ratio, total neutrophil count, and percent of mature neutrophils (P < 0.05). Consequently the percentage of eosinophils decreased as day of gestation increased (P < 0.05). Multiple behaviors were also influenced by day of gestation (P < 0.05); as day of gestation increased sows performed less ONF, sham-chew, lay, and sit bouts (P < 0.05).

Discussion

The results of the study reported within indicate that sow performance, productivity, immune status and behavior were all affected by floor-space allowance and dietary treatments imposed, with dietary-fiber having a greater impact on sow well-being than did floor-space allowance. Based on findings herein, feeding sows a high-fiber diet and keeping sows in groups of 10 sows/pen at a floor-space allowance of 1.7 m^2/sow can improve sow well-being based on measures of sow well-being including sow performance, immune status, and behavior. These results indicate that when combining management factors, such as type of diet, as well as physical housing component, such as floor-space allowance, these factors can influence one another and need to be considered. It is apparent that modifications in housing components or management strategies, such as dietary strategy, within housing systems can improve sow well-being. One interesting finding was the significant impact that feeding a high-fiber diet during gestation can impact measures of well-being. Sow body weight gain through mid-gestation were better amongst sows fed the high-fiber diet when compared with those sows fed a control diet, indicating that dietary fiber may influence dietary ME. Sow maintenance behaviors were altered due to the dietary treatment as well. Sows fed high-fiber diet were motivated to drink continuously throughout the feeding period than were sows fed control diet, thus it appears that the typical eat-drink sequence is re-established by feeding a high-fiber diet. Because sows fed control diet tended to binge on feed and then once feed disappeared, these sows would binge on water, thus altering the typical eat-drink-eat sequence. However, within the pens with floor-space allowance of 2.3 m^2, the placement of the waterer and the limited numbers most likely lead to more agonistic encounters since sows had to leave "feeding space" and seek waterer, only to attempt to return to original "feeding space". Hence, indicating that placement of resources must be considered. Therefore, the competition within group pens during floor-feeding, when fed control diet, apparently disrupts the natural sequence of eat-drink sequence behaviors and a high-fiber based diet may actually restore this natural sequence of maintenance behaviors, but waterer placement is crucial. Also, based on significant treatment interactions, sows fed high-fiber and kept at 1.7 m^2 had improved well-being, while sows fed high-fiber and kept at 2.3 m^2 did not perform as well. These results indicate that fiber based diets do have the potential to improve well-being, but only if physical components and resources are considered and optimized.

Dietary Treatments

Sows fed high-fiber had greater, body weight gain, body condition scores and back-fat depth. Sows were allocated based on body weight and parity, therefore indicating this increase in body weight gain is due mostly to the high-fiber based diet. There are several theories as to why high-fiber diet may have increased fat deposition and body weight gain. Cronin et al. (1986) reported an increase in heat production concomitant with increased stereotypic behavior amongst sows fed a high-fiber diet, which resulted in lower retention of energy over pregnancy. This could explain the greater weight gain throughout gestation. However another theory is that this increased weight gain might also be related to a greater gut fill or to an increase in the development of the gastrointestinal tract in connection with the high level of fiber. Another theory is that the greater drink behavior could impact water-holding capacity of the high-fiber diet. Also overall activity was less amongst sows fed high-fiber, therefore expending less energy on activity and thus conserving more and putting it into body weight gain.

Immune status was impacted by dietary treatment. Plasma cortisol concentrations were greater amongst sows fed control diet than high-fiber diet. However when observing the means of the cortisol concentrations we can determine that statistically they are different but biologically they are not. Mitogen-induced lymphocyte proliferation was greater amongst sows fed high-fiber diet while neutrophil phagocytosis was greater amongst sows fed control diet. Based on these two immune traits (which represent different aspects of the immune system) it may be concluded that diet may impact different aspects of the immune system and/or that the coping mechanisms of the sow are different when fed a high-fiber diet during gestation thus impacting the physiological response to stress. Moreover, from a physiological standpoint, fiber may activate a different immune pathway via a different signaling pathway.

Maintenance behaviors were influenced by dietary treatment. Eat and drink bouts were performed more frequently amongst sows fed high-fiber diet than for sows fed control diet. These results indicate that high-fiber diet may motivate sows to drink more frequently, consequently increasing the number of eating bouts as well. Competition is extremely high during eating in group-pens in which the sows are floor-fed and this competition will typically cause sows to binge and hoard feed while it is present, thus disrupting natural eat-drink-eat sequence. However, the addition of fiber to the diet may actually “reset” this typical eat-drink-eat sequence by increasing the desire (and/or motivate) sows to drink during the eating period rather than to binge on feed even in this highly competitive environment. Fiber content, such as wheat middlings and soy hulls, may have altered sow motivation when housed in group-pens and floor-fed.

Oral-nasal-facial behaviors were reduced by high-fiber diet while sham-chew was observed more frequently. Oral-nasal-facial behaviors may have been reduced because of the overall activity decrease when feeding sows high-fiber diets. The increase in sham-chew activity could be caused by the impact of fiber on thirst, as previously mentioned. Oral behaviors such as sham-chew have been known to produce more saliva which could be used as a digestive buffer. Therefore, indicating that these oral behaviors may not always be considered stereotypies when there is a purpose to performing them.

Floor-Space Treatments

Floor-space allowance alone had minimal effects on sow well-being. The most prominent finding was the increase in lesion scores amongst sows kept in pens at 1.7 m^2/sow. However similar results have been found in previous research (Salak-Johnson et al., 2007). Moreover, although those same sows consistently had greater lesion scores, their performance was similar to sows kept in 2.3 m^2/sow pens. Therefore, indicating that lesion severity does not impact sow performance or productivity.

Implications

When implementing a group-pen system and using a floor-feeding method, feeding a high-fiber diet and keeping sows at 1.7 m^2 can improve sow performance (back-fat, BW gain, and BCS) and litter productivity (live litter weight, number weaned, mummys). The high-fiber diet motivates sows to utilize their natural sequence of eat-drink-eat, while the smaller floor-space allows for closer access to water. When feeding a control diet either floor space allowance is sufficient based on industry standards of well-being. These results indicate that combining components that comprise a housing system and/or managements strategies can impact sow well-being and therefore should be assessed further in order to determine an optimized system that truly improves sow well-being.