Title: Retrofit an optimized gestation stall system based on sow well-being: A pilot study.
NPB #09-050 (yr 2 of 07-026)

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Industry Summary

Sow housing has become a very controversial welfare issue for pork producers. We cannot justify implementing alternative housing systems without concrete scientific data from these system that provide for improved sow well-being. Therefore the specific objectives of this project were to: 1) design a housing system that can be retro-fitted to provide the same animal capacity in existing housing facilities, yet constructed so as to allow flexibility in stall dimensions to address welfare issues of physical size of the stall, the freedom of sows to move, and to socialize (*if important to sow*) and **2**) to assess the practicality of these systems and the impact on sow welfare using an integrative approach. Based on results of this study, the long term objective is to design, optimize and implement sow housing and management systems that will enhance sow well-being while sustaining the productivity and profitability of swine production. Ninety-six multi-parous crossbred Yorkshire sows were allotted to either a modified gestation stall (**FLEX**) that allows the expansion of the width of the stall, the free access stall-pen which gives sows the option to be in a group pen or individual stall (**FREE**), or a standard non-adjustable stall which was used as a control (**STALL**). On d 89 of gestation, the width of the FLEX was increased to provide the sow an additional 7-8 cm of space. Sow performance and productivity measures were collected along with behavioral and physiological measures throughout gestation. Data were analyzed using Proc MIXED with repeated measures and Proc CORR (SAS software).

Comparing alternative housing systems (FLEX and FREE) with STALL multiple performance characteristics were affected. Sow body wounds and swelling were greater amongst sows kept in FREE compared with sows kept in either STALL or FLEX, however as day of gestation progressed the severity and frequency of body wounds and swelling for sows kept in FREE decreased, but continued to remain higher than sows kept in either of the individual stall type. Conversely,

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sows kept in FLEX had greater front leg swelling than sows kept in STALL, while sows kept in FREE had greater hind leg swelling than did sows kept in either individual stall type. Sows kept in STALL had greater wounds or lesions on the ears than did sows kept in FLEX or FREE. Additionally sows kept in FREE also had greater mean BW, back-fat depth, and BCS than did sows kept in STALL or FLEX. Endocrine and immune responses were influenced by alternative housing types; with those sows kept in FREE having greater neutrophil and lymphocyte counts, as well as plasma cortisol levels, but lower percentages of eosinophils compared with sows kept in either STALL or FLEX. Sows kept in STALL had greater total WBC count than sows in FLEX and greater T-lymphocyte proliferation than sows kept in either FLEX or FREE. Twenty-four hours after expanding the width of the FLEX (7 to 8cm), sows in those stalls had an increase in lymphocyte counts and greater total WBC count, while neutrophil chemotaxis decreased when compared with their sample prior to the expansion of the stall. Postural, maintenance, and oral-nasal-facial (**ONF**) behaviors were also influenced by housing type. Postural change—from laying to standing and vice-versa were greater for sows kept in FLEX than for those sows kept in either STALL or FREE. Sows kept in STALL had longer drink durations than did sows in both FLEX and FREE, but have less frequent bouts of eating than sows kept in FREE. Sows kept in FLEX performed significantly more frequent and longer duration of sham-chew bouts than did sows kept in either STALL or FREE.

When assessing the impact that social status has on space utilization and general behaviors of sows kept in FREE system, we found that submissive sows have greater duration of sitting bouts than did dominant sows; while dominant sows perform more eat bouts and have longer durations of drink than submissive sows. Dominant sows also performed more sham-chew behavior than did submissive sows. When given the choice to utilize a group pen or an individual stall, dominant sows (70-80%) use the group-pen area more than submissive sows (40-50%). However, day of gestation also influenced utilization of group-pen area across social ranks. On d30 (day of allotment) dominant sows (70%) used the group-pen area more than submissive sows (18%), through mid-gestation dominant sows still utilized the group-pen area more than submissive sows, but submissive sows did use pen area more than they did on d30. However as day of gestation increased (closer to parturition), submissive sows began to utilize the individual stalls more, while dominant sows percentage of time (70-80%) in group-pen area stayed consistent throughout gestation.

The results of the study reported within indicate that sow performance, productivity, immune status, and behavior were influenced by alternative individual housing systems (FLEX), as well as a combination of both individual stall and group-pen area (FREE). Allowing researchers to identify which concepts or components of each alternative accommodations (FLEX (expanding width) or FREE (stall or group pen preference)) improve well-being and therefore should be used to optimize a housing system for gestating sows.

When comparing two alternative housing systems to a standard gestation stall, results suggest that lesions/wounds, swelling, and behavior are more affected by housing design than either performance traits or endocrine and immune responses, biologically. However, the physical, biological, and social components within each alternative system may be imposing more of a response than the housing system itself. For example, sows kept in a FLEX stall change postures (stand, sit, lay) significantly more than did sows kept in either FREE or STALL, Furthermore, other oral activity (sham-chew) was also increased amongst sows kept in FLEX before, during, and after feeding than sows in other treatments. We hypothesize this increase in sham-chew behavior and postural changes around feeding could be due to limited ability to perform ONF behavior, since all bar-direction on the FLEX system are vertical. When expanding the stall an additional 7-8 cm late in gestation can influence an immune response. An increase in total WBC and lymphocyte counts could suggest an acute immune response occurred, however the significant decrease in neutrophil chemotaxis implies that there was more likely a shift in the immune system. Nevertheless, finding that expanding the width of stalls does influence indicators of well-being, causes us to hypothesize that correcting the front gate of the FLEX stall, to allow or encourage bar-biting or ONF behavior, could increase the immune benefits of expanding the stall even more so, resulting in overall improved well-being. When comparing the FREE system to the standard gestation STALL few biologically relevant results were reported. Lesions were found to be significantly greater amongst sows kept in FREE compared to sows kept in either of the individual stall types, however this increase in lesions/wounds did not seem to influence other indicators of well-being. Sow BW, BF, and BCS may have been statistically different, however biologically not relevant as indicators of improved well-being. Results pertaining to sow social status on behavior and space utilization within FREE indicate that dominance status has a major impact on how and when sows prefer to spend their time, as well as, where they choose to spend the majority of their time when given the opportunity to choose between individual stalls and a group pen. Since, few biological differences were found when comparing sows kept in either FLEX or FREE to sows kept in STALL, we hypothesize that industry standards of well-being exist across various sow housing systems and that physical, biological, and social components within existing housing systems may influence well-being more hence that upon refining these various components all of these systems could be acceptable alternative systems.

Keywords

Behavior, Gestation, Group-pen, Immune, Lesion, Performance, Sow, Stall, Well-being

Scientific abstract

Sow housing is one of the most controversial welfare issues facing the swine industry. New housing systems are being implemented without scientifically evaluating the impact these alternative systems have on sow well-being. The objectives of this study were to: a) develop an adjustable sow stow for use in existing sow gestation facilities that will better accommodate the physical size of the sow, b) determine the impact of the adjustable stall on sow well-being by assessing physiological and psychological needs of sow, and c) to determine the impact of providing sow freedom to leave stall on well-being. On d30 of gestation 96 multi-parous sows were allocated to a standard stall (**STALL**; control), an adjustable stall (**FLEX; width only**), or free access stall-pen (**FREE**). For FLEX stall only, on d89 of gestation, FLEX width was adjusted to achieve 4cm space between sow and stall on each side. BW and back-fat depth were measured on d0 (wean), 30, 89, and 110. Lesion severity and BCS were assessed on d0, 30, 45, 60, 75, 89, 103, and 110. Immune and endocrine status was measured on d0, 30, 31, 89, 90 (FLEX only) and 110. Behavior was recorded and registered on d30, 66, 87, and 102. Data were analyzed using Proc MIXED with repeated measures and Proc CORR (SAS). There were treatment × day of gestation interactions for lesions and swelling scores, immune responses, and oral behaviors (**ONF**). Total wound and swelling scores were greater ($P < 0.05$) among sows kept in FREE from d 45 to 110 of gestation compared to sows kept in either FLEX or STALL; while sows kept in STALL had greater ($P < 0.05$) lesion and swelling on d45 and 60 compared to sows kept in FLEX. Sows kept in FREE had greater ($P < 0.05$) neutrophil counts and CONA induced lymphocyte proliferation on d 31 (24 h post treatment allotment) than sows kept in either STALL or FLEX. On d30 of gestation (day of allotment) sows kept in FREE and FLEX performed greater ($P < 0.05$) bouts of ONF behavior than did sows kept in STALL. Treatment time of day interactions occurred; sows kept in FLEX performed more ($P < 0.05$) sham-chew behavior before (0300-0700), during (0700-1100), and after (1100-1500) feeding than sows kept in STALL or FREE. Housing treatment alone influenced measures of well-being. Sows kept in FREE had greater ($P < 0.05$) mean BW, back-fat depth, and BCS than sows in either STALL or FREE. Total body swelling and wounds were greater ($P < 0.01$) among sows kept in FREE than for sows kept in STALL. Sows kept in FLEX had greater ($P < 0.01$) front leg swelling than did sows kept in STALL; while sows kept in STALL had greater ($P < 0.01$) ear wounds than sows kept in FLEX or FREE. Sows kept in FREE had greater ($P < 0.05$) neutrophil and lymphocyte counts than sows kept in either STALL or FLEX; while T-lymphocyte proliferation was greater ($P < 0.05$) among sows kept in STALL than for sows in FLEX or FREE. Sows kept in FLEX performed more ($P < 0.05$) postural changes (stand, sit, lay) than sows kept in either STALL or FREE; while sows kept in STALL performed greater ($P < 0.05$) durations of drinking bouts than did sows kept in FLEX or FREE. Both frequency and duration of sham-chewing was greater ($P < 0.01$) among sows kept in FLEX than for sows in other housing environments. When FLEX stall was expanded an additional 7-8cm on d 89, 24 h after expansion of stall width these sows had greater ($P < 0.05$) lymphocyte counts and lower neutrophil chemotaxis. Within the FREE system social rank was determined and these results imply that submissive sows sit for longer ($P < 0.05$) durations than dominant sows, while drink and sham-chew behaviors were greater ($P < 0.05$) among dominant sows than submissive sows. The group-pen area was utilized more ($P < 0.05$) by dominant sows (70-80%) than submissive sows (40-50%) throughout gestation. However, submissive sows kept in the FREE spent only (18%) of time in pen-area on d30 and late in gestation the submissive sows once again spent less time in pen-area. Results reported herein indicate that alternative housing systems do influence indicators of well-being; however well-being was more influenced by physical, biological, and social components within alternative housing systems than the system itself. Therefore, these data strongly support that housing systems can be optimized when specific components of existing systems have been identified that improve sow well-being.

Introduction:

Adequacy of housing systems for the gestating sow is a major public issue, driven primarily by public perceptions and regulations promulgated in Europe, not by science. New innovative approaches are needed to satisfy the concerns of outside special interest groups and to minimize the economic disadvantages that would be incurred by the swine industry if the current housing systems were banned. The factors that are empirically proven to enhance the success of such systems must be identified so that we can provide producers with information needed to make decisions on how to implement these new technologies in existing production systems or incorporate into new buildings while sustaining profitability. Producers must have scientifically developed optimal production schemes and systems that will enable the industry to improve health, productivity, and reproductive efficiency of the individual sow while sacrificing neither animal well-being nor profitability. The knowledge and data from this study will provide producers with guidelines and strategies that will enable them to make changes without compromising the well-being of the sow.

Objectives:

The long term objectives of this project are to design, optimize and implement sow housing and management systems that will enhance sow well-being while sustaining the productivity and profitability of swine production. The *specific objectives* of this proposal were to: 1) design a housing system that can be retro-fitted to provide the same animal capacity as in existing housing facilities, yet constructed so as to allow flexibility in stall dimensions to address welfare issues of physical size of the stall and the freedom of sows to move and **2**) to assess the practicality of these systems and the impact on sow welfare using an integrative approach.

1. Project Objectives

The objectives of this study were as follows with responsibility for each objective shown in parenthesis:

A. *Develop an adjustable sow stall for used in existing sow gestation facilities that will better accommodate the physical size of the sow—all producers could be in compliance.*

B. *To determine the impact of the adjustable stall on sow well-being by assessing physiological and psychological needs of sow.*

C. *To determine the impact of providing sow freedom to leave stall on well-being.*

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 stalls until d30 of gestation. Pregnancy was detected at d27 post-breeding using an Aloka-500V ultrasound machine for trans-abdominal examinations, and then pregnant sows were allocated to their respective treatments based on body weight and parity. Multiparous sows were used ranging from 2-5. Sows remained in their respective gestation treatment groups until ~d110, when they were moved to a stall farrowing facility. Sows diagnosed open were removed from the study.

Sows were housed in a well-insulated, mechanically ventilated room. The gestation room was set at 22° C. Temperatures varied between seasons (Table 1.). Lighting was set at 12:12 hour light:dark schedule.

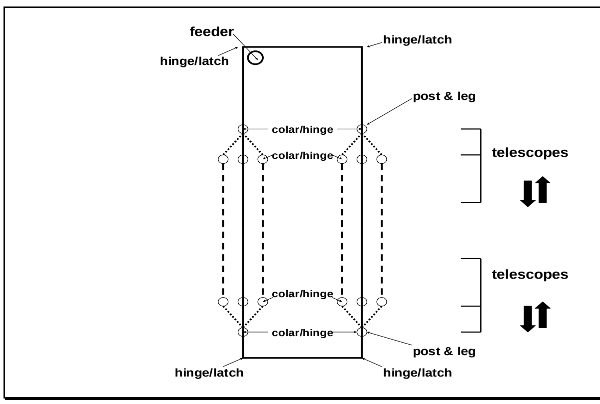
Table 1. Indoor Temperatures across Replicates

Replicate	Season[1]	Mean Temperature (C°)[2]
1	Fall	21.6
2	Winter	20.2
3	Summer	23.1
4	Fall	20.7
5	Winter	20.1
6	Summer	24.7
7	Fall	21.7
8	Spring	22.1

[1] Season that replicate began
[2] Mean temperature of the week that each replicate started

Eight blocks of 12 sows were allotted to one of three treatments (total 96 sows) over two consecutive parities. For each block, sows were assigned to a standard stall (STALL; control), a width adjustable stall (FLEX) and a free-access stall and pen (FREE). The control STALL is a commercially available 61 × 216 cm standard gestation stall in which sows are trough fed.

FLEX was designed by John Kane in collaboration with University of Wisconsin and is not commercially available. FLEX is 216 cm long and has the capability to expand width based on the dimensions of the individual sow. On d29, sow's mid-girth was measured from top of the back to bottom of the udder and then FLEX width was adjusted to achieve an additional 2 cm space between sow and bottom of the stall on each side of the sow. On d89 of gestation, FLEX width was expanded an additional 7-8 cm total. Sows kept in FLEX were floor fed and front gate was equipped with vertical bars (picture below).



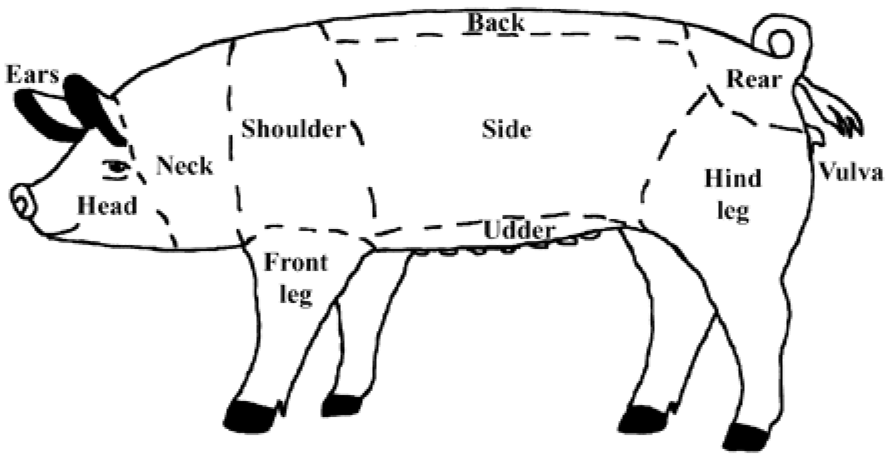
FREE stalls are 69 × 226 cm with additional access to a 2.44 × 1.46 m group-pen area. FREE system provides sows the opportunity to choose to utilize a group-pen area or an individual stall. Sows kept in FREE system were fed using a feeding trough. Each stall space was equipped with one nipple water drinker.

Sows were fed a standard gestation diet based on corn and soybean meal, in which nutrients were present at concentrations that are at or above current requirement estimates (NRC, 1998).

Performance and Productivity Measures.

Sow body weight and12th rib back-fat were recorded on d0 (wean), 30, 89, and 110 of gestation. Sow body condition scores and lesion severity scores were made and recorded on d0, 30, 45, 60, 75, 89, 103, and 110 of gestation. Lesion scores were made and recorded for each of the following regions (Figure 1): head, ears, neck, chest/breast, shoulders, back, udder, rear, vulva, perineum, legs, and hooves. Sow lesion score was based on the presence or absence of an apparently new or old lesion in conjunction with severity of the wound. Scoring definitions were: 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; 6 = severe wound, open wound; and, 7 = severe swelling. Thus, a sow could receive a score ranging from 0 (normal, no lesions) to 7 (severe swelling) for any location on any particular day. Sows also could be assigned combined scores for a given location. For example, a sow might have at a certain location: dehairing (1), redness + swelling (2), swelling + callus (3), and marked wound/fresh scratch (5), for a total combined lesion score of 11. Additionally scores were divided up into two categories of swelling and actual wound. Swelling scores including scores of 1-3 as well as 7, while actual wound scores including scores of 4-6 only.

Figure 1. Body Location for Lesion Scoring



Standard litter traits were recorded: litter weight, number born alive, number laid on, number stillborn, number euthanized due to low birth weight or deformation, number weaned, weaning weight and body weight gain.

Physiological Measures.

A blood sample was collected from all sows from each treatment on d0 (wean), 30, 31, 89, 90 (sows in FLEX only), and 110 of gestation. Blood samples (~10 mL) were obtained from sows by vena-puncture of the jugular vein using heparin or EDTA vacutainers. Blood samples were analyzed for total white blood cell counts, leukocyte populations, neutrophil and lymphocyte counts, neutrophil phagocytosis and chemotaxis. Lymphocyte proliferation and natural killer cell cytotoxicity were assessed as previously described (Salak et al., 1993; Salak-Johnson et al., 1996; Sutherland et al., 2005; Niekamp et al., 2006). Using a validated commercial radioimmunoassay (Coat-A-Count®, Los Angeles, CA) plasma cortisol concentrations were measured.

Behavioral Measures.

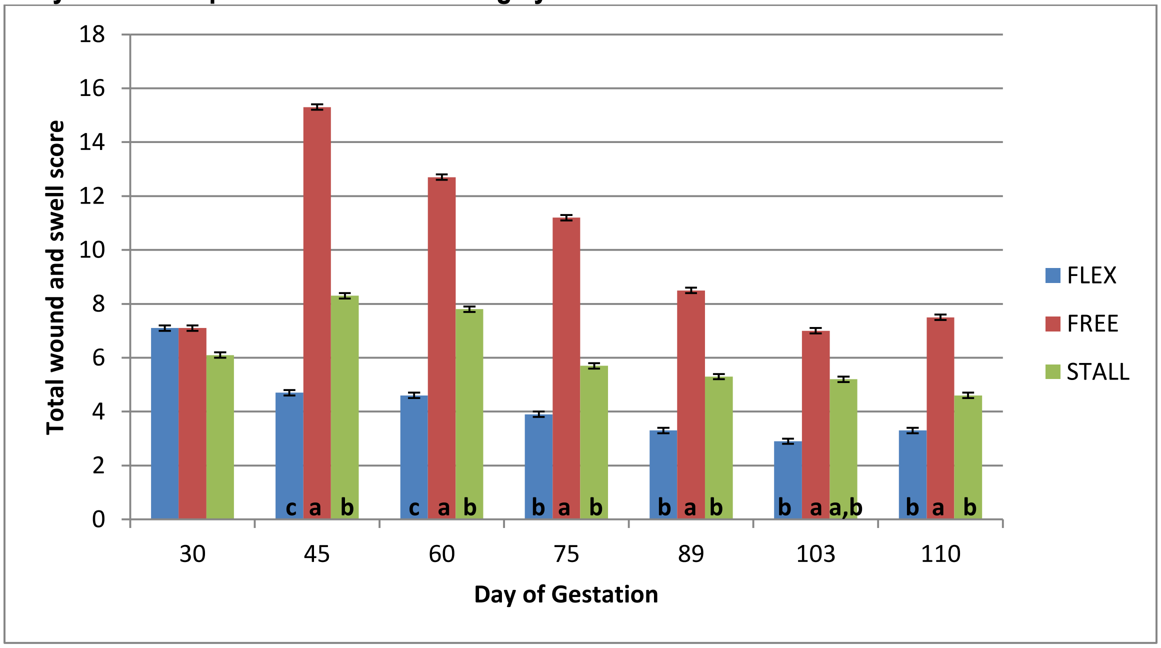
Sow behavior was recorded using time-lapse DVR recorders. Behavior was observed and registered for 24 hours on d30, 66, 87, and 102 of gestation during blocks 1 and 2. Data were divided into 6 periods per 24-h:period 1; 0300-0700, 2; 0700-1100, 3; 1100-1500,4; 1500-1900, 5; 1900-2300, 6; 2300-0300. Behaviors were registered and analyzed using continuous-sampling for all treatments and included: drink, eat, lay, stand, sit, oral-nasal-facial (**ONF**), and sham-chew. Additional behavioral assessment was registered on the same days during block 1, 2, and 4 for sows only kept in FREE system. Dominance status was established among these sows by determining how many agonistic encounters were won and loss as well as the frequency of being displaced and displacing con-specifics. Additional behaviors registered for sows kept in FREE include: aggressive interactions and space utilization. Durations of each behavioral bout and frequencies of each behavior were assessed.

RESULTS

Sow Performance and Productivity

There was a treatment × day of gestation interaction for body/leg swelling and lesion/wound characteristics across the entire body of the sow ($P < 0.05$). **Figure 2** shows treatment × day of gestation interaction for accumulative swelling/wound score ($P < 0.05$). Assessing swelling and lesion/wound separately treatment × day of gestation interactions were reported: on d45 sows kept in FLEX had greater ($P < 0.05$) total swelling than did sows kept in FREE. Conversely, on d75 sows kept in FREE had greater ($P < 0.05$) total swelling over the body than sows kept in either STALL or FLEX. Later in gestation, sows kept in FLEX had greater ($P < 0.05$) total swelling on d103 and 110 compared to sows kept in STALL. When assessing wounds/lesions, on d45, 60, 75, and 89 sows kept in FREE had greater ($P < 0.05$) lesions than did sows kept in either STALL or FLEX, while sows in STALL had greater ($P < 0.05$) lesions compared to sows kept in FLEX on d45, 60, and 89. Later in gestation (d103) sows kept in STALL and FREE had greater ($P < 0.05$) lesions than did sows kept in FLEX, while sows kept in FREE had greater ($P < 0.05$) lesion scores than sows kept in FLEX on d 110. There were significant main treatment effects on sow performance traits (Table 1; $P < 0.05$). Very few litter characteristics were influenced by housing systems. Number of piglets that were euthanized due to low birth weights or deformation was significantly greater ($P < 0.05$) among sows kept in FREE compared to sows kept in FLEX. No other litter traits were influenced by housing type during gestation ($P > 0.10$).

Figure 2. Effect of treatment and day of gestation on total wound and swell score assessed over the entire body of sows kept in alternative housing systems



[a,b,c] Within a day of gestation, means without a common superscript letter differ (*P* < 0.05)

Table 1. Main effects of treatment on productivity and litter-related traits for sows in alternative housing systems or individual stalls during gestations (least squares means ± SE)

	Gestation Treatment			
Item	FLEX	FREE	STALL	*P*-value
BW d 0, kg	199 ± 3.5	202 ± 3.5	195 ± 3.5	0.533
BW d 30, kg	199 ± 3.5	202 ± 3.5	196 ± 3.5	0.646
BW d 89, kg	219 ± 3.5	224 ± 3.5	217 ± 3.5	0.313
BW d 110, kg	229 ± 3.5	234 ± 3.5	227 ± 3.5	0.393
Mean BW, kg	212 ± 1.7^{a,b}	215 ± 1.7^{a}	209 ± 1.7^{b}	0.034
BW change (d 0 to 30), kg	-0.11 ± 1.5	-1.0 ± 1.5	0.59 ± 1.6	0.486
BW change (d 30 to 89), kg	18 ± 1.6	22 ± 1.6	21 ± 1.6	0.257
BW change (d 89 to 110), kg	10 ± 1.6	9.5 ± 1.6	10 ± 1.6	0.720
Mean BW change, kg	9.4 ± 0.94	10 ± 0.94	10 ± 0.94	0.736
Mean back-fat (BF), cm	1.66 ± 0.03^{b}	1.88 ± 0.03^{a}	1.66 ± 0.03^{b}	<0.001
BCS, 1-5	3.14 ± 0.05^{b}	3.29 ± 0.05^{a}	3.10 ± 0.05^{b}	0.031
Litter size, No.	10.3 ± 0.6	10.8 ± 0.6	9.9 ± 0.6	0.587
Born alive, No./litter	9.0 ± 0.4	8.8 ± 0.5	8.2 ± 0.5	0.494
Weaned, No./litter	8.0 ± 0.4	8.0 ± 0.4	7.7 ± 0.4	0.847
Litter birth BW, kg	1.5 ± 0.04	1.5 ± 0.04	1.5 ± 0.04	0.999
Litter weaning BW, kg	6.5 ± 0.2	6.4 ± 0.2	6.3 ± 0.2	0.795
Pig BW gain (birth to wean), kg	5.1 ± 0.1	4.9 ± 0.1	4.8 ± 0.1	0.504
Laid on, No.	0.61 ± 0.2	0.38 ± 0.2	0.47 ± 0.2	0.685
Stillborn, No.	0.48 ± 0.2	0.90 ± 0.2	0.63 ± 0.2	0.221
Euthanized, No.	0.23 ± 0.1^{b}	0.72 ± 0.1^{a}	0.56 ± 0.1^{a,b}	0.123
Total mortality, No.	2.3 ± 0.4	2.7 ± 0.4	2.1 ± 0.4	0.601

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

Table 2. Main effects of treatment on lesion and swelling score for sows in alternative housing systems or individual stalls during gestation (least squares means ± SE)

	Gestation Treatment			
Item	FLEX	FREE	STALL	*P*-Value
Total swell and wound	4.39 ± 0.31^{c}	9.27 ± 0.31^{a}	5.81 ± 0.31^{b}	<0.001
Swelling[1]				
Body total	1.69 ± 0.11^{a}	1.76 ± 0.11^{a}	1.27 ± 0.11^{b}	0.007
Head	0.15 ± 0.04	0.16 ± 0.04	0.16 ± 0.04	0.994
Ears	0.032 ± 0.02	0.02 ± 0.02	0.05 ± 0.02	0.599
Neck	0.07 ± 0.03	0.07 ± 0.03	0.09 ± 0.03	0.859
Shoulders	0.04 ± 0.03	0.07 ± 0.03	0.11 ± 0.03	0.211
Back	0.07 ± 0.02^{a,b}	0.04 ± 0.02^{b}	0.12 ± 0.02^{a}	0.030
Udder	0.02 ± 0.01	0.04 ± 0.01	0.02 ± 0.01	0.610
Rear	0.03 ± 0.02	0.03 ± 0.02	0.05 ± 0.02	0.715
Front legs	1.2 ± 0.07^{a}	1.0 ± 0.07^{a}	0.61 ± 0.07^{b}	<0.001
Hind legs	0.09 ± 0.04^{b}	0.22 ± 0.04^{a}	0.05 ± 0.04^{b}	0.003
Wound[2]				
Body total	2.70 ± 0.3^{c}	7.48 ± 0.3^{a}	4.54 ± 0.3^{b}	<0.001
Head	0.84 ± 0.1^{b}	1.60 ± 0.1^{a}	1.03 ± 0.1^{b}	<0.001
Ears	0.27 ± 0.09^{b}	0.41 ± 0.09^{b}	1.35 ± 0.09^{a}	<0.001
Neck	0.23 ± 0.08^{c}	0.82 ± 0.08^{a}	0.46 ± 0.08^{b}	<0.001
Shoulders	0.60 ± 0.1^{b}	1.57 ± 0.1^{a}	0.45 ± 0.1^{b}	<0.001
Back	0.24 ± 0.08^{b}	1.19 ± 0.08^{a}	0.24 ± 0.05^{b}	<0.001
Udder	0.08 ± 0.05^{b}	0.31 ± 0.05^{a}	0.08 ± 0.05^{b}	0.001
Rear	0.25 ± 0.09^{c}	1.34 ± 0.09^{a}	0.62 ± 0.09^{b}	<0.001
Front legs	0.17 ± 0.06	0.20 ± 0.06	0.19 ± 0.06	0.899
Hind legs	0.06 ± 0.04	0.10 ± 0.04	0.04 ± 0.04	0.496

^{a,b,c} Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]Swelling definitions were: 0 = normal (no lesions); 1 = dehairing, callus, balding; 2 = redness, swelling; 3 = swelling + callus; and 7 = severe swelling

[2]Wound definitions were: 0 = normal (no lesions); 4 = moderate wound, scabbed over scratch; 5 = marked wound, fresh scratch; 6 = severe wound, open wound;

Sow Endocrine and Immune Response

Several endocrine and immune characteristics were influenced by treatment × day of gestation interactions ($P <$ 0.05). Sow neutrophil counts and lymphocyte proliferation were influenced by treatment and day of gestation ($P < 0.05$); sows kept in FREE had greater ($P < 0.05$) neutrophil counts and conA induced lymphocyte proliferation on d 31 (24 h post treatment allotment) than sows kept in either STALL or FLEX. No other endocrine or immune responses were influenced by treatment × day of gestation interaction ($P > 0.10$). On the other hand main treatment effects influenced multiple endocrine and immune measures ($P < 0.05$; Table 3).

Expanding the width of the FLEX stall on d 89 of gestation did impact sow immune response 24 h after providing sows an additional 7-8 cm total ($P < 0.05$; Table 4)

Table 3. Main effects of treatment on endocrine and immune response for sows in alternative housing systems or individual stalls during gestation (least squares means ± SE)

	Gestation Treatment			
Immune trait	FLEX	FREE	STALL	*P*-value
Total WBC, 10^7/mL	2.22 ± 0.06^{b}	2.30 ± 0.06^{a,b}	2.41 ± 0.06^{a}	0.073
Neutrophils, 10^7/mL	4.73 ± 0.17^{b}	5.26 ± 0.17^{a}	5.03 ± 0.17^{a,b}	0.093
Lymphocyte, 10^7/mL	2.54 ± 0.09^{b}	2.87 ± 0.09^{a}	2.62 ± 0.09^{b}	0.022
Neutrophils, %	39.9 ± 1.0	38.9 ± 1.0	38.8 ± 1.0	0.718
Lymphocytes, %	50.2 ± 1.0	53.2 ± 1.0	52.1 ± 1.0	0.124
Monocytes, %	3.77 ± 0.2	3.54 ± 0.2	3.41 ± 0.2	0.528
Eosinophils, %	6.03 ± 0.3^{a}	4.42 ± 0.3^{b}	5.41 ± 0.3^{a}	0.001
Neutrophil-to-lymphocyte ratio	0.96 ± 0.07	0.93 ± 0.07	0.85 ± 0.07	0.573
Phagocytosis, %	55.2 ± 1.2	58.2 ± 1.2	55.6 ± 1.2	0.146
LPS-induced proliferation 02	1.39 ± 0.08	1.22 ± 0.08	1.33 ± 0.08	0.303
ConA-induced proliferation 02	1.25 ± 0.13^{b}	1.38 ± 0.13^{b}	1.76 ± 0.13^{a}	0.019
NK cytotoxicity, % 25:1	39.8 ± 5.4	44.9 ± 5.2	43.3 ± 5.4	0.789
Chemotaxis, IL-8	53.1 ± 7.1	54.7 ± 7.7	59.6 ± 6.7	0.785
Chemotaxis, C5a	50.01 ± 5.9	54.1 ± 6.2	60.1 ± 5.7	0.467
Plasma cortisol, ng/mL	29.9 ± 1.3^{b}	33.9 ± 1.3^{a}	30.2 ± 1.3^{a,b}	0.087

^{a,b,c} Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 4. Effect of width expansion late in gestation on endocrine and immune responses for sows kept in FLEX (least squares means ± SE)

	FLEX width expansion time points		
Immune trait	Pre-adjustment	24 h post-adjustment	*P*-value
Total WBC, 10^7/mL	2.18 ± 0.14	2.53 ± 0.14	0.085
Neutrophils, 10^7/mL	4.69 ± 0.31	4.44 ± 0.32	0.567
Lymphocyte, 10^7/mL	2.21 ± 0.15[b]	2.72 ± 0.15[a]	0.021
Neutrophils, %	40.1 ± 2.4	41.5 ± 2.5	0.675
Lymphocytes, %	50.5 ± 1.0	49.1 ± 1.0	0.685
Monocytes, %	3.3 ± 0.5	3.9 ± 0.5	0.452
Eosinophils, %	6.3 ± 1.2	5.3 ± 1.2	0.564
Neutrophil-to-lymphocyte ratio	0.96 ± 0.2	0.98 ± 0.2	0.944
Phagocytosis, %	57.2 ± 2.9	62.3 ± 3.0	0.232
LPS-induced proliferation 02	1.21 ± 0.14	1.27 ± 0.16	0.753
ConA-induced proliferation 02	1.30 ± 0.08	1.35 ± 0.09	0.698
NK cytotoxicity, % 25:1	30.4 ± 7.6	49.5 ± 10.5	0.167
Chemotaxis, IL-8	54.0 ± 6.0[a]	13.9 ± 7.0[b]	0.001
Chemotaxis, C5a	62.6 ± 7.9[a]	25.2 ± 9.7[b]	0.005
Plasma cortisol, ng/mL	30.6 ± 3.0	28.2 ± 3.1	0.569

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

Sow Behavior

There were treatment × day of gestation interactions for sow postural, maintenance, and oral behaviors ($P < 0.05$). On d 87 ($P < 0.10$) and d 102 ($P < 0.05$) sows kept in FLEX had greater frequency of lay bouts than did sows kept in either FREE or STALL. To coincide with the frequency of lay bouts, stand bout frequency on d 87 and 102 was greater ($P < 0.05$) amongst sows kept in FLEX than sows kept in FREE and STALL. Frequency of sit bouts was greater ($P < 0.05$) amongst sows kept in FLEX compared to sows kept in FREE or STALL, on d 66 and 102 of gestation. On d 30 of gestation (day of allotment) sows kept in FREE and FLEX performed greater ($P < 0.05$) bouts of ONF behavior than did sows in STALL.

Treatment × time period influenced sow postural, maintenance and oral behaviors ($P < 0.05$). During time period 1(0300-0700), sows kept in FLEX had greater ($P < 0.05$) frequency of stand bouts than did sows kept in STALL; while from 0700-1100 sows kept in FLEX had greater ($P < 0.05$) frequency of stand bouts than did sows in both STALL and FREE. FLEX kept sows also stood more frequently ($P < 0.05$) than did sows kept in FREE during time period 3 (1100-1500). During time period 5 (1900-2300) sows kept in FREE had a greater ($P < 0.05$) duration of lay behavior than did sows kept in STALL. Conversely, during time period 6 (2300-0300) sows kept in STALL and FLEX had greater ($P < 0.05$) duration of lay bouts than did FREE kept sows. Duration of sit bouts was greater ($P < 0.05$) amongst sows kept in FLEX compared to sows kept in STALL and FREE from 1100-1500. Duration of drink behavior was greater ($P < 0.05$) amongst sows kept in STALL compared to FREE from 0700-1500; while STALL kept sows continued to drink greater ($P < 0.05$) durations than FLEX kept sows during time period 4 (1500-1900). Sham-chew behavior was more ($P < 0.01$) frequent amongst sows kept in FLEX than sows kept in either STALL or FREE during time periods 1 (0300-0700) and 3(1100-1500); while FLEX kept sows continued to sham-chew more ($P < 0.01$) frequently during time period 2 (0700-1100) than did sows kept in STALL. There were several main treatment effects on frequency and duration of sow postural, maintenance, and oral behaviors (Table 5.)

Table 5. Main effects of treatment on frequency and duration of postural, maintenance, and stereotypic behavior for sows in alternative housing systems or individual stalls during gestation (least squares means ± SE)

	Gestation Treatment			
Behavior	FLEX	FREE	STALL	P-value
Lay				
Frequency, no.	16.27 ± 1.4	13.2 ± 1.3	12.6 ± 1.3	0.133
Duration, min	80.8 ± 4.8	82.5 ± 4.4	81.9 ± 4.4	0.966
Sit				
Frequency, no.	8.8 ± 1.3	8.5 ± 1.1	7.9 ± 1.2	0.881
Duration, min	2.0 ± 0.3	1.2 ± 0.3	1.5 ± 0.3	0.169
Stand				
Frequency, no.	14.8 ± 1.2[a]	11.3 ± 1.1[b]	11.1 ± 1.1[b]	0.050
Duration, min	22.8 ± 3.0	21.5 ± 2.8	27.0 ± 2.8	0.343
Eat				
Frequency, no.	4.5 ± 1.0[a,b]	4.6 ± 1.0[a]	1.8 ± 1.0[b]	0.082
Duration, min	20.6 ± 3.4	14.6 ± 3.2	16.8 ± 3.0	0.438
Drink				
Frequency, no.	22.1 ± 4.3	16.4 ± 3.9	17.8 ± 4.2	0.613
Duration, min	0.33 ± 0.06[b]	0.33 ± 0.05[b]	0.54 ± 0.05[a]	0.004
ONF				
Frequency, no.	35.9 ± 3.7	33.6 ± 3.3	30.8 ± 3.5	0.588
Duration, min	6.4 ± 1.3	6.7 ± 1.2	7.9 ± 1.2	0.638
Sham chew				
Frequency, no.	32.8 ± 3.7[a]	18.9 ± 3.4[b]	18.1 ± 3.6[b]	0.009
Duration, min	3.1 ± 0.3[a]	2.4 ± 0.3[a,b]	2.2 ± 0.3[b]	0.074

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

Correlation Analysis: Selected Performance, Immune and Behavior

There were several significant correlations between selected performance and productivity measures with physiological and behavioral measures. Several lesion and swelling measures were correlated with sow body weight, body condition scores (BCS) and BF depth. Most of these correlations were low but significant. Both sow BCS (r = -0.06, P = 0.078) and BF depth were (r = -0.10, P = 0.015) negatively correlated with the total swelling and lesion score over the entire boy of the sow whereas, total wound scores were also negatively correlated (r = -0.11, P < 0.01) with BF depth. Conversely, BW was positively correlated (r = 0.11, P < 0.01) with total swelling score.

Several performance traits were correlated with immune traits (P < 0.05). Sow BW was negatively correlated (P < 0.05) with total WBC count (r = -0.16), lymphocyte count (r = -0.12), neutrophil count (r = -0.13), neutrophil phagocytosis (r = -0.20), and NK cytotoxicity (r = -0.33). While BF depth is also negatively correlated (P < 0.05) with total WBC (r = -0.15), neutrophil count (r = -0.18), and NK cytotoxicity (r = -0.18), however is positively correlated (r = 0.10, P < 0.05), with neutrophil phagocytosis. Total lesion scores were negatively correlated (r = -0.12, P < 0.05) with total WBC, but positively correlated (P < 0.05) with neutrophil phagocytosis (r = 0.14), CONA induced lymphocyte proliferation (r = 0.14), and **NK cytotoxicity *(r = 0.42)***.

Behavioral measures were also correlated with sow BW, BCS, and BF depth. Both sow BW (r = 0.12, P < 0.05) and BF depth (r = 0.10, P = 0.05) were positively correlated with sit behavior. While sow BW was negatively correlated (r = -0.14, P < 0.01) with stand behavior. BW was also negatively correlated (r = -0.14, P < 0.01) with ONF, however BW was positively correlated (r = 0.14, P < 0.01) with sham-chew behavior. Litter characteristics were also correlated with behavioral measures. Piglet mortality was negatively correlated with drink (r = -0.12, P < 0.01) and sham-chew (r = -0.10, P < 0.05) behavior. Sham-chew behavior was also negatively correlated (r = -0.11, P < 0.05) with the number of piglets laid on.

Social status effects for FREE system.

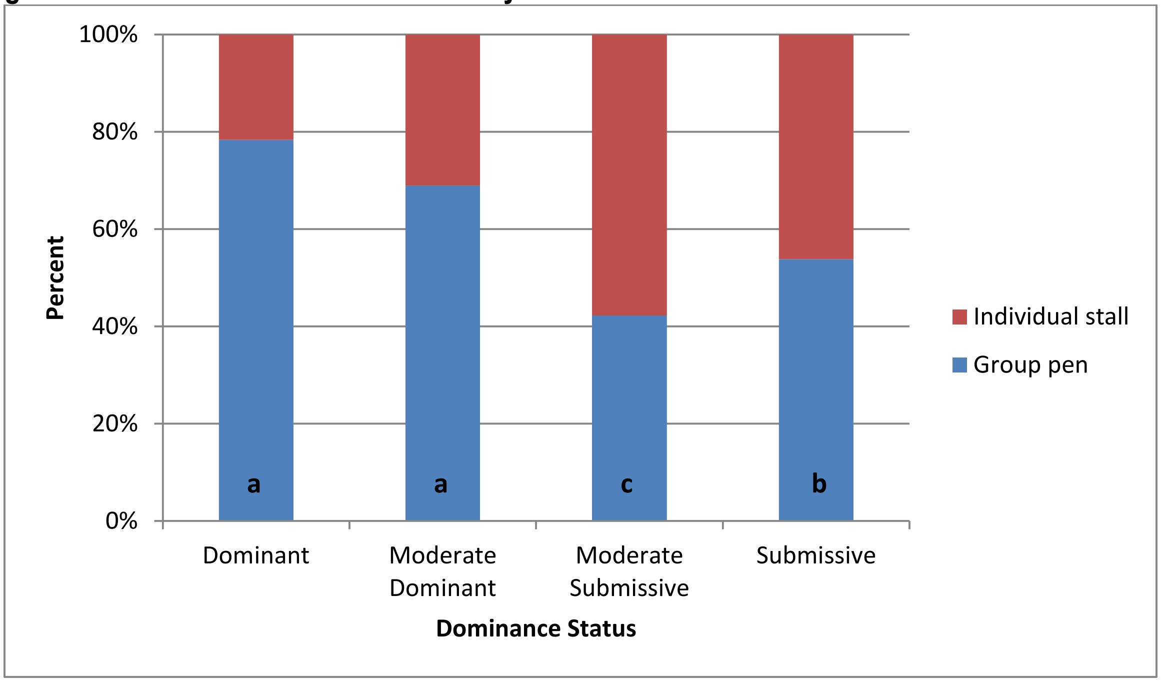
There were several dominance status × time period interactions for behavioral measures when sows were kept in FREE (P < 0.05). During time period 3 (1100-1500h) the submissive sows performed greater (P < 0.01) frequency of drink bouts than all other sows of higher dominance statuses. Additionally from 0700-1100h the submissive sows performed greater (P < 0.05) drink bouts than did dominant sows. Conversely duration of drink bouts was greater (P < 0.05) among moderate-dominant sows than all other sows of other social statuses during time periods 1 (0300-0700h), 3 (1100-1500h), and 4 (1500-1900h) Duration of lay behavior was greater (P < 0.05) during time period 4 (1500-1900h) among dominant sows than all other sows of lower social rank. Moderate-submissive sows had greater (P < 0.05) duration of lay behavior than either dominant or submissive sows during time period 6 (2300-0300h). Dominant status influenced the frequency and duration of postural, maintenance, and oral behaviors (P < 0.05; Table 6). Dominant status influenced the group-pen area or stall preference (Figure 3.) and day of gestation also influenced this choice (Figure 4.).

Table 6. Effect of dominance status on frequency and duration of postural, maintenance, and stereotypic behavior for sows kept in FREE (least squares means ± SE)

	Dominance Status				
Behavior	Dominant	Moderate dominant	Moderate submissive	Submissive	*P*-value
Lay					
Frequency, no.	16.3 ± 2.4	11.9 ± 2.4	14.3 ± 2.4	10.4 ± 2.4	0.352
Duration, min	84.8 ± 6.8	80.8 ± 7.8	95.6 ± 6.8	72.7 ± 6.8	0.121
Sit					
Frequency, no.	8.3 ± 1.6	8.5 ± 1.6	10.8 ± 1.6	6.6 ± 1.6	0.390
Duration, min	0.85 ± 0.25[b]	0.81 ± 0.28[b]	1.88 ± 0.25[a]	2.01 ± 0.25[a]	0.001
Stand					
Frequency, no	13.6 ± 2.5	9.1 ± 2.5	9.8 ± 2.5	12.5 ± 2.5	0.541
Duration, min	15.4 ± 3.6	27.6 ± 4.2	21.9 ± 3.6	20.6 ± 3.6	0.174
Eat					
Frequency, no	1.3 ± 1.9[b]	10.3 ± 1.9[a]	5.5 ± 1.9[a,b]	1.3 ± 1.9[b]	0.011
Duration, min	2.72 ± 0.63	1.18 ± 0.74	1.90 ± 0.63	2.32 ± 0.63	0.439
Drink					
Frequency, no	13.8 ± 5.8	16 ± 5.8	17.3 ± 5.8	18.6 ± 5.8	0.943
Duration, min	0.19 ± 0.06[b]	0.50 ± 0.07[a]	0.30 ± 0.06[b]	0.33 ± 0.06[b]	0.007
ONF					
Frequency, no.	29.4 ± 6.3	43.8 ± 6.3	27.8 ± 6.3	33.4 ± 6.3	0.302
Duration, min	10.9 ± 2.2	7.0 ± 2.5	5.7 ± 2.2	4.8 ± 2.2	0.212
Sham-chew					
Frequency, no.	12.5 ± 5.0[b]	31.8 ± 5.0[a]	18.8 ± 5.0[a,b]	12.5 ± 5.0[b]	0.046
Duration, min	2.32 ± 0.45	3.79 ± 0.51	2.58 ± 0.45	3.24 ± 0.45	0.130

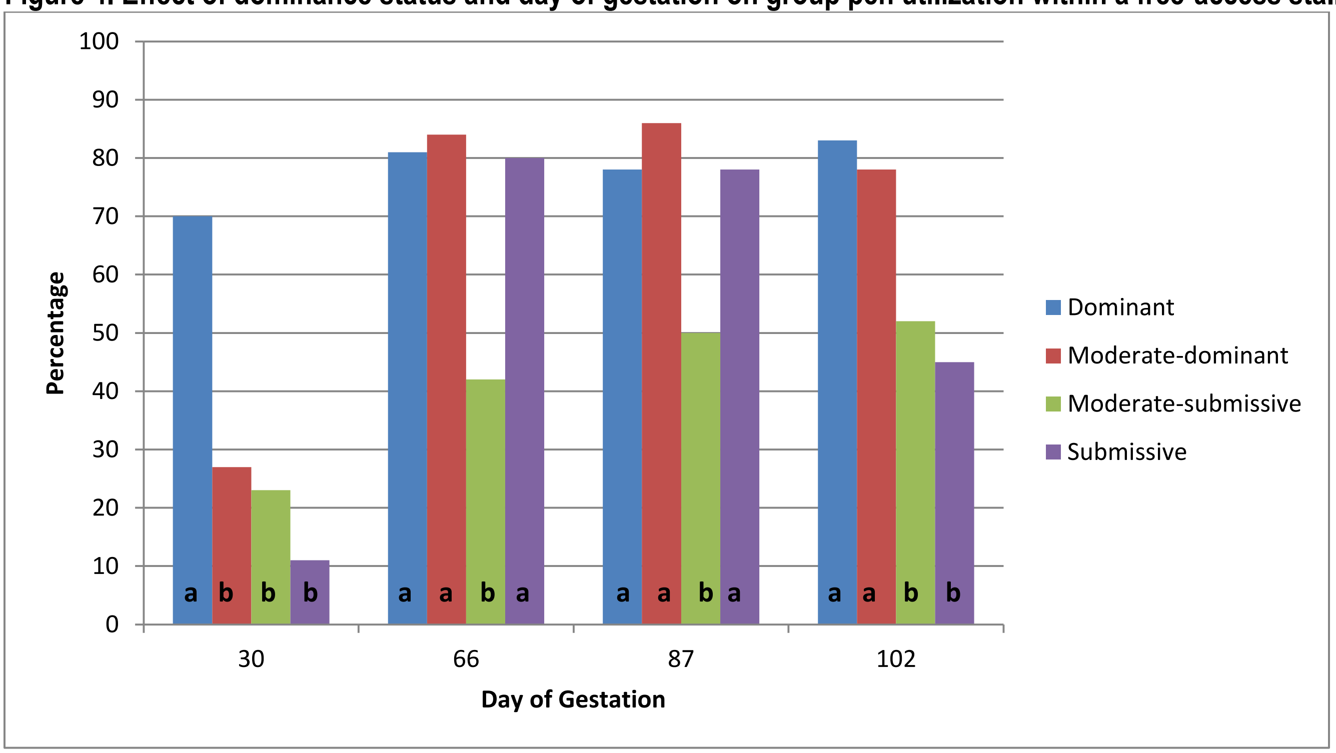
[a,b,c] Within a row, means without a common superscript letter differ ($P < 0.05$).

Figure 3. Effect of dominant status on percentage of time spent utilizing either group pen or individual stall when given the choice in a Free-access stall system



[a,b,c] across dominance status, means without a common superscript letter differ ($P < 0.05$).

Figure 4. Effect of dominance status and day of gestation on group pen utilization within a free-access stall system



[a,b,c]within day of gestation, means without a common superscript letter differ ($P < 0.05$).

Correlation Analysis: Selected Performance, Dominance status, Behavior and Space Utilization

There were several positive and negative correlations between selected performance characteristics, plasma cortisol concentrations and behaviors within FREE system although most correlations were low ($P < 0.05$). Dominance status was positively correlated ($r = 0.21$, $P < 0.05$) with sit behavior and piglet mortality ($r = 0.24$), however negatively correlated ($P < 0.001$) with ONF ($r = -0.13$), use of the group pen ($r = -0.27$), and plasma cortisol ($r = 0.23$). BF depth was positively correlated ($r = 0.16$, $P < 0.05$) to ONF behavior. Plasma cortisol levels were negatively correlated with ($P < 0.05$) stand ($r = -0.17$), drink ($r = -0.15$), and piglet mortality ($r = -0.37$).

Discussion

The results from this study indicate that sow performance, productivity, immune status, and behavior were influenced by alternative individual housing systems (FLEX), as well as a combination of both individual and group pens (FREE). Allowing researchers to identify which concepts or components of each alternative accommodations (FLEX (expanding width) or FREE (stall or group pen preference)) improve well-being and therefore should be used to optimize a housing system for gestating sows.

Alternative housing systems impact on sow well-being

When comparing two alternative housing systems to a standard gestation stall, results suggest that lesions/wounds, swelling, and behavior are more affected by housing design than either performance traits or endocrine and immune responses. However, the physical, biological, and social components within each alternative system may be imposing more of a response than the housing system itself. For example, sows kept in a FLEX stall change postures (stand, sit, lay) significantly more than did sows kept in either FREE or STALL, more specifically this increase in postural changes was before, during, and after feeding. Furthermore, other oral activity (sham-chew) was also increased amongst sows kept in FLEX before, during, and after feeding than sows in other treatments. We hypothesize this increase in sham-chew behavior and postural changes around feeding could be due to limited ability to perform ONF behavior, since all bar-direction on the FLEX system are vertical. Therefore inhibiting the ability to chew on bars is causing a behavioral adaptation to occur, causing an increase in sham-chew behavior, as well as, a strong motivation to change postures in order to have access to manipulable environmental components. This flaw in the FLEX design did alter postural and oral behaviors, and therefore could have caused the increase in total swelling, specifically on the front legs of sows. During postural changes, sows will slowly adjust from one position to the other using the front legs to complete the adjustment. Another theory is that the only horizontal bar sows have access too is located at the bottom of the front gate of FLEX, forcing sows to lower their body onto their front knees in order to bar-bite. This fact, as well as the innate motivation to bar-bite could be causing the increase in swelling as well as increase in frequency and duration of sham-chew behavior. Hence changes in design of the FLEX stall could benefit sow well-being.

Simple components within the FLEX system may be inhibiting the potential advantages, not allowing sows to reach their maximum potential. The major concept of the FLEX stall was to accommodate the dimensional needs of the gestating sow by expanding the width during late gestation. Results reported herein indicate that allowing an additional 7-8 cm of space, late in gestation can influence an immune response. An increase in total WBC and lymphocyte counts could suggest an acute immune response occurred, however the significant decrease in neutrophil chemotaxis implies that there was more likely a shift in the immune system. Nevertheless, finding that expanding the width of stalls does influence indicators of well-being, causes us to hypothesize that correcting the front gate of the FLEX stall, to allow or encourage bar-biting or ONF behavior, could increase the immune benefits of expanding the stall even more so, resulting in overall improved well-being.

When comparing the FREE system to the standard gestation STALL few biologically relevant results were reported. Lesions were found to be significantly greater amongst sows kept in FREE compared to sows kept in either of the individual stall types, however this increase in lesions/wounds did not seem to influence other indicators of well-being. For example, total lesion scores were negatively correlated with total WBC count, but were positively correlated with more functional aspects of the immune system (neutrophil chemotaxis and phagocytosis, and lymphocyte proliferation and NK cytotoxicity). Sows kept in FREE showed an increase in neutrophil and lymphocyte counts and lower CONA-induced lymphocyte proliferation than sows kept in STALL, therefore corroborating the theory that an increase in lesions may not influence overall well-being. However, sows kept in FREE did have greater hind leg swelling and mean BW than sows kept in either of the individual stall systems. This increase in BW was found to be positively correlated with total swelling. Perhaps the ability to walk or be more active didn't influence the hind leg swelling, but more so the increase in BW and BF depth. However, there was not a real biological difference in the greater mean BW and BF depth found among sows kept in FREE than sows kept in either of the other treatments. This slight increase in BW and BF depth could be due to the ability to thermoregulate more efficiently by utilizing con-specifics for huddling in the group pen, or to seek alternative micro-environments within the housing system. Few biological differences were found when comparing sows kept in FREE to sows kept in either of the individual stall systems, indicating that industry standards of well-being exist across various sow housing systems.

Social ranks impact on behavior and space utilization

Within the FREE system, social status influenced indicators of well-being, specifically behavior and space utilization. Both frequency and duration of postural, maintenance, and oral behaviors were altered by dominance status of sows within FREE. Submissive and moderate-submissive sows had greater duration of sitting behavior compared to the two more dominant sows. This is important since dominance status was positively correlated with sit behavior and piglet mortality. Therefore, indicating that submissive sows within a group pen setting, may sit more causing an increase in piglet mortality, most likely due to crushing of piglets. Very few other postural behaviors were influenced by dominant status, except for dominant sows lay more during evening hours while sows of other social status lay more during late night hours

(2300-0300h). This could indicate that dominant sows will influence the activities of con-specifics, most likely based on location. Drinking behavior throughout the day was also found to be greater amongst moderate-dominant sows than sows of other social rank, while submissive sows drink the most during the feeding period; once again, implying that social rank does greatly influence the behaviors of animals in a group pen setting. Oral behaviors, such as sham-chewing, were performed more amongst moderate-dominant sows than either the dominant or submissive animals. Several other behaviors were found to be altered amongst the moderate-dominant animal; this potentially could imply that group pen setting influence the moderate-dominant animal either more or less than animals of other social rank.

How sows preferred to utilize the space provided for them was influenced by social hierarchy. Dominant sows spending the majority of the time (70-80%) in the group pen and the submissive sows utilizing the group pen only 40-50 % of the time, this difference in space utilization can be indicative of fear response in the submissive animals. These results were expected and similar to other findings (Mack et al., 2010; Gonyou et al., 2011; Mack et al., 2011). However, the results depicting the group pen utilization in Figure 4 was different. Finding that dominant sows use the group pen the majority of the time throughout all of gestation, while the con-specifics of lower social status' group-pen utilization fluctuates significantly based on day of gestation. However as parturition nears, submissive sows prefer to spend the majority of their time alone within individual stalls. These results indicate that social status has a major impact on how and when sows prefer to spend their time, as well as, where they choose to spend the majority of their time when given the opportunity to choose between individual stalls and a group pen.

Implications

When implementing alternative housing systems, physical, biological, and social components within systems should be considered greatly. Findings reported herein indicate that these internal components influence sow well-being more so than the housing system itself. When comparing housing systems very few biological differences were found, however determining what components within those systems is compromising the sow's genetic potential, and correcting those flaws, may be more influential on animal well-being. These results indicate that optimizing existing and new keeping systems is achievable to improve sow well-being, by correcting the physical, biological, and considering the sow's social components that make up each housing system.

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