TITLE: **Comparison of Housing Systems for Gestating Sows - NPB #02-164**

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II. Abstract

The objectives of this study were to measure the putative well-being indices in sow-housing systems, to compare these along with the costs of using and refining these systems and to provide guidance to producers and other members of the pork chain in discussing these issues. The study assessed the welfare status of gestating sows of mixed parities (0-6) housed in individual stalls (n=176), group pens (n=206) with electronic sow feeders (ESF) and groups in deep bedded hoops (n=60) in terms of injury levels, cortisol concentration and behavior along with longevity and production performance. Data were collected at different time points during the stay of the sows in their respective housing systems. The total injury scores (TIS) of sows in pens with ESF were higher at the time of mixing than at other stages of gestation ($P<0.05$) and in stall-housed sows TIS was the highest at late gestation ($P<0.05$). The TIS and salivary cortisol concentration were lower ($P<0.05$) in stall-housed sows compared to sows in pens with ESF during gestation. The cortisol concentration was not correlated with TIS in both systems. As parity increased, the likelihood for higher median TIS decreased ($P<0.05$) in sows in pens with ESF and increased ($P>0.05$) in stall-housed sows. The TIS of sows in pens with ESF was negatively ($P<0.05$) correlated with body weight and backfat and in sows in stalls it was positively ($P<0.01$) correlated. Aggressions performed and received and number of queuing were higher ($P<0.05$) at late gestation and were similar to that at the time of second mixing among sows in pens with ESF. Aggressions performed and received were positively correlated ($P<0.05$) with proportion of time spent queuing, queuing number and ESF entry. Cortisol was positively correlated with aggressions performed and received ($P<0.05$). The proportion of time spent lying was higher on day 108 of gestation than days 5 and 56 ($P<0.05$ for both) in stall-housed sows. Proportion of time spent on exploration was higher ($P<0.05$) on day 56 than the other stages in stall-housed sows. The median frequency of overall postural change and the median of frequencies of standing to lying, sitting to lying, lying to standing, and lying to sitting were higher on day 5 than at mid and late gestation ($P<0.05$ for all) in stall-housed sows. There was no significant difference among sows from both systems in terms of number of squares entered, time to have the first interaction and number of interactions with the novel arena/object. Stalls and pens with ESF did not differ in terms of litter size, born alive/litter and stillborn/litter. Proportion of sows removed from the pens with ESF was significantly higher ($P <0.05$) than sows in stalls and the major removal reason was lameness though both systems had fully slatted floors.

The hoop-housed sows had lower injury levels and cortisol concentrations and higher litter size ($P<0.05$) than stall-housed sows. Overall cost comparisons were inconclusive due to two factors. The first is that the capital costs for university herds do not reflect normal costs in the industry. Particularly in the case of hoop structures, there are opportunities to use local resources on farms. This includes flexible labor, straw as a grain production byproduct, and nightly inspections. The second reason for the lack of differentiation was the design requirements superimposed on the facility by the University of Minnesota. In conclusion, stalls indicated a benefit in terms of production and welfare at the expense of freedom of movement. The possibility of injuries consequent to aggression both at mixing and at the feeder made the group pen system with ESF also a stressful type of accommodation for gestating sows. The deep-bedded hoop barns, another alternative to individual confinement, may be welfare friendly in terms of lower salivary cortisol concentration and injury levels, though it needs special attention to sort out the issues of higher return rate, smaller group size, labor requirement and waste management.

III. Introduction

The major housing system in the US for pregnant sows is individual stalls. Approximately 60-70% of sows in the US are housed in stalls throughout gestation (Barnett et al., 2001), followed by group housing, both of which have reported welfare advantages and disadvantages. The alternatives to these systems such as the deep-litter group housing system are often claimed to be more welfare-friendly. Besides the positive welfare image, low capital investment and access to niche market are other attributes that make alternative swine production systems such as deep-bedded hoop barns with individual feeding stalls attractive to the producers in the US (Brumm et al., 1997, 1999; Honeyman, 1996). Deep-bedded hoop systems are however, relatively new to the US for gestating sows and account for a very small proportion of pig production (Hinrichs and Welsh 2003).

The health and welfare of gestating sows has always been a primary concern of pig producers. It may be likely that individuals may react to animal welfare issues without factual biological information (Estienne and Harper, 2003). The responses of governments, industries and the public may force the producer to change their production systems in ways to meet possible concerns raised by the public who ultimately are the deciding factor in the competitive market. Therefore, it is important to study the welfare status of sows housed in various housing systems during gestation. In order to have a total understanding of the welfare status of sows in any housing system it is essential to study all possible welfare parameters; performance and health, behavior, physiology, longevity and cost (McGlone, 2001). The specific objective of this project was to compare the strengths and weaknesses of the three gestating sow housing systems in temperate climates viz. individual stalls, group pens with ESF and deep-bedded hoops, in terms of sow welfare, sow performance and costs involved in order to be able to refine the current systems and to provide guidance to the producers and others associated with the industry to make improvements in the production systems.

IV. Objectives

- Measure the putative well-being indices in sow-housing systems
- Compare these along with the costs of using and refining these systems
- Provide guidance to producers and other members of the pork chain in discussing these issues

V. Materials and Methods

General

The studies were conducted at two research centers of the University of Minnesota, the Southern Research and Outreach Center (SROC) at Waseca and the West Central Research and Outreach Center (WCROC) at Morris. The swine unit at SROC was an 800-sow breed to wean facility. The study at SROC involved 382 sows (Genetically Advanced Pigs, Winnipeg, MB, Canada) of parity one through five and body weight ranging from 140-278 kg housed in individual stalls or in pens with ESF. The study at WCROC involved 60 sows (Yorkshire-Landrace crosses from Zierke company) of mixed parity (0-6) and body weight ranging from 144-321 kg maintained in deep-bedded hoops.

Diets, Housing and Husbandry

Experiment 1. SROC:

One hundred and seventy six sows were allocated to gestation stalls (length 200 cm x width 60 cm x height 97 cm) in four groups of 44 sows each. The stalls had fully slatted flooring and an individual feeder with one waterer per sow. Two hundred and six sows were allocated to four pens with a central ESF in each pen and group sizes varied from 40 to 50 sows per pen (12.75 x 6.75 m size). Each pen had fully slatted flooring and three watering bowls positioned at the partition walls between pens. Sows were fed 2.2–3.0 kg of feed daily (CP content 15%), based on body weight and backfat at weaning. The backfat was measured at the last rib using a Lean-Meater® ultrasound unit (Renco Corporation, Minneapolis, MN). The sows were fed about 2.2 kg from breeding to day 90 of gestation. The feed allowance was increased to 2.4 kg from days 91 to 97 and increased again to 2.6 kg from day 98 until day 109 when they were moved into the farrowing crates. The sows were then offered 3 kg feed per day until farrowing. The feed was offered to a sow in the ESF in 100 g allotments every 35 seconds with 25 ml of water at each feed delivery. The stall housed sows also had a similar feeding schedule with an automatic dry feed drop system (Crystal Spring feeders) and were fed once daily.

All sows were weaned at (19.4 $\pm$ 0.05 days) days of lactation and were housed in gestation stalls for the first 10 days before moving to either the gestation stall or pens with ESF. Sows that were in the pen in the previous gestation were allotted to pens and sows that were in stalls during their previous gestation were allotted to stalls. A fortnightly weaning system was being followed in the unit and it required two weaning batches to complete the allocation of sows to a single pen, resulting in two mixings in each pen. First batch of weaned sows was mixed in pens at 5 days after breeding and the second batch was mixed 14 days after the first. When the allotment of sows to one pen was completed sows were allotted to the next pen in the same manner. The allocation of sows to all pens with ESF was completed in eight weanings. However, more weanings were needed to complete the allocation of sows to stalls due to limited availability of sows at the time of the research. Some of the sows were allocated to the stall trial when the unit had a Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) outbreak. All sows were artificially inseminated on standing heat and after 24 h interval and repeated if required. A vasectomized boar was used to aid in heat detection.

Experiment 2. WCROC:

Sixty sows were housed in a naturally ventilated, straw-bedded, hoop from weaning (24.5 ± 0.6 days) to day 109 of gestation. The hoop was divided into four pens measuring 10.2 x 7.5m (15 sows per pen) and had individual lock-in feeding stalls (185cm x 46cm when closed) for each sow and one heated bowl waterer with two drinking spaces, attached to the partition wall of the hoop. The sows were provided with fresh bedding (straw) as needed to maintain dry sleeping areas. An automatic spray cooling system with temperature and time controls was also installed. The water misters were activated for one minute in every 20 minutes when the temperature reached 80°F (27°C). The misting nozzles were located over the bedded area on the opposite side of the barn from the feeding stalls. The sows were restrictively fed once daily via hand feeding according to a formula (feed requirement =1% of body weight in kg + 0.3 kg + (0.1 kg for every 1mm P2 <20mm) and the requirement was re-assessed on day 30, 60 and 90 of gestation after weighing and P2 backfat measuring. The feed contained 15% crude protein. There were four replicates in total in this experiment involving 60 sows, conducted over a 16-month period (replication 1 had 15 sows/pen and replications 2, 3 and 4 had 2 pens each with 15 sows/pen). The data collection thus pertained to 105 farrowings of these 60 sows. The same batch of sows was used in each replicate, with the addition of replacement sows (at time of mixing at weaning) for those that were not bred or were culled after farrowing. Sows were weaned into the group and were not remixed. Any sow that was not bred (i.e. did not cycle) remained within the group and was bred in the next cycle if sow cycles matched another group, however they remained within the same group until the bred sows were moved to the farrowing stalls on day 109 of gestation. Sows were weaned as a group into an empty pen and were housed with a vasectomized boar for three days and the boar was moved out on the third day. On the fourth day, the vasectomized boar was reintroduced and the sows were bred within the group setting in the pen. The breeding operations continued for 3 days, with each sow being inseminated twice, once at first standing heat and again 24 hours later.

Cost analysis
Estimates of cost of construction, maintenance, utilities and labor (attributable hours) were collected from farm managers and farm employees.

<u>Salivary cortisol concentration, Injury levels, Behavior measures and Performance</u>

Experiment 1. SROC:

A total of four batches of focal sows were identified each for the pens and the stalls and the total number of focal sows was 80 (10 sows per batch; n = 40 in pens with ESF and n = 40 in stalls). The focal sows were randomly identified (from the first weaning batch allotted to stalls/ each pen) before weaning, to be involved in the behavior and salivary cortisol assessment and novel arena/object test (fear test). However, only 36 sows in pens with ESF and 29 sows in stalls could be included for data analysis as the rest returned. Injuries of all sows including focal sows were scored.

Experiment 2. WCROC:

Ten focal sows from each replicate in hoops (n = 40 sows) were randomly identified as focal sows in deep-bedded hoops for behavior and salivary cortisol assessment and novel arena/object test (fear test). Saliva samples from 29 sows from hoop system could be included for analysis after exclusion of the samples from returned and culled sows and from those sows without samples for all the collection days.

Salivary cortisol concentration and injury levels were assessed at pre-weaning (4 days before weaning) and subsequently at different stages of gestation as shown in Table 1. Although mixing was a known stressful event, saliva samples were not collected from the focal sows in hoops at mixing time to avoid the possible influence of the presence of boar and breeding activities going on in the group at that time.

Table 1. Saliva collection and injury scoring schedule in stalls, pens with ESF and hoops

Data collection points		
Stall	Pens with ESF	Deep bedded Hoops
Pre-weaning	Pre-weaning	Pre-weaning
	.	1 (Mixing)
5	5 (First mixing)	-
	19 (Second mixing)	-
28	28	-
	-	30
56	56	-
	-	60
84	84	-
	-	90
108	108	-

Salivary cortisol:
Saliva samples were collected using a salivette with cotton wool swab (SARSTEDT, Aktiengesellschaft and Co, Numbrecht, Germany). Sows were allowed to chew the cotton wool swab clipped to a flexible thin metal rod until the swab was thoroughly moistened. Care was taken to keep the sows minimally disturbed to avoid activity during the process of saliva collection and the saliva samples were collected between 10-11am on all collection days. Approximately 5 minutes were needed to collect saliva from a sow. The Salivette with moistened cotton swabs were centrifuged at 2000 rpm for five minutes to extract the saliva and kept frozen at -20^0C until radioimmunoassay. Approximately 0.5 ml saliva was obtained from each swab. The solid phase cortisol radioimmunoassy kit, (Coat-A-Count TKCO, Diagnostic Products Corporation, Los Angels, U.S.A) was modified to measure cortisol concentrations in saliva. Phosphate buffered solution (0.01M and 7.2pH) was used to dilute the supplied human serum based calibrators to final cortisol concentrations of 0.000 (maximum binding or B0), 0.3125, 0.625, 1.25, 2.5, 5, 10, 20, and 40 ng/ ml. Saliva samples and calibrators were analyzed in duplicate aliquots of 200µl; after adding ^{125}I cortisol, tubes were mixed and incubated for 45 minutes at 37^{o}C. Following incubation, unbound ^{125}I cortisol was aspirated and remaining radioactivity was counted using a gamma counter (Packard instrument company). The recovery rate of calibrator cortisol added to porcine saliva was determined by adding calibrator solutions to saliva containing both relatively high and low concentrations of endogenous cortisol. The recovery percentage of cortisol from the saliva was 104%. The intra-assay coefficient of variation calculated from duplicate low, medium and high cortisol saliva pools was 5.3%. Different amounts of calibrators added to the saliva samples gave a slope similar to that of the calibrator added to the buffer solution. The minimal detectable sensitivity (concentration at 92% of the maximum binding) of the assay was 0.31ng/ml.

Injury score
Injuries of all sows were scored after saliva collection and before video recording on the days of measurement. Injuries were assessed according to a scoring pattern reported (Anil et al., 2003a). Injuries on various body parts such as ear (right and left), snout, face, forehead, shoulder (right and left sides), forelimb (right and left), neck (right and left sides), thorax (right and left sides), flank (right and left sides), top of the back (dorsum), udder, croup-hind quarters (right and left sides), hind limb (right and left), tail and vulva were recorded. If the depth of a wound was > 0.5 cm, it was considered a deep wound. A score of zero was given for no injury, 1 for mild injury (< 5 superficial wounds), 2 for obvious injury (5 to 10 superficial wounds, ≤ 3 deep wounds, or both), and 3 for severe injury (> 10 superficial wounds, > 3 deep wounds, or both). Total injury score (TIS) was calculated by adding injury scores for individual sites. The TIS with the exception of that on limbs, udder, vulva and tail were added together to estimate the TIS-aggression score as the injuries on these body parts were more likely to be due to flooring conditions and behavior problems and not always due to aggression. The same individual did scoring of all injuries in each experiment.

Behavior
A time-lapse video recorder was used to videotape the behavior of the focal sows for 24 hours at 30H speed (12fields/Seconds). The focal sows were identified using large numbers painted on their back using spray paint, applied prior to the start of videotaping. The cameras were fixed on the ceiling of the pen in such a way to view an area including the entry of the ESF in the field of vision. The field of vision was the same in all the pens. Similarly, cameras were mounted on the ceiling above the stalls. Each camera recorded between 4 and 5 sows. The frequency and duration of behaviors for the first 15 minutes of every hour for the 24h period were analyzed from the videotape using a software ('The Observer', version 4.1. Noldus Information Technology Inc, Leesburg, USA).

Agonistic interactions and stereotypies, social interaction with pen mates and non-social physical interactions as well as frequencies of feeding, lying, standing and walking among sows housed in the ESF system were recorded continuously for 24h.

Videotapes from stalls were analyzed for frequency and duration of lying, standing, sitting, non-social physical interactions (exploration) and stereotypies (Table 2).

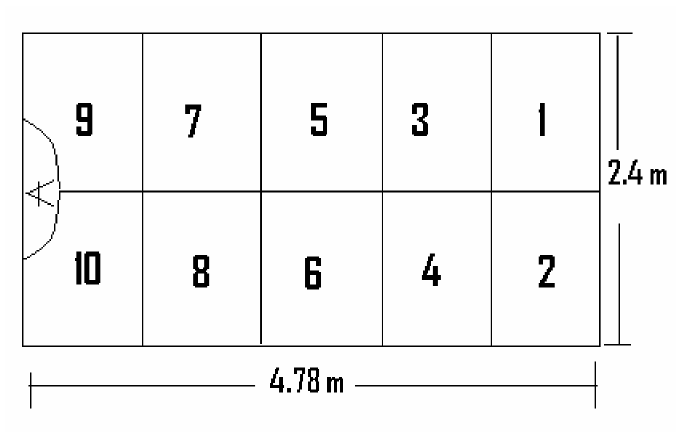
Table 2. Behavioral ethogram for sows housed in pens with ESF following the behavioral definitions from Jensen (1980), Jensen et al., (1995) and Morrison et al., (2003).

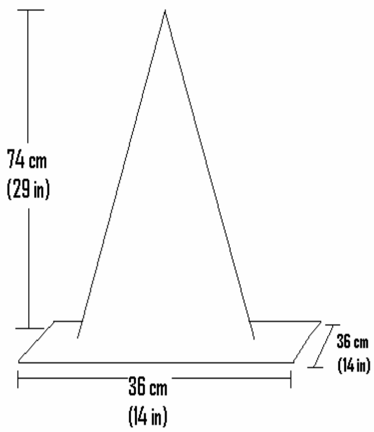
Measure	Definition
Behavior	
Agonistic	Performed and received such as parallel pressing (two pigs standing side-by-side in the same direction, pressing against each other's shoulder, with one throwing its head against the head or the neck of the other pig), inverse parallel pressing (two pigs standing side-by-side in opposite directions, pressing against each other's shoulder/croup), head-to-head knock (a rapid thrust upward or sideways with the head or snout against the neck, head or ears of another pig), levering (the pig puts its snout under the body of another pig from behind or from the side and lifts the other pig up into the air) and biting on any part of the body.
Postures	Standing (the pig is upright on all four legs) and lying (the pig is recumbent on its belly, either sternal or lateral recumbency).
Queuing	Waiting in front of the ESF entrance for an opportunity to enter the feeder. The duration of waiting by each sow till entry or leaving the attempt was taken as the duration of queuing and presented as proportion of time spent queuing and the number of times a sow queues was treated as the queue number.
ESF entry	A sow was considered as entered the ESF when the entry door closed behind the sow.
Non-social physical interactions	Nosing the concrete floor (counted only if the snout of a pig had physical contact with the surface or it approached within 5 cm of the surface).
Social tactile interactions	Nose-to-body and nose-to-nose interactions performed and received.
Stereotypy	Behavioral patterns performed repetitively in a fixed order and without any obvious function such as repetitive vacuum chewing and pen fixture biting/licking were considered

<u>*Sow behavioral response to novel arena/object (Fear test*)</u>

A novel arena/object test (fear test) was conducted on day 108 of gestation for the focal sows in both stalls and pens with ESF, before the sows were moved into farrowing stalls. These assessments were performed to test the stress-related fearfulness in sows to a novel arena/object, by modifying the methodology suggested by Pedersen et al., (1998). A completely enclosed rectangular pen with the dimensions of 4.78 m x 2.4 m was divided into 10 equal segments and numbered one through 10. In the middle, opposite from the side of entrance a semicircle of radius 0.5 m was marked off for placement of a novel object (area A) as shown in Figure 1.

Figure 1: Diagram of fear arena and novel object. "A" denotes semicircle containing novel object





The focal sows, which had never been in the rectangular pen prior to the test, were moved into the pen, one at a time directly from their daily environment. Sows were observed for a total of five minutes by two observers. The sow was observed for the first two minutes for the areas it entered within the arena and it was considered to be in an area if the snout entered the area. After the initial two minutes, a novel object was placed in the semicircle. The novel object for this test was a fluorescent orange safety cone, an object the sows had never seen previously. The cone measured 74 cm tall, and the base was 36 cm x 36 cm. The sow was observed for the three minutes that the object was present. Data taken during this time consisted of (i) areas entered during the time when the object was present, (ii) time to approach the area with the object, (iii) total time spent in the area with the object, (iv) time to first interaction with the object and (v) number of interactions. An interaction was defined as a contact with the object and the snout of the sow. The same arena and novel object were used for testing sows from both group houses and stalls. The same procedure was performed with the focal sows from the hoops on day 109 of gestation.

Performance, Body condition and Longevity:
A total of 144 sows from stalls and 154 sows from pens with ESF had farrowing performance and sow condition recorded. Farrowing performance and body conditions were assessed on 105 farrowings of 60 hoop-housed sows. The farrowing measures taken from the PigCHAMP database of the research units included litter size, number of stillborns and mummies, litter birth weight, piglet death and farrowing rate. Mummies and stillborns were defined by the herd personnel, with any sign of autolysis resulting in on a definition of mummy, and any piglet born dead without autolysis being defined as a stillbirth. Body weight and backfat thickness were measured at weaning, day 28, 56, 84 and 108 of gestation for sows in stalls and pens with ESF whereas these measurements were performed at weaning and on days 30, 60 and 90 for hoop-housed sows. These measurements were made only after the 24h video recording of behavior to avoid disruption of the behavior. Sow deaths, euthanasia and culls were also recorded along with reasons from the PigCHAMP database.

Statistical Analysis

Mean and SE, median and range were used to describe the data collected. All the agonistic interactions received or performed were added together and expressed as aggressions performed or received for behavior analysis. The proportion of time spent on a specific behavior was expressed as percentage of observation time and the number of occurrences in observation time was expressed as frequency of behavior. ANOVA for repeated measures and Tukeys pair-wise comparisons were performed for comparing cortisol concentration, and proportion of time spent on behavior at different stages of gestation. A Friedman's chi-square test based on Cochran-Mantel-Haenszel statistics with rank scores (after adjusting for sows to reduce the variation due to individual sow differences) followed by non-parametric multiple comparison (comparison of mean ranks) were employed for comparing frequency of behavior and injury scores. The correlation between cortisol and the proportion of time spent on different behaviors were analyzed using Pearson correlation. Spearman rank correlation was the method for studying the association between cortisol and behavior frequency, cortisol and injury scores, behavior and injury scores, and aggression performed or received and TIS-aggression. The associations of injury scores with body weight and backfat were also analyzed using Spearman rank correlation. The association between injury scores and parity was explained using logistic regression model. For regression analysis, TIS was dichotomized using its median value ($<$ median as 0 and $\geq$ median as 1). χ^2 test was performed to study the association between stage of gestation and severity of injuries in different anatomical locations in the case of sows in pens with ESF while in stall-housed sows, the association between presence or absence of injuries in different locations and stage of gestation was analyzed as there was not sufficient distribution of observations in different severity categories of TIS at different anatomical locations. An independent sample T-test was performed to compare the production performance in the two systems. The results of the novel arena/object test were compared using independent sample T-test and Kruskal-wallis ANOVA. All the analyses were performed using SAS (version 8.2, 2001). A *P* value ≤ 0.05 was considered significant for all comparisons.

VI. Results

Realizing the difference in stress factors and reasons for stress, statistical comparisons of injuries, salivary cortisol concentration and behaviors were made only within each housing system to highlight the changes at different stages of gestation. However, the results are presented side-by-side with stall as the basis for comparison. The data on performance and novel arena/ object test were compared between the housing systems.

Stall vs. pens with ESF

Injury scores, salivary cortisol concentration, and behavior of sows housed in stalls and in pens with ESF

Median and range of TIS for all sows and mean and SE of salivary cortisol concentration (ng/ml) of focal sows at different stages of gestation in stalls and pens with ESF are reported in Table 3.

In both systems the TIS were similar at the pre-weaning stage. The TIS on day 56 was lower than that at all other stages ($P<0.05$) except day 84 in sows in pens with ESF. The TIS was similar on mixing days and day 108 of gestation. In stall-housed sows, the TIS were higher ($P<0.05$) on day 108 and there was no difference in TIS at other stages of gestation (Table 3).

The salivary cortisol concentrations at first mixing and on day 108 were higher than the concentrations on days 28 and 56 of gestation ($P<0.05$ for all) in sows in pens with ESF and the lowest cortisol concentration was at pre-weaning ($P<0.05$). In stall-housed sows cortisol concentration was higher at pre-weaning, day 5 and day 108 than the other stages ($P<0.05$ for all). At all stages of gestation, both the TIS and cortisol concentrations were lower in stall-housed sows than in group-housed sows.

Table 3: Median and range of total injury scores (TIS) for all sows and mean ± SE of salivary cortisol concentration (ng/ml) of focal sows at different stages of gestation in pens with ESF and in stalls

Measures	Pre-weaning	Day 5	1st mixing	2nd mixing	Day 28	Day 56	Day 84	Day 108	P
TIS-for all sows (pens with ESF)	4(1-11)^{a}	-	25 (9-41)^{b}	22 (10-40)^{bc}	21(9-38)^{cd}	18 (7-34)^{e}	19 (7-39)^{de}	20 (7-38)^{cd}	0.0001^{f}
TIS-for all sows (stalls)	5 (1-11)^{a}	5(1-16) ^{a}	-	-	5(1-14) ^{a}	4.5(2-14) ^{a}	5(2-13) ^{a}	6(2-13)^{b}	0.0001^{f}
Cortisol (ng/ml)-for focal sows (pens with ESF)	0.54 ± 0.09^{a}	-	4.12 ± 0.54^{b}	3.14 ± 0.42^{bc}	2.49 ± 0.23^{c}	2.11 ± 0.25^{c}	3.13± 0.48^{bc}	4.24± 0.58^{b}	0.0001$^{\tau}$
Cortisol (ng/ml)-for focal sows (stalls)	1.21 ± 0.12^{a}	1.02 ± 0.15^{a}	-	-	0.44 ± 0.07^{b}	0.45 ± 0.13^{b}	0.53 ± 0.07^{b}	0.95 ± 0.12^{a}	0.0001$^{\tau}$

^{a,b,c,d,e}Within each row, values with different superscripts are significant (*P*<0.05).

^{f} Friedman's χ^2 test; $^{\tau}$ ANOVA for repeated measures. The injury scores on different body parts were added together to get the total injury score (TIS).

Injuries (%) with varying degree of severity on different body parts at different stages of gestation in sows housed in pens with ESF and the percentages of observations with and without injuries on different body parts of stall-housed sows are presented in Table 4 and Table 5 respectively. The χ^2 test indicated that the frequencies of injuries on various body parts of sows housed in pens with ESF were different ($P<0.05$) at different stages of gestation with the exception of injuries in forehead and tail (Table 4). Higher percentages of injuries were noticed on neck, shoulder, thorax, croup-hind quarters and limbs. The percentage of observations with injuries in udder and vulva increased towards later stages of gestation. More severe and obvious injuries were noted at the time of mixings. As gestation advanced, severity (obvious and severe) of injury decreased in all body parts with the exception of udder and vulva where it increased towards late gestation (days 84 and 108) in sows housed in pens with ESF (Figures 2 and 3).

Figure 2: The injury levels in udder of sows in pens with ESF at different stages of gestation

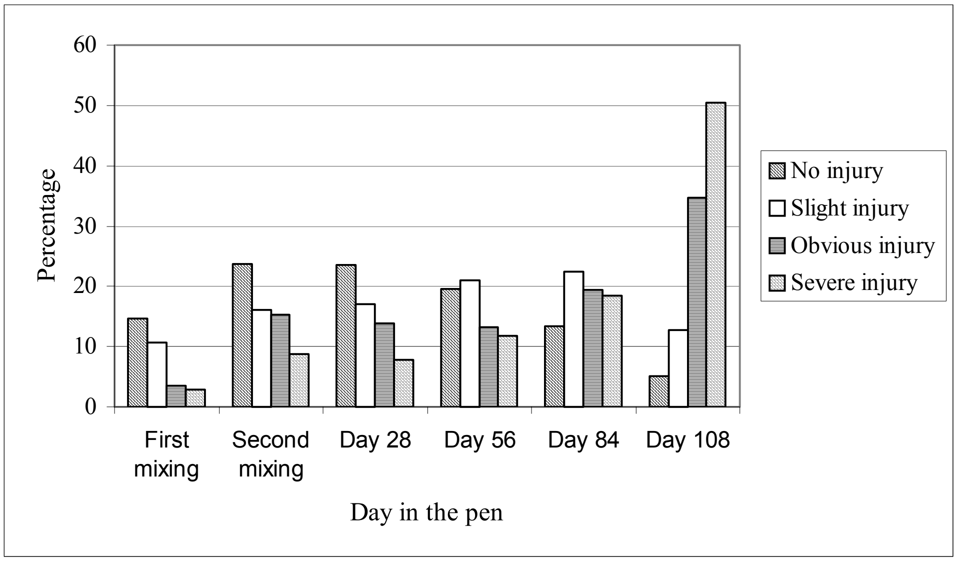
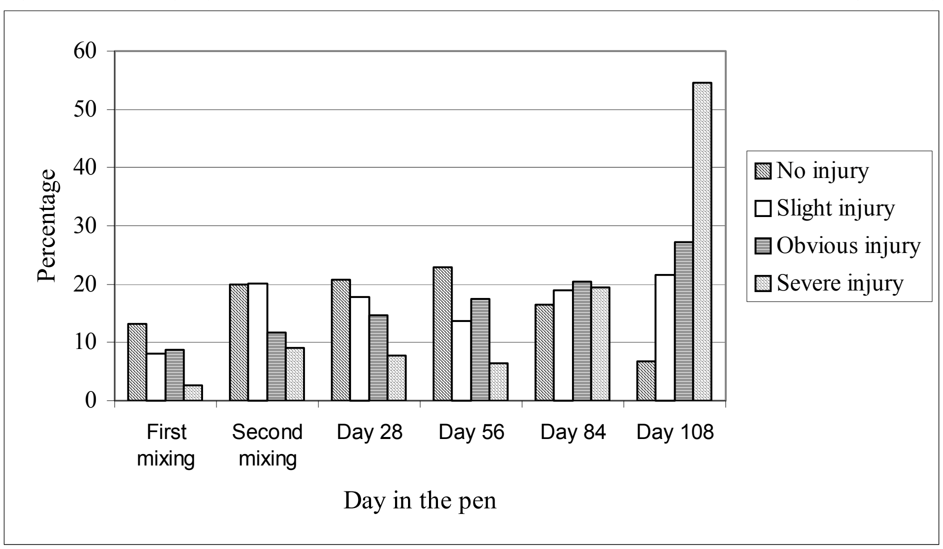


Figure 3: The injury levels in vulva of sows in pens with ESF at different stages of gestation



In stall-housed sows, higher percentages of injuries were noticed on top of the back, forelimbs, hind limbs and udder (Table 5). χ^2 test indicated that presence of injuries on face, snout, forehead, ears, neck, hind limbs and tail of the stall-housed sows did not ($P>0.05$) change with advancement of gestation. However, injuries on flank, thorax, top of the back, croup-hind quarters, forelimbs, vulva and udder increased ($P<0.05$) as gestation advanced. There was a reduction ($P<0.05$) in injuries on the shoulder as gestation advanced. On day 108, top of the back and udder had highest percentage of injuries (Figures 4 and 5).

Figure 4: The injury levels in udder of sows in stalls at different stages of gestation

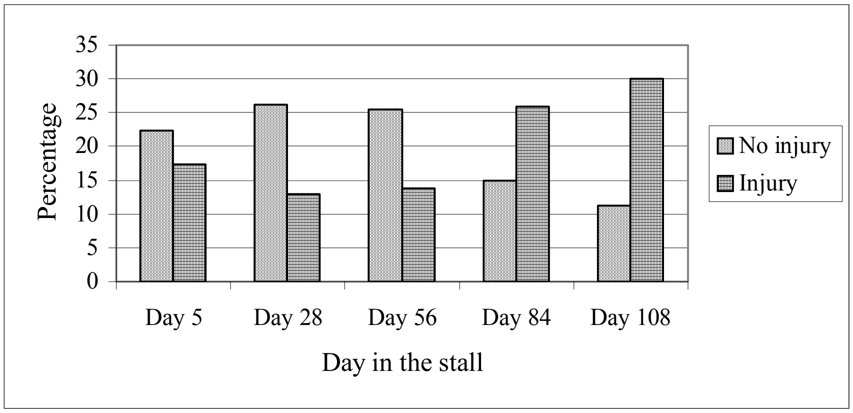


Figure 5. The injury levels on top of the back of sows in stalls at different stages of gestation

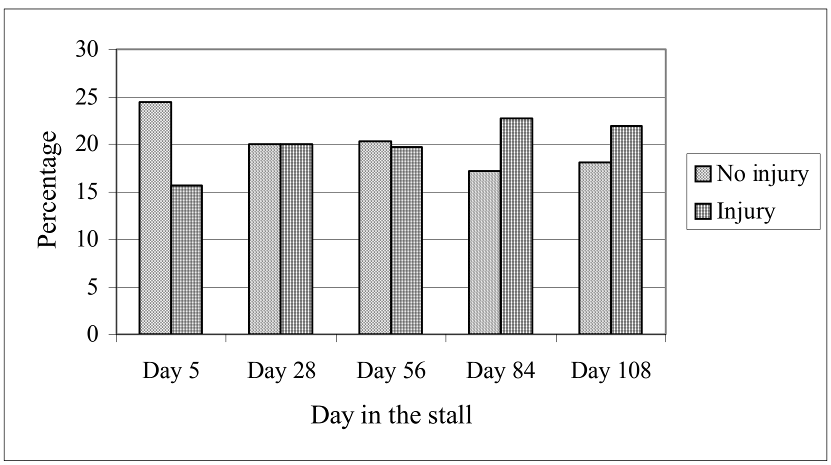


Table: 4. Percentage of injuries with varying degree of severity on different body parts at different stages of gestation in sows in pens with ESF

Location	No injury						Mild injury						Obvious injury						Severe injury						
	1st mix	2nd mix	Day 28	Day 56	Day 84	Day 108	1st mix	2nd mix	Day 28	Day 56	Day 84	Day 108	1st mix	2nd mix	Day 28	Day 56	Day 84	Day 108	1st mix	2nd mix	Day 28	Day 56	Day 84	Day 108	χ^2 and *P* Value
Face†	63.22	78.71	78.71	90.97	93.55	94.84	20.69	14.84	20	9.03	5.81	5.16	14.94	4.52	1.29	0	0.65	0	1.15	1.94	0	0	0	0	(χ^2 66.674, *d.f*=5)***
Snout†	78.16	83.23	89.68	90.97	86.45	81.94	19.54	12.90	10.32	7.74	13.55	18.06	2.30	3.87	0.00	1.29	0	0	0	0	0	0	0	0	(χ^2 12.118, *d.f*=5)*;
Forehead†	71.26	76.77	74.19	82.58	80.00	74.84	21.84	17.42	23.23	16.77	18.06	25.16	5.75	5.81	2.58	0.65	1.94	0.00	1.15	0.00	0.00	0.00	0.00	0.00	χ^2 6.237, *d.f*=5) NS
Ear‡	45.40	57.74	66.13	71.29	71.94	70.32	27.59	21.94	30.00	26.45	25.81	27.42	20.69	18.39	3.23	1.94	2.26	1.94	6.32	1.94	0.65	0.32	0.00	0.32	(χ^2 198.134, *d.f*=10)***
Neck	17.82	25.16	34.19	47.74	50.32	45.81	17.82	25.16	37.74	34.19	32.90	38.71	23.56	21.29	21.94	16.13	14.84	13.55	40.80	28.39	6.13	1.94	1.94	1.94	(χ^2 159.859, *d.f* = 15)***
Shoulder	11.49	10.32	12.26	23.87	23.23	15.81	10.92	23.23	28.71	34.84	36.13	30.97	36.21	32.90	39.35	32.90	26.77	32.90	41.38	33.55	19.68	8.39	13.87	20.32	(χ^2 386.263, *d.f* = 15***
Thorax	27.59	31.61	28.06	30.65	25.48	21.29	14.37	22.58	28.39	33.55	25.81	32.58	36.21	26.13	31.94	27.74	30.97	29.68	21.84	19.68	11.61	8.06	17.74	16.45	(χ^2 57.334, *d.f* = 15)***
Flank	47.13	47.10	41.61	44.19	36.77	45.81	17.82	26.13	32.90	36.13	39.03	31.61	23.56	19.35	18.71	18.06	21.29	17.74	11.49	7.42	6.77	1.61	2.90	4.84	(χ^2 56.645, *d.f* = 15) ***
Back‡	79.31	66.45	63.23	56.77	54.84	54.84	14.94	23.23	27.10	29.03	27.74	34.19	4.60	9.03	6.45	13.55	12.90	7.74	1.15	1.29	3.23	0.65	4.52	3.23	(χ^2 25.318, *d.f*=10)**
Croup-hind qaurters	28.16	32.90	17.74	23.55	22.90	22.58	24.71	22.90	29.68	31.94	35.81	44.52	29.89	25.16	30.97	26.45	27.42	21.94	17.24	19.03	21.61	18.06	13.87	10.97	(χ^2 63.669, *d.f* = 15)***
Fore limbs‡	21.26	26.77	30.00	35.48	29.03	30.97	56.32	58.39	56.77	50.00	63.87	62.26	20.69	13.23	11.94	13.87	5.81	6.77	1.72	1.61	1.29	0.65	1.29	0.00	(χ^2 46.967, *d.f*=10)***
Hind limb	14.37	11.61	9.35	10.00	14.52	14.89	39.66	49.03	55.16	57.10	57.10	62.14	39.66	32.26	27.74	27.10	21.61	17.15	6.32	7.10	7.74	5.81	6.77	5.83	(χ^2 49.628, *d.f* = 15)***
Udder	56.32	50.97	50.97	41.94	29.03	10.97	34.48	29.03	30.97	38.06	40.65	23.23	5.75	14.19	12.90	12.26	18.06	32.26	3.45	5.81	5.16	7.74	12.26	33.55	(χ^2 175.027, *d.f* = 15)***
Vulva	63.22	53.55	56.13	61.94	44.52	18.06	24.14	34.19	30.32	23.23	32.26	36.77	10.34	7.74	9.68	11.61	13.55	18.06	2.30	4.52	3.87	3.23	9.68	27.10	(χ^2 132.576, *d.f* = 15)***
Tail†	57.47	56.77	61.29	63.23	65.16	64.52	33.33	38.06	31.61	30.97	30.32	32.90	9.20	4.52	7.10	5.16	4.52	2.58	0.00	0.65	0.00	0.65	0.00	0.00	(χ^2 3.720, *d.f*=5) NS

P*<0.05;*P*<0.01; ****P*<0.001; NS- Statistically not significant.

† - No injury and presence of injury were considered for analysis; ‡ - No injury, mild injury and obvious and severe together were considered for analysis.

Table 5: Percentage of observations with and without injuries on different body parts of sows in stalls at different stages of gestation

Location	No injury					Injury					χ^2 and *P* value
	Day 5	Day28	Day56	Day84	Day108	Day 5	Day28	Day56	Day84	Day108	
Face	84.93	85.62	85.62	91.78	84.93	15.07	14.38	14.38	8.22	15.07	(χ^2 4.314, df=4) NS
Snout	79.45	86.30	87.67	85.62	83.56	20.55	13.70	12.33	14.38	16.44	(χ^2 4.565, df=4) NS
Forehead	86.30	84.25	88.36	92.47	90.41	13.70	15.75	11.64	7.53	9.59	(χ^2 5.992, df=4) NS
Ear	90.75	90.41	93.49	92.47	89.73	9.25	9.59	6.51	7.53	10.27	(χ^2 3.596, df=4) NS
Neck	92.47	94.52	93.84	92.12	89.73	7.53	5.48	6.16	7.88	10.27	(χ^2 5.79, df=4) NS
Shoulder	67.81	70.21	75.34	76.71	78.42	32.19	29.79	24.66	23.29	21.58	(χ^2 12.205, df=4) *
Thorax	94.52	94.86	90.41	87.67	86.30	5.48	5.14	9.59	12.33	13.70	(χ^2 21.058, df=4) ***
Flank	96.23	95.21	91.44	87.67	85.62	3.77	4.79	8.56	12.33	14.38	(χ^2 31.050, df=4) ***
Back	60.27	49.32	50.00	42.47	44.52	39.73	50.68	50.00	57.53	55.48	(χ^2 11.125, df=4) *
Croup-hind qaurters	81.85	73.97	68.84	69.18	67.47	18.15	26.03	31.16	30.82	32.53	(χ^2 20.263, df=4) ***
Forelimbs	59.25	65.07	69.86	70.21	60.96	40.75	34.93	30.14	29.79	39.04	(χ^2 12.867, df=4) *
Hindlimbs	61.64	56.51	61.99	66.78	64.38	38.36	43.49	38.01	33.22	35.62	(χ^2 7.270, df=4) NS
Udder	59.59	69.86	67.81	39.73	30.14	40.41	30.14	32.19	60.27	69.86	((χ^2 73.055, df=4) ***
Vulva	93.84	97.95	98.63	93.84	92.47	6.16	2.05	1.37	6.16	7.53	(χ^2 9.995, df=4) *
Tail	82.19	80.82	91.78	86.99	86.30	17.81	19.18	8.22	13.01	13.70	(χ^2 8.899, df=4) NS

*P<0.05; ***P<0.001; NS- Statistically not significant.

Table 6: The proportion of time spent (% of observation time) on different behaviors and time taken for postural changes (seconds) of sows in stalls and in pens with ESF at different stages of gestation.

	Pens with ESF					Stalls			
Behavior	First mixing	Second mixing	Day 56	Day 108	*P* value	Day5	Day56	Day108	*P* value
Lying	7.97 ±1.45^{ab}	4.65 ± 1.08 ^{ac}	2.49 ± 0.43^{c}	11.73 ±2.03^{b}	0.0001	74.9 ± 2.15^{a}	73.28 ± 2.14^{a}	83.91 ± 1.45^{b}	0.0001
Queuing	1.41± 0.25^{a}	2.82± 0.41^{bc}	1.83 ± 0.29^{ac}	3.54± 0.58^{b}	0.001	-	-	-	-
Standing	3.15± 0.51 ^{a}	3.48± 0.50^{a}	6.79 ± 0.8^{b}	5.52± 0.91^{b}	0.001	21.28 ± 2.26^{a}	24.85 ± 2.11^{a}	13.42 ± 1.32^{b}	0.0001
Walking	1.49± 0.2	1.69± 0.15	2.04 ± 0.26	1.50± 0.19	NS	-	-	-	-
Non-social physical interactions /exploration	2.19 ± 0.35^{a}	2.16± 0.36^{a}	3.82 ± 0.50^{b}	3.28 ± 0.50^{ab}	0.006	14.78 ± 1.82^{a}	23.71 ± 2.00^{b}	12.83 ± 1.31^{a}	0.0001
Stereotypies	1.34 ± 0.39	1.30± 0.19	1.83 ± 0.32	1.79± 0.37	NS	1.33 ± 0.43	2.91 ± 0.74	2.61 ± 0.53	NS
Sitting duration	-	-	-	-	-	3.82 ± 0.55	1.88 ± 0.62	2.65 ± 0.82	NS
Time taken for Standing to sitting (seconds)	-	-	-	-	-	10.65 ± 5.00	8.76 ± 3.25	10.11 ± 2.62	NS
Time taken for Standing to lying (seconds)	-	-	-	-	-	14.44 ± 1.01	16.88 ± 1.10	14.70 ± 1.10	NS
Time taken for Sitting to standing (seconds)	-	-	-	-	-	5.62 ± 0.95	4.15 ± 0.48	3.47 ± 0.41	NS
Time taken for Sitting to lying (seconds)	-	-	-	-	-	10.33 ± 0.45 ^{ab}	8.73 ± 0.57 ^{b}	11.61 ± 0.89 ^{a}	0.032
Time taken for Lying to standing (seconds)	-	-	-	-	-	8.34 ± 0.89	6.61 ± 0.89	5.64 ± 0.55	NS
Time taken for Lying to sitting (seconds)	-	-	-	-	-	7.30± 1.12	5.79 ± 0.49	6.77 ± 0.63	NS

^{a,b,c}Within each row, values with different superscripts are significant (P<0.05).

The proportion of time spent queuing was lower (P<0.05) at first mixing than at second mixing and day 108 (Table 6). The highest proportion of time spent on non-social physical interactions was noted on day 56. However, the difference between day 108 and day 56 was not significant (Table 6). Sows spent lesser proportion of time standing (P<0.05) at mixing days than at the other stages of gestation. The proportion of time spent lying was higher (P<0.05) on day 108 than at the other stages except at the time of first mixing. Stereotypies and proportion of time spent on walking did not show significant changes with stage of gestation.

In stall-housed sows, the proportions of time spent lying was higher and time spent standing was lower on day 108 of gestation (P<0.05 for both). Sows spent higher proportion (P<0.05) of time for non-social physical interactions /exploration on day 56 than days 5 and 108 of gestation. The stages of gestation did not differ in terms of the proportion of time spent on sitting and stereotypic behaviors in stall-housed sows. The time taken for postural changes from standing to sitting, standing to lying, lying to stand, lying to sit and sitting to stand did not vary with the stage of gestation in stall-housed sows whereas the time taken for sitting to lying was higher on day 108 of gestation than day 56.

Table 7 presents the median and ranges of frequencies of postural behavior of stall-housed sows at different stages of gestation. The median frequency of overall postural change and the median of frequencies of standing to lying, sitting to lying, lying to standing, and lying to sitting were higher on day 5 than mid and late gestation (P<0.05 for all). The frequencies of standing to sitting and sitting to standing did not vary (P>0.05) with the stage of gestation.

Table 7: Median and ranges of frequencies of postural behavior of stall-housed sows at different stages of gestation.

Measures	Day 5	Day 56	Day 108	P value
Postural change (including getting up and getting down)	14 (3-52)^{a}	6 (0-16)^{b}	6 (0-21)^{b}	0.0001
Standing to sit	0 (0-3)	0 (0-8)	0 (0-2)	NS
Standing to lying	4 (1-14)^{a}	2 (0-5)^{b}	1 (0-6)^{b}	0.0001
Sitting to standing	2 (0-7)	1 (0-6)	1 (0-5)	NS
Sitting to lying	1 (0-11)^{a}	0 (0-4)^{b}	0 (0-4)^{b}	0.0013
Lying to standing	2 (0-8)^{a}	1 (0-4)^{ab}	1 (0-3)^{b}	0.0182
Lying to sitting	4 (0-18)^{a}	1 (0-5)^{b}	1 (0-8)^{b}	0.0007

^{a,b} Within each row, values with different superscripts are significantly (P<0.05) different in their in mean rank.

Aggressive behaviors performed and received by sows in pens with ESF were lower (P<0.05) on day 56 than that on second mixing and day 108 (Table 8). The number of queuing was lower (P<0.05) on day 56 than on day 108. Aggressions performed, aggressions received and number of queuing were similar on both mixing days. Median TIS-aggression was higher (P<0.05) on day of first mixing than all the other stages. The median TIS aggression on day 56 was lower (P<0.05) than that on both the mixing days. The number of ESF entries and social-tactile interactions were not different at different stages of gestation.

Correlations between cortisol concentration, behaviors and injury scores for sows in pens with ESF (including two mixing days, days 56 and 108) are given Table 9. Cortisol concentration was positively correlated with aggression performed (P<0.01) and received (P<0.05). Aggression performed was positively correlated with both queue duration (P<0.001) and queuing number (P<0.001), number of ESF entry (P<0.001) as well as TIS-aggression (P<0.05). Aggression received and total aggressions were similarly correlated with the above variables. ESF entry was positively associated with queue duration (P<0.001) and queuing number (P<0.001).

Table 8: Median and range of frequency of behaviors of sows in pens with ESF at mixing days, day 56 and day 108

Behavior and injury scores	Median and range				P
	First mixing	Second mixing	Day 56	Day 108	
Aggressions performed	13 (0-62)[ac]	18.5 (5-77)[ab]	7.5 (1-30)[c]	27.5 (0-83)[b]	0.0001
Aggressions received	11.5 (0-50)[ac]	23.5 (1-69)[ab]	8 (0-36)[c]	24 (0-85)[b]	0.0001
Number of ESF entry	1 (0-7)	1 (0-5)	1 (0-3)	1 (0-5)	NS
Number of queuing	4.5 (0-14)[ab]	5 (1-28)[ab]	3 (0-12)[a]	8 (0-24)[b]	0.002
Social-tactile interactions	3.5 (0-27)	3 (0-16)	2 (0-17)	3.5 (0-36)	NS
TIS-aggressions	20 (9-29)[a]	14.5 (3-27)[b]	9.5 (1-23)[c]	11 (4-25)[bc]	0.0001

[a,b] Within each row, values with different superscripts are significantly (*P*<0.05) different in their in mean rank.

Table 9: Correlations between cortisol, behaviors and injury scores for sows in pens with ESF

Welfare indicators	Correlation coefficient	*P* (one-tail probability)
1. **Cortisol**		
Queue duration[p]	+ 0.127	NS
Stereotypies[p]	- 0.072	NS
Number of queue[s]	+ 0.130	NS
Aggressions performed [s]	+ 0.213	0.005
Aggressions received[s]	+ 0.155	0.032
Total aggressions (performed + received)[s]	+0.184	0.013
Non-social physical interaction[s]	+0.020	NS
TIS-aggression[s]	+0.119	NS
TIS[s]	+0.126	NS
Number of feeder entry[s]	+0.088	NS
Standing stationary[p]	-0.147	NS
Walking[p]	-0.114	NS
Lying[p]	-0.017	NS
2. Aggressions performed		
Queue duration[s]	+0.649	0.0001
Queue number[s]	+0.672	0.0001
Number of ESF entry[s]	+0.309	0.0001
TIS-aggressions[s]	+0.173	0.019
TIS [s]	+0.099	NS
3. Aggressions received		
Queue duration[s]	+0.701	0.0001
Queue number[s]	+0.754	0.0001
Number ESF entry[s]	+0.317	0.0001
TIS-aggressions[s]	+0.149	0.037
TIS[s]	+0.088	NS
4. Total aggressions		
Queue duration[s]	0.696	0.0001
Queue number[s]	+ 0.743	0.0001
Number of ESF entry[s]	+0.335	0.0001
TIS - aggressions[s]	+0.170	0.021
TIS	+0.056	NS
5. Number of ESF entry		
Queue duration[s]	+0.368	0.0001
Queue number[s]	+0.496	0.0001

[P] Pearson correlation; [s] Spearman's rank correlation; NS- Statistically not significant.

In stall-housed sows, the salivary cortisol concentration was not correlated with TIS, non-social physical interactions /exploration, durations and frequencies of postural behavior while the body weight had significant correlations with durations of exploration (-0.261, $P<0.05$), lying (+0.233, $P<0.05$) and standing (-0.278, $P<0.05$). The correlation between cortisol and stereotypy was non-significant. Similarly, body weight of stall-housed sows had non-significant correlations with frequencies of standing to lying and lying to standing. The TIS of stall-housed sows was not significantly correlated with duration of postures or frequencies of postural changes.

Relationship of injury scores with parity, body weight and backfat among sows housed in stalls and in pens with ESF

Logistic regression analysis (Table 10) with the dichotomized median TIS (median 20 and 5 for sows in pens with ESF and stalls respectively) indicated that as parity increased the likelihood for higher median TIS decreased ($P<0.05$) in sows in pens with ESF (OR 0.56, 0.34 and 0.53 respectively for parity 2, 3 and ≥4 vs. parity 1) whereas in stall-housed sows although the likelihood increased numerically; it was not statistically different between parities (1.23, 1.18 and 1.31 respectively for parity 2, 3 and ≥4 vs. parity 1).

Table 10. Relationship of parity with likelihood of total injury scores greater than the median in pregnant sows housed in group pens with ESF and gestation stalls

Predictors	Pens with ESF		Stalls	
	Odds ratio	Confidence interval	Odds ratio	Confidence interval
Parity 2 vs. parity 1	0.56*	0.34-0.94	1.23	0.72-2.12
Parity 3 vs. parity 1	0.34*	0.20-0.57	1.18	0.77-1.80
Parity 4 and above vs. parity 1	0.53*	0.32-0.87	1.31	0.0.87-1.97

* $P<0.05$

TIS of sows in pens with ESF was negatively and significantly correlated with body weight and backfat (-0.068 and -0.087 respectively with 1-tail $P<0.05$ for both), whereas TIS of sows in stalls was positively and significantly correlated with body weight and backfat (0.204 and 0.093 respectively with 1-tail $P<0.01$ for both).

Behavioral response of sows housed in stalls and in pens with ESF to novel arena/object (Fear test)

Although not significant, stall-housed sows entered greater number of squares, both in the presence and absence of the novel object, took less time to have the first interaction and interacted more number of times than sows from pens with ESF (Table 11).

Table 11: Number of squares entered, the time taken to enter the areas and the time spent in the areas by sows from stalls and pens with ESF during the novel object/arena test

Measurements (Median and range/ mean)	Pens with ESF	Stalls
Total number of animals tested	36	29
No of squares entered during exploration period (median and range)	12.5 (5-22)	13 (3-26)
No of squares entered during novel object test (median and range)	12.5 (1-25)	14 (3-35)
Number of animal entered the area A	13	16
Time (seconds) taken to enter the area A (mean)	112.62 ± 13.00	72.50 ± 15.61
Time (seconds) spent in the area A (mean)	11.46 ± 3.66	11.88 ± 2.91
Time to first interaction with the novel object (mean)	2.31 ± 0.89	2.05 ± 0.44
Number of interactions (median and range)	1 (0-8)	2.5 (0-20)

Performance and longevity of sows housed in stalls and in pens with ESF

A higher conception rate and lower removal rate compared to pens with ESF was observed in stalls. There was no difference in performance between sows housed in pens with ESF and in stalls in terms of litter size, born alive/litter, stillborn/litter and foster-on. Stall-housed sows had fewer mummies/litter and foster-off than group-housed sows (*P*<0.05 for both). Pre-weaning mortality was lower (*P*<0.05) in group-housed sows. (Table 12). Proportion of sows removed from the pens with ESF was significantly higher (*P*<0.05) than sows in stalls. The major removal reasons were lameness and poor reproductive performance among sows in pens with ESF.

Table 12. Details of population, longevity and production performance of sows in pens with ESF and stall-housed sows

Performance Measures	Pens with ESF	Stalls
Population and longevity (Number)		
Total sows	206	176
Farrowed	154	144
Returned	33	26
Destroyed due to lameness	7	1
Culled due to lameness	3	0
Culled due to farrowing performance	6	4
Moved lame	1	0
Aborted	2	1
Production performance (Mean ± SE)		
Average litter size [NS]	10.88± 0.27	10.98 ± 0.29
Born alive/litter [NS]	9.10 ±0.28	9.36± 0.28
Stillborn/litter [NS]	0.92 ±0.11	0.94 ± 0.11
Mummies/litter*	0.86±0.16	0.67 ± 0.14
Litter weight kg (birth) [NS]	14.39± 0.41	14.8 ± 0.40
Piglet death/litter before weaning***	1.22±0.12	1.58 ± 0.21
Pre-weaning mortality (piglet death/born alive x100)***	13.16± 1.41	16.24 ± 2.22
Foster-off **	0.79±0.13	0.67± 0.11
Foster-on [NS]	0.88±0.12	0.77± 0.13
Conception rate after first service (%)	74.76	81.81

**P*<0.05; ***P*<0.01; ****P*<0.001; NS –Statistically not significant.

<u>**Stall vs. Deep-bedded hoops**</u>

In order to facilitate comparison, data collection points that are comparable in both stalls and hoops were only included for analysis.

Injury scores and salivary cortisol concentrations of sows housed in stalls and in hoops

Median and range of TIS and mean and SE of salivary cortisol concentration (ng/ml) of sows at different stages of gestation in both the housing systems are reported in Table 13.

Table 13. Median and range of total injury scores (TIS) and mean ± SE of salivary cortisol concentration of sows in stalls and in hoops at pre-weaning and at different stages of gestation

Injury scores and Cortisol concentration	Pre weaning	Day 0 (day after mixing)	Day 5	Day 30 / Day 28	Day 60 / Day 56	Day 90 / Day 84	*P*-value
TIS -for all sows (hoops)	1(0-4)^{a}	3 (0-13)^{b}	-	1 (0-7)^{ac}	2 (0-14)^{bc}	2 (0-9)^{bc}	0.008^{f}
TIS -for all sows (stalls)	5 (1-11)	-	5(1-16)	5(1-14)	4.5(2-14)	5(2-13)	NS^{f}
Cortisol (ng/ml)- for focal sows (hoops)	0.79 ± 0.06^{a}	-	-	0.45 ± 0.05^{b}	0.64 ± 0.07^{ab}	0.85 ± 0.13^{a}	0.0031 $^{\tau}$
Cortisol (ng/ml)- for focal sows (stalls)	1.21 ± 0.12^{c}	-	1.02 ± 0.15^{c}	0.44 ± 0.07^{b}	0.45 ± 0.05^{b}	0.53 ± 0.06^{b}	0.0001 $^{\tau}$

^{a,b,c} within each row, values with different superscripts differ significantly (P<0.05). NS –Statistically not significant.^{f} Friedman's χ^2 test; $^{\tau}$ ANOVA for repeated measures. The injury scores on different body parts were added together to get the total injury score (TIS).

Total injury scores were lower for hoop-housed sows at all stages when compared to the stall-housed sows. There was no difference in TIS at different stages of gestation in stall-housed sows whereas lower (P<0.05) TIS were observed at pre-weaning in hoop-housed sows. The TIS on day 30, 60 and 90 were not different in hoop-housed sows. In hoop-housed sows, the salivary cortisol concentration on day 90 was higher (P<0.05) than that on day 30. In stall-housed sows, the cortisol concentration was the highest at pre-weaning stage and was not different (P>0.05) from that on day 5 of gestation. At all other stages of gestation the cortisol concentrations were similar and were lower than that of hoop-housed sows. The pre-weaning cortisol concentration was higher (P<0.05) in stall-housed sows than in hoop-housed sows.

Relationship of injury scores with parity, body weight and backfat among sows housed in stalls and in hoops

Logistic regression analysis (Table14) with the dichotomized median TIS (median 2 and 5 for sows in hoops and stalls respectively) indicated that parity of the sow did not have association with injury levels in these systems. TIS of sows in hoops was negatively correlated with body weight (-0.067, P>0.05) and backfat (-0.113, 1-tail P<0.05), whereas TIS of sows in stalls was positively correlated with body weight and backfat (0.138 and 0.072, with 1-tail P <0.01 and P <0.05 respectively).

Table 14. Relationship of parity with likelihood of total injury scores greater than the median in pregnant sows housed in hoops and in stalls

Predictors	Hoops		Stalls	
	Odds ratio	Confidence interval	Odds ratio	Confidence interval
Parity 0 vs. Parity 1	1.51	0.63-3.61	-	-
Parity 2 vs. Parity 1	0.48	0.20-1.12	1.08	0.60-1.96
Parity 3 vs. Parity 1	0.80	0.34-1.85	1.08	0.68-1.71
Parity ≥4 vs. Parity 1	0.69	0.32-1.49	1.06	0.68-1.66

Behavioral response of sows housed in stalls and in hoops to novel arena/object (Fear test)

More hoop-housed sows entered the arena with novel object than stall-housed sows (Table 15). The median number of squares entered during exploration period and novel object test were the same in both the housing systems. Similarly, there was no difference in time taken to enter the area A and time spent in the area A by the sows in both the systems. Stall-housed sows took less ($P<0.001$) time to have the first interaction with the novel object and interacted more number of times ($P>0.05$) than sows from hoops.

Table 15. Details of the number of squares entered, the time taken to enter the areas and the time spent in the areas by sows from stalls and hoops during the novel object/arena test

Measurements (Median and range/ mean)	Hoop	Stall	P
Total number of sows tested	34	29	
Number of animal entered the area A	22	16	
No of squares entered during exploration period (median and range)	12 (5-33)	13 (3-26)	NS
No of squares entered during novel object test (median and range)	12 (5-43)	14 (3-35)	NS
Time (seconds) taken to enter the area A (mean)	63.64 ± 10.126	72.50 ± 15.61	NS
Time (seconds) spent in the area A (mean)	14.40 ± 2.77	11.88 ± 2.91	NS
Time to first interaction with the novel object (mean)	23.14 ± 6.24	2.06 ± 0.44	0.0001
Number of interactions (median and range)	3 (0-8)	2.5 (0-20)	NS

NS –Statistically not significant.

Performance and longevity of sows housed in stalls and in hoops

In hoop system, 11.4 % of sows could not be bred. A higher farrowing percentage and lower removal rate compared to hoops was observed in stalls. The average litter size, born alive/litter ($P<0.05$ for both), and average litter birth weight ($P<0.001$) were significantly higher in hoops. However, stillborn /litter was less ($P<0.05$) in stall-housed sows. The number of mummies/litter, piglet death/litter before weaning, fostering-off and fostering-on were not significantly different ($P>0.05$) among the housing systems (Table 16)

Table 16. Details of population, longevity and farrowing performance of sows in hoops and in stalls.

Measures	Hoop	Stall
Population and longevity (Number)		
Farrowings observed in the housing system	105	176
Not bred	12	0
Culled (Pregnancy check negative / farrowing performance)	10	4
Dead (difficult farrowing)	1	0
Dead (non pregnant sow)	1	0
Destroyed (downer/lame)	3	1
Bred and returned	16	26
Aborted	0	1
Farrowed	62	144
Production performance (Mean ± SE)		
Average litter size*	12.24± 0.50	10.98 ± 0.29

Born alive/litter*	10.42 +0.47	9.36+ 0.28
Stillborn/litter*	1.56 +0.29	0.94 + 0.11
Mummies/litter NS	0.26+0.07	0.67 + 0.14
Litter weight kg (birth)***	20.72+ 0.75	14.81 + 0.40
Piglet death/litter before weaning	1.63+0.22	1.58 + 0.21
Pre-weaning mortality [(dead piglet/born alive)*100] NS	15.80+ 2.04	16.24 + 2.22
Foster-off NS	0.68+ 0.16	0.67+ 0.11
Foster-on NS	0.73+ 0.23	0.77+ 0.13
Farrowing %	66.67 %	81.81%

*P<0.05; ***P<0.001; NS –Statistically not significant.

Direct Costs

Direct cost comparisons were difficult to perform, as there were added costs associated with operating such facilities in a University environment. Space requirements for pens with ESF are approximately 21% higher than for gestation in stalls. Flooring and ventilation was the same for both systems of housing in this study. The costs for the equipment used in this study there were not a difference between stalls with automatic feeders and the electronic sow feeding system. Penning costs were lower for the deep-bedded system as there was no automatic feeding system. Without the feeding system, there was also an increased cost of labor, with approximately an 18% (1.8 hrs per yr) higher labor requirement, mainly due the increased time required for feeding sows. Surprisingly, there was only little difference in labor requirements outside of the obvious requirements associated with feed delivery in hoops. Pen housed breeding cohorts were mostly removed at the same time. What is less obvious is the skill required for the different systems. Though difficult to measure, it does appear that a higher level of skill sets are required for extensive housing systems other than stalls.

VII. Discussion

Stall vs. pens with ESF

During the pre-weaning period the sows were in individual farrowing stalls which were structurally different from gestation stalls in terms of flooring type (cast iron) and dimensions (214cm x 66cm, excluding the creep area) which corresponded to the lower TIS scores for sows during the pre-weaning period (Table 3). Injuries in sows housed in pens with ESF were caused mainly by two factors; fighting consequent to mixing of sows to establish social hierarchy and fighting for feeder entry. Most of the injuries in sows housed in pens with ESF during the mixing period (Table 4) were on the neck, ears, shoulder, thorax, flank and croup-hind quarters as these body parts were more likely to be injured due to parallel and inverse parallel encounters during fighting. The higher limb injuries at the time of mixing may have resulted from chasing on slatted floors during fighting. Once hierarchy is established agonistic interactions reduce in frequency and intensity (Hessing, 1993) and the subordinate sows tended to avoid dominant sows rather than the dominant sows attacking the submissive ones (Jensen, 1980; Jensen, 1982). In the present study, the injury scores reduced towards mid-gestation. However, the injury scores in sows in pens with ESF in this study increased after mid-gestation when there was no mixing (Table 3). Competition for feeder entry also contributed to injuries in ESF system. In addition, social facilitation motivated sows to enter the feeder (Hsia and Wood-Gush, 1983; Gonyou et al., 1992) even after receiving the daily allotment (Hunter et al., 1988) leading to a competition to enter the feeder. These aggressive interactions were not intense as those occurred at the mixing times and might not have caused severe injuries similar to those at the mixing time (Table 4). With advancement of gestation and the consequent increase in metabolic demand, the sow may be hungrier making more attempts to enter the feeder and getting involved in aggressive encounters. It has been suggested that although the level of feeding during gestation is usually sufficient for maintenance, growth of the sow and fetal development result in increased motivation to feed (Barnett et al., 2001). With advancement of gestation body parts such as udder and vulva became engorged and were injured easily during aggression. The chances of the swollen vulva getting wounded increased whilst queuing for feeder entry. Once the vulva is wounded it is more likely to get bitten again as the blood, swollen labia and/or the dark color attract more attention (van Putten and van de Burgwal, 1990). The prevalence proportion of sows with vulva injuries has been reported to increase from farrowing to end of gestation (Gjein and Larssen, 1995a), especially during the last three weeks before farrowing. In addition, the engorged udder may get injured when the sow lies on the slatted floor in advanced gestation. The higher injuries in udder and vulva at later stages of gestation (Table 4; Figures 2 and 3) may explain the higher TIS towards later gestation than at mid gestation (Table 3) in sows in pens with ESF.

In stall-housed sows, both the number and severity of injuries were less than that of sows in pens with ESF (Table 3). As in the ESF system, udder injuries contributed mostly to injuries at the later stages of gestation (Table 5; Figure 4). In addition, injuries on top of the back were also more at later stages of gestation (Table 5; Figure 5). Increased prevalence of injuries on flank, thorax and croup-hindquarters with advancement of gestation (Table 5) was due to increase in body size with advancement of pregnancy and consequent reduction in space availability within the stalls for movements. Although the relative measurements of stall to sow size were not assessed in the present study, a previous report (Anil et al., 2002) has indicated that injuries are likely to occur when sows make postural adjustments within restricted space. In addition, the authors reported that injuries on the back were produced when the back of the sow was pressed forcefully against the bars on the sides of the stall during lateral recumbency due to inadequate stall width in relation to height of the sow. Because of inadequate stall width, sows often had to place their limbs in the adjacent stall when in lateral recumbency and the sow in the adjacent stall might have stepped on their outstretched limbs. Lying down and getting up are mostly supported by forelimbs and these postural changes on slatted floor can be injurious. Interactions with the feeder (stepping on the feeder) might have also caused injuries to the forelimbs. The shoulder injuries, however, were resulting from prolonged lateral recumbency in the farrowing stalls and these injuries disappeared with time. Injuries on vulva and hindquarters were resulted when the sow moved backward in the stall during postural changes. However, the severity of all these injuries was less in stall-housed sows than the injuries in sows in pens with ESF.

There were no aggressive interactions while the sows were in farrowing stalls with their litters and with *ad libitum* feeding. Besides, there is a progressive decline in cortisol concentration during lactation in sows (Willcox et al., 1983). This may explain the lowest pre-weaning salivary cortisol concentration in sows (Table 3). The increase in cortisol concentration at mixing days (Table 3) in sows in pens with ESF could be related to the stress associated with the aggressive encounters performed to establish/re-establish hierarchy. The cortisol concentrations at two mixings were not different (Table 3) as the cause of elevation of cortisol was the same in both mixings. Once hierarchy is established there will be less aggressive interactions as the tendency of the submissive sows would be to get away from the dominant ones, and only the threat behavior would be sufficient to maintain hierarchy (Hessing, 1993) which may explain the lowering of cortisol level after the mixing period when compared with the other stages. However, aggression and associated stress related to feeder entry still remain. The hungrier the sow, as in later stages of gestation, the more they competed for feeder entry and the more they became stressed which may be the reason for the increase in cortisol concentration towards the later stages of gestation. The fetal initiation of cortisol production at later gestation might have also contributed to the elevation in cortisol concentration at later stages. Piglets initiate the increase in cortisol in late gestation as preparation for farrowing. Elevated levels of fetal (Fowden and Silver, 1988) and maternal (Nikolić and Živković, 1996) cortisol have been reported in swine towards the end of gestation.

Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) outbreak and immunization stress at the time of the study could have caused an elevated cortisol concentration in saliva in stall-housed sows during the pre-weaning period and day 5 of gestation. The elevation in cortisol concentration towards later stages of gestation in stall-housed sows could be preparatory to farrowing. However, the cortisol concentration in stall-housed sows at later gestation was lower than that in sows in pens with ESF since there were no additional factors such as aggression or competition for feeder entry in stalls. A perusal of the causes of stress in a group house (after the establishment of hierarchy) reveals that the feeder is the focal point and the motivating factor is hunger. It has been suggested that aggression in pigs is induced by competition for resources as well as by the frustration resulting from the inability to access the resource (Giersing and Studnitz, 1996). So each time the animal approaches the feeder it is likely to perform or receive aggression, the cause of stress. Some of these encounters may result in injuries. Each time the sow visits the feeder it is subjected to stressful stimuli and each one is capable of increasing cortisol content. The high cortisol contents in sows in pens with ESF compared with stalls indicate this.

Stereotypies may be related to feed motivation (Lawrence and Terlouw, 1993) and all sows in pens with ESF were equally susceptible to this behavior. Confinement and limited occupational opportunity of sows in stalls might be responsible for stereotypies, indicating boredom and frustration (Morris et al., 1993) and these conditions remained unchanged throughout gestation and this may explain the lack of difference in the duration of stereotypic behavior (Table 6) between stages of gestation in both stalls and pens with ESF.

The proportions of time spent lying and exploration on day 56 (Table 6) were all suggestive that the sows in pens with ESF were getting settled and had established some form of hierarchy by mid-gestation. Pigs are explorative in nature and exploratory behavior is considered as an important component of pig welfare (Wood-Gush and Vestergaard, 1993). An increase in time spent on exploration as observed on day 56 of gestation compared to other stages in stall-housed sows indicates that sows in stalls were also less compromised at this stage. Often a sitting posture is the result of an unsuccessful attempt to lie down or to get up. In stalls, this is likely in two situations; when there is no adequate space for postural changes or when sows are unable to adjust to the space restriction and make postural changes within restricted space. It may be that during early gestation sows might not have successfully mastered the technique to make postural changes within the stalls as they were in farrowing stalls, which were structurally and dimensionally different from gestation stalls, for approximately a month before moving into the stalls again. However, towards late gestation there was a reduction in space availability due to increase in body size. This reasoning is supported by the time taken for sitting to lying observed in this study, which was higher on day 108 of gestation and was not different from that on day 5 (Table 6). The easiness in lying has previously been suggested to be indicative of sow comfort (Clough, 1984; Baxter 1991) and therefore the longer time taken for sitting to lying on day 5 and day 108 is indicative that sows were relatively less compromised on day 56 of gestation compared to early and late gestation.

The lower proportion of time spent queuing at the time of first mixing (Table 6) was likely because the sows were observed on the first 24 hours in the pens with ESF after they were away from the ESF for more than 30 days and might be taking a while to get familiarized with the ESF. Fighting may be another reason distracting the less dominant sows from approaching the feeder and waiting there, which was also a focal point of aggressions. The proportion of time spent queuing on day 108 was higher probably because of increased hunger at this stage consequent to higher metabolic demands, as mentioned elsewhere, making them wait longer at the feeder. The higher queue number for feeder entry on day 108 supports this (Table 8).

The increase in frequency of overall postural change of sows in stalls on day 5 of gestation (Table 7) could have resulted from the stress associated with separation of piglets and change in the accommodation coupled with restriction of feed. Behavior indicators of stress include high activity levels characterized by frequent postural changes. However, a reduction in frequency of postural changes may not necessarily mean a reduction in stress. If there is no sufficient space for an animal to perform an activity then that activity is not performed or suppressed (Ekkel et al., 2003; Petherick, 1983). The reduction in frequency of overall postural change observed on day 108 of gestation (Table 7) thus could be due to reduction in space availability making postural changes tedious consequent to the increase in body weight.

In pens with ESF most of the aggressions after the mixing period were feeder related (Jensen et al., 2000) and frequent feeder visits may be leading to more aggressive interactions. The significantly higher number of queuing on day 108 compared to day 56 indicated that sows at this stage visited the feeder more frequently (Table 8). This explains the higher number of aggressions performed and received at late gestation than at mid-gestation though there was no addition of sows at this stage. Aggressive interactions were not totally absent at any stage as the resources such as feed and spaces were limited. These aggressions may not result in injuries unlike the ones at mixing. This was evident from lack of increase in TIS or TIS-aggressions despite higher proportion of time spent on queuing and frequency of queuing (Table 6 and Table 8) on day 108. The correlation analyses (Table 9) in this study indicated that feeder was a source of aggression in ESF system. It has to be noted that although aggressions associated with mixing were important stress factors in group housing systems, these were relatively transient compared with the feeder related stress which was present throughout in a restricted feeding system with ESF.

The association between parity and TIS was mediated through growth in the size of the animal with increase in parity and consequent increase in body weight, especially in younger parities as in the present study. It is likely that sows with increased body weight were the dominant sows in the group (Arey, 1999), which rarely receive aggression from other group members. This may explain the reduction in median TIS with increase in parity (Table 10) and the negative correlation between body weight and TIS, and backfat and TIS observed in this study. A previous report also suggested similar association between body weight and TIS and parity and TIS (Anil et al., 2003a). Other studies (Hodgkiss et al., 1998; Arey, 1999) have also found a negative association between parity and sow injuries when sows were group-housed. Unlike in pens with ESF, in stall-housed sows, the likelihood of higher median TIS increased with increase in parity, though not significantly. This was expected because body dimensions could be expressed as a function of live-weight (Petherick, 1983) and when body weight increased with increase in parity, the available space within the stall was reduced, thereby increasing the chances of injuries during normal postural adjustments (Anil et al., 2002). The positive correlations between TIS and body weight and TIS and backfat also supported this association.

The number of areas entered during the test period, time taken to enter the area with novel object, time to have first interaction with the novel object, number of interactions with the novel object and the time spent in the area with novel object (Table 11) were all indicative of the exploratory nature of stall-housed sows when they were exposed to an open area. Although stall-housed sows appeared to be more explorative in the novel arena, the results were inconclusive. There was no significant difference among sows from both the housing systems in their response to novel arena/object and there was no possibility to account for the excitement in stall-housed sows when they were permitted to have a short walk and a larger area during the test. According to Wemelsfelder et al., (2000) sows from substrate impoverished conditions took longer time to enter the test arena and to start interacting with the novel object than that taken by sows from substrate enriched conditions. Though not comparable with the experimental settings in Wemelsfelder's study, the stalls may be considered as more barren than the group pens and hence the finding of the present study does not agree with their observations.

The incidence of lameness was more in pens with ESF than in stalls though both had slatted floor without any bedding (Table 12). Most of the incidences of lameness among sows in pens with ESF began following the aggressive interactions associated with mixing in slatted floors. This was mainly due to animals falling down or legs, especially hind legs, slipping in opposite directions during fighting, running away or chasing. Tearing of the horny structure of hoof or injury to the accessory digit due to the slatted floor also contributed to lameness. Fighting amongst mixed sows on slatted floors without bedding is likely to lead to a high incidence of lameness (Kroneman et al., 1993; Gjein, and Larssen, 1995b). There was no chance for this to happen in stalls, which may explain the low incidence of lameness in stalls. The number of sows removed was also less in stalls. Lameness has been reported to be a major removal reason in swine herds (Jorgensen, 2000) and a reduction in incidence of lameness could have lowered the removal rates in stalls.

There were no differences observed for the number of piglets born alive and number of mummies for sows housed in pens with ESF or stalls. This finding agrees with previous reports by Backus et al., 1997; Bates et al., 2003. However, den Hartog et al., (1993) reported that number born alive was 0.65 pigs lower for females housed in groups with ESF compared to sows housed in stalls. High pre-weaning mortality in stall housed sows than in sows in pens with ESF observed in this study is contradictory to previous reports that pre-weaning mortality is higher in group housed sows (Cronin et al., 1996; Korthals, 2001; Wechsler,. 1996). The PRRSV outbreak at the time of study in some replicates of the stall trial could have caused the higher pre-weaning mortality in stalls. The variation in management and stockmanship needs to be considered while comparing the results of the previous studies. Housing conditions is not the only factor affecting the reproductive performance of sows as the sow itself and its management are also important (Barbari, 2000). The grouping routines have profound effect on the reproductive performance of sows housed in pens (Hemsworth et al., 1986, Nicholson et al., 1993). The aggression due to mixing and subsequently related to the feeder may adversely affect the reproductive performance of sows housed in pens with ESF (Svendsen et al., 1992; Nielsen, 2003). In the present study, sows were moved to pens 10 days after weaning, post-breeding and these sows were exposed to aggressive encounters at the time of implantation and the first batch were again exposed to aggression before the end of the implantation stage when the second group was added 14 days later. The stress during implantation stage and early embryonic development is suggested to be a reason for the lower conception rate and smaller litter size in group housed sows (Anil et al., 2003b; Safranski, 2003). During the study period the research center had a PRRSV outbreak. Although difficult to distinguish, the effects of stress due to the housing system were further increased by the PRRSV outbreak and this may be the reason for the relatively low reproductive performance of sows in the current study.

Stall vs. deep-bedded hoops

Total injury scores were lower for hoop-housed sows at all stages when compared to the stall-housed sows (Table 13). The higher injury scores at mixing in hoops were due to aggression to establish hierarchy and the median injury scores reduced after mixing, suggestive of a stabilized hierarchy. The individual feeding stalls in hoops avoided the chances of aggression due to competition for feed/ feeder. The straw-bedded floor and larger space to retreat might have also helped to avoid injuries. The lower TIS in hoop-housed sows during pre-weaning compared to stall-housed sows though the farrowing accommodation was similar in both systems could not be explained.

The salivary cortisol concentrations in both the systems were lower than that observed in group houses with ESF where the competition for feeder entry was ever present. Where there is continuous competition for feed, the heavy / higher parity sows may dominate in aggressive encounters and may be less injured. In hoops, there are only lesser chances for aggression and consequent injuries explaining the lack of association of parity or body weight with TIS (Table 14).

As in the comparison between stalls and pens with ESF, the results of fear test need to be interpreted with caution, as there was no possibility to account for the excitement in stall-housed sows when they were permitted to have a short walk and a larger area during the test. The difference in the persons doing the observation and the difference in the test environment also restricted the comparability of this data.

Literature on the welfare status or performance of gestating sows in deep-bedded hoop system is not abundant. Honeyman and Kent (2003a) compared reproductive performance of parity 1 and 2 sows in stalls, and hoops and reported that the litter size was similar, unlike in the present study. Honeyman and Kent (2003b) in another study observed a pre-weaning mortality of 18-24% in hoop-housed sows, which was higher than that observed in this study (15.79%). However, the conception rate (>95%) and average number of piglets born alive per litter (11.3) observed were higher in their study. Lower stillborn/ litter of 0.4 (Honeyman et al., 2003a) in hoop-housed sows has been reported previously. The reproductive performance of hoop-housed were significantly better than that of stall-housed sows in terms of litter size, born alive and litter birth weight, however, a higher stillborn and lower farrowing percentage were observed in stalls (Table 16). Honeyman, et al., (2003b) have reported culling and mortality rates of 5.5% and 1.1% among sows housed in hoops. However, in the present study, higher culling (9.5%) and mortality rates (4.76%) were observed. It must however, be noted that the genetics and management of the sows in the two systems were different in this study. The number sows involved in the present study was also less compared to the stall system.

V. Lay interpretation

As expected, there are benefits and challenges to all the sow housing gestation systems studied. The aim of this study was to identify and understand these benefits and challenges of each gestation sow housing system before progressing to improve the housing systems for pregnant sows. By its nature, stalls provide protection from aggression. However, stalls impose severe restriction in postural changes especially towards late gestation sufficient to cause notable injuries. The possibility of aggression both at mixing and at the feeder makes the pens with electronic sow feeding (ESF) a stressful type of accommodation for gestating sows. The injury levels and cortisol contents were lower in stall-housed sows compared to sows in pens with ESF, which is one measure detailing better welfare. The production data indicated a higher conception rate and lower sow removals in stall-housed sows which identifies the benefit of gestation stalls. More sows from pens with ESF had to be removed due to lameness though the flooring of stalls was also slatted; the disadvantage of slatted floor could be aggravated in group housing. The fear test did not give conclusive results regarding the advantage of the systems. Even though hoop system may be welfare friendly in terms of lower cortisol and injury, it needs special attention to sort out the issues of higher return rate, smaller group size, labor requirement and waste disposal.

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