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Behavior, reproduction, and immunity of crated pregnant gilts: Effects of high dietary fiber and rearing environment[1]

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ABSTRACT: The objective of this study was to examine effects of increased gut fill and diverse developing environments on pregnant gilts' behavior and physiology. Gilts were cross-fostered at 1 d of age and transferred to either an indoor or outdoor production unit. Littermate gilts remained in their different environments during development and were moved into individual gestation crates in an indoor gestation unit. Of the 42 gilts, 19 were fed a control diet of fortified sorghum-soybean meal and 23 were fed the same diet with 25% beet pulp (high fiber). Control sows ate 2.0 kg/d and high-fiber sows ate 2.67 kg/d in a large pellet (thus resulting in approximately equal energy intake and differing total dietary intakes). Pregnant gilts had behavior and immune measures sampled at 30, 60, and 90 d of gestation. The day × diet interaction was significant ($P = 0.01$) for duration of standing: sows fed high-fiber diets stood less on d 30, but on d 60 and 90 they and the control sows stood for a similar duration. Sham chewing duration and frequency showed significant (P < 0.05) effects of gestation stage × diet × environment. Gilts reared outdoors and fed high fiber increased sham chewing over gestation, whereas all other treatment groups decreased this behavior over time. Outdoor-reared gilts had greater ($P < 0.05$) frequency and duration of drinking behavior than indoor-reared gilts. White blood cell numbers were higher ($P < 0.05$) for gilts fed high-fiber diets than for gilts fed the control diet. Immune (humoral and cellular systems) and reproductive measures (farrowing rate and litter size) and plasma cortisol concentrations were generally not influenced ($P > 0.10$) by diets and rearing environments, suggesting that in spite of significant changes in behavior and feed intake gilts' immune systems were not suppressed or enhanced. Behavioral data alone suggested that indoor-reared gilts showed fewer behavioral adaptations to the crates than outdoor-reared gilts. However, immune measures did not indicate that any treatments resulted in physiological effects indicative of stress.

Key Words: Animal Housing, Behavior, Pigs, Welfare

Introduction

Most sows are fed a limited diet to prevent them from becoming fat (NRC, 1998). Adult pigs limit-fed and penned in crates show repeated oral/nasal/facial behaviors that some consider a sign that they are stressed (Terlouw et al., 1991; Lawrence and Rushen et al., 1993); however, another view considers these oral/nasal/facial behaviors normal chewing whose expression depends on available substrate on which to direct the behavior (Dailey and McGlone, 1997).

The effects of feed restriction and housing are difficult to separate because many sows that show stereotyped behavior are fed a limited amount each day and are individually penned. Hughes and Duncan (1988) suggested that the effects of environmental and dietary factors are additive. Several authors (Robert et al., 1993; Matte et al., 1994) suggested that a bulky diet reduced stereotypies and improved pig welfare.

Our hypothesis holds that if the crate and feeding level combine to reduce sows' well-being and if feeding a diet high in fiber reduces oral/nasal/facial behaviors, then one could demonstrate an improvement in some sensitive immune measures for sows fed bulky diets. Genetics and developmental experience were carefully controlled by cross-fostering litters and rearing the sub-

jects in diverse indoor and outdoor systems to test our hypothesis.

Materials and Methods

Animals, Treatments, and Analysis

All procedures were consistent with the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 1999) and were approved by the Texas Tech University Health Sciences Center Institutional Animal and Care Use Committee. Forty-two PIC C-15 (maternal line) × PIC 405 (sire line) crossbred gilts were cross-fostered at 1 d of age and transferred to sows in either an outdoor or indoor production unit. Cross-fostering was accomplished by selecting two sows that farrowed within 24 h of each other. The pair of sows then had one-half their gilts swapped so that littermates from one sow were reared both indoors and outdoors. After weaning and until entry into the breeding and gestation barn, penmates were placed in pens providing 16.0 m² either outdoors or indoors. The indoor growing environment consisted of totally slatted floors in mechanically ventilated buildings. Slats were woven wire during the nursery stage (4 to 9 wk of age) and concrete slats during the growing and finishing period. The outdoor environment consisted of pens with a shelter bedded with straw and an outdoor area that allowed for dunging on soil. The shelter covered about one-half the pen space.

When gilts reached approximately 68 kg body weight they were sorted into groups of eight, with two littermates indoors and outdoors for each of four litters (per block). Gilts remained in these groups until they were moved into an indoor gestation unit, where they were placed into individual gestation crates. Crates measured 0.67 by 2.1 m and were standard metal crates that allowed for individual penning without the ability to turn around. Gilts were visually evaluated for signs of estrus daily while in the gestation crates. A boar was used in the aisle to encourage estrous behaviors.

After they were placed into gestation crates, 19 of 42 gilts were fed a control diet of fortified sorghum-soybean meal and 23 gilts were fed an identical diet with the addition of 25% beet pulp (diets are presented in Table 1). The diets were formulated to meet or exceed National Research Council (NRC, 1998) requirements. The control gilts ate 2.0 kg/d and high-fiber gilts ate 2.67 kg/d. Each block consisted of four littermate gilts each representing one of four treatments, arranged in a two × two factorial: indoor- vs outdoor-reared and control vs high-fiber diet. Some blocks were incomplete because gilts failed to be bred. A total of seven blocks were examined.

Data were analyzed by least squares analysis of variance as a randomized block design with a 2 × 2 factorial arrangement of treatments. All data were analyzed using SAS (SAS Inst. Inc., Cary, NC) software using gen-

Table 1. Swine gestation diets and lactation diet

| Item | Gestation diets | | Lactation diet meal |
	2.0 kg/d control pellet	2.67 kg/d + beet pulp pellet	
Ingredient, %			
Milo	77.7	58.3	63
Soybean meal, (44% CP)	15.2	11.4	29
Nutri-binder	2.50	1.88	—
Swine premix	1.50	1.13	0.15
Fat (tallow)	—	—	4.25
Dical (18.5%)	1.43	1.07	2.7
Calcium (limestone)	1.10	0.83	0.55
Dyna-K (KCl)	—	—	0.05
Salt	0.50	0.38	0.35
Banmith dewormer	0.10	0.08	—
Beet pulp	—	25.0	—
Calculated composition			
Crude protein, g/d	280	304	391
ME, Mcal/kg	6.4	7.7	14.2
Calcium, g/d	16.0	14.4	22.6
Phosphorus, g/d	12.1	12.3	25.4

eral linear models procedures. Blocks contained littermate gilts reared indoors or outdoors and fed either the control or high-fiber diet. For production measures, the main effects of developmental environment and diet and the interaction term were tested with the block × treatment interaction. Some measures were repeated over time (immune and behavior), and for these a repeated measures analysis was used. The time was represented in two levels; thus, the data were a split-split plot. Three stages of gestation were sampled (30, 60, and 90 d of gestation). In addition, for behavior measures 24-h video tapes were included as subplots within stage of gestation. The block × treatment within time effects were the error terms for each time level (day or hour within day).

Reproductive Performance Measures

Gilts were raised in their treatment environments from day of birth until puberty. They were then moved into individual crates in the indoor gestation unit, which was a totally enclosed, environmentally controlled building. They remained in their crates for one estrus and were bred on the second estrus. Five days before they were due to farrow, the gilts were moved into a totally enclosed, environmentally controlled farrowing facility. During lactation the gilts were fed a common diet (Table 1) and had access to a self-feeder. The amount of feed added to the feeder was measured daily. The piglets were weaned after a 28-d lactation. Measurements that were recorded in the farrowing phase include number of pigs born, number of pigs born live, litter birth weight, number of pigs weaned, litter weaning weight, average weaning weight, mortality, and sow weight change.

Immune Measures

Twenty milliliters of blood over sodium heparin was obtained by a jugular puncture from each gilt at 30, 60, and 90 d of gestation. Blood was always collected 1 h after feeding (starting at 0900). Blood samples were assayed for natural killer cell cytotoxicity, neutrophil chemotaxis and chemokinesis, mitogen-induced lymphocyte proliferation, and differential counts. Blood smears were made using whole blood. The smears were fixed in methanol and stained with Hemo-3 (Biochemical Sciences, Bridgeport, NJ) for differential white cell counts. One hundred cells were counted per slide. At 1:500 dilution, the number of white blood cells (**WBC**) was counted using a Coulter cell counter (Coulter Electronics, Hialeah, FL).

The neutrophil chemotaxis and chemokinesis assay was performed according to published methods (Salak et al., 1993). A modified Boyden chamber (Neuro Probe, Cabin John, MD) was used to measure the migration of neutrophils toward RPMI (chemokinesis) or toward $10^{-8} M$ of recombinant human complement fragment C5a (chemotaxis). The RPMI and C5a were added to the bottom wells and the neutrophils were added to the top. The filter was fixed and stained using Lekostat I and II solution (Fisher Scientific, Houston, TX). Five fields per well of the cells that migrated to the underside of the filter were counted in a blind fashion at 1,000× magnification.

The natural killer (**NK**) cell cytotoxicity assay was performed according to the standard techniques for porcine NK assay (Lumpkin and McGlone, 1992). The target for the assays was K-562 cells, a human chronic mylogenous leukemia cell line (American Type Culture Collection, Rockville Pike, MD) labeled with ^{51}Cr. Samples were run at effector: target ratios (**E:T**) of 12.5:1, 25:1, 50:1, and 100:1; 10^4 target cells were added to each well. Percentage cytotoxicity, the measure of NK cell cytotoxicity, was calculated as described in Lumpkin and McGlone (1992).

The mitogen-induced lymphocyte proliferation assay was used to determine proliferation of lymphocytes according to an established method (Morrow-Tesch et al., 1994). Briefly, washed peripheral blood mononuclear cells were added at a fixed number (10^5) per well in the presence of concentrations of the mitogen phytohemagglutinin, (Sigma Chemical Co., St. Louis, MO) of 0, 0.2, 2 and 20 µg/mL. Radiolabeled thymidine was added after 48 h of incubation and then cells were harvested at 72 h. The uptake of the nucleic acid is proportional to activity of the cultured lymphocytes.

Plasma samples were frozen at –5°C for later assay for cortisol. Cortisol was assayed by a validated radioimmunoassay using previously published techniques (Salak-Johnson et al., 1997). The cortisol assay was performed in a single assay where the intraassay coefficient of variation was less than 15%.

Behavior During Gestation

Each gilt was time-lapse-videotaped for 24 h within 1 wk of d 30, 60, and 90 of gestation. The tapes were viewed by trained observers. Standing, sitting, lying, feeding, drinking, and oral/nasal behaviors were recorded as described in detail by McGlone et al. (1994). Each mutually exclusive behavior was assigned a number and entered into a behavior recording program described by McGlone et al. (1985). Behaviors were considered to constitute feeding when feed was known to be present while gilts were chewing. The transition between actual feeding and oral behaviors is difficult to observe, and thus the behavioral category "all oral/nasal/facial" behaviors was calculated as the sum of oral/nasal, feeding, and sham chewing behaviors (in addition to measuring sham chewing independently). The use of oral/nasal/facial behaviors is more precise because definitions in the literature vary widely when describing stereotyped behaviors (Dailey, 1995).

Behavior was recorded at 0.8 frames/s and tapes were viewed at 2.4 frames/s, a data summary technique previously validated by Arnold-Meeks and McGlone (1986). The 24-h time period was divided into 2-h intervals, resulting in 12 periods per day.

Results

Reproductive data were collected for 28 gilts raised in either an outdoor or indoor environment (Table 2). The number of piglets born live, total litter weight, and number of piglets weaned were not affected by the differing environments or the diets. In spite of being at the same age at breeding and farrowing, gilts fed the high-fiber diet were heavier ($P < 0.001$) at farrowing than those fed the control diet. The interaction between diet and developmental environment was significant ($P < 0.05$) for sow weight entering the farrowing area (Figure 1). Sow weight change during lactation did not significantly differ among treatments or interaction.

Least squares means for the immune data for gilts obtained at 30, 60, and 90 d throughout gestation are given in Table 3. The gilts fed a high-fiber diet showed a significant increase ($P < 0.05$) in white blood cell count compared with gilts fed a more traditional low-fiber diet. The remaining measures showed no effects of diet, developmental environment, or their interaction.

Plasma cortisol concentrations are given in Table 3. Dietary and developmental environments did not influence plasma cortisol concentrations.

Gilts fed the high-fiber diet stood less than those fed the control diet on d 30 of gestation (Figure 2) but for a similar length on d 60 and 90 (day × treatment, $P = 0.02$).

The effects of treatments on gilt behavior are given in Table 4 and in Figures 2 to 6. The main effect of dietary treatments did not influence gilts' behavior. However, several interactions were observed between dietary treatments and time (see below). The main ef-

Table 2. Reproductive performance and growing performance for gilts; table values
are least squares means ± SE for main effects

Measure	Treatment		Developing environment		P values		
	High fiber	Control	In	Out	Diet	Env	D × E
Number	13	15	16	12	—	—	—
Wt born gilts, kg/piglet	2.05 ± 0.19	1.98 ± 0.20	1.93 ± 0.18	2.10 ± 0.23	0.56	0.22	0.23
Wean wt gilt, kg/piglet	6.82 ± 0.77	6.59 ± 0.78	6.40 ± 0.71	7.00 ± 0.91	0.62	0.26	0.47
Wt at estrus check, kg	80.3 ± 8.32	74.9 ± 9.01	77.9 ± 7.44	77.3 ± 10.09	0.32	0.93	0.84
Gilt prefarrowing wt, kg	170.7 ± 4.3	155.3 ± 4.1	159.2 ± 4.1	167.7 ± 5.19	0.001	0.07	0.04
Gilt wean wt, kg	180.9 ± 19.3	148.6 ± 17.1	157.4 ± 20.0	172.1 ± 22.8	0.08	0.43	0.98
Mummies, no./litter	0.05 ± 0.11	0.03 ± 0.11	0.08 ± 0.09	0 ± 0.12	0.93	0.60	0.88
Stillbirths, no./litter	0.77 ± 0.64	0.86 ± 0.61	1.32 ± 0.54	0.30 ± 0.70	0.92	0.27	0.92
Number born/litter	8.1 ± 1.06	8.5 ± 0.99	7.9 ± 0.87	8.7 ± 1.14	0.77	0.61	0.70
Weight born, kg/litter	13.2 ± 3.31	15.8 ± 3.21	14.3 ± 3.02	14.,7 ± 3.67	0.26	0.87	0.45
Number alive/litter	7.38 ± 0.75	8.79 ± 0.73	8.4 ± 0.68	7.8 ± 0.83	0.22	0.58	0.61
Died, no./litter	1.07 ± 0.55	0.78 ± 0.44	1.80 ± 0.50	0.05 ± 0.57	0.71	0.06	0.74
Weaned, no./litter	7.34 ± 0.93	9.09 ± 0.84	8.25 ± 0.92	8.2 ± 0.99	0.22	0.97	0.82
Litter weight, kg/litter	45.6 ± 15.0	60.8 ± 13.6	42.9 ± 14.8	63.6 ± 16.1	0.15	0.10	0.75
Gilt food intake, kg	168.7 ± 40.0	181.9 ± 38.4	144.9 ± 39.4	205.7 ± 42.7	0.64	0.07	0.66
Days lactation	29.7 ± 1.46	30.5 ± 1.41	27.2 ± 1.40	30.0 ± 1.66	0.70	0.04	0.93

fects of developmental environment did influence gilts' feeding and standing behaviors. Gilts reared outdoors spent less time feeding and standing than indoor-reared littermates (Table 4).

Sham chewing among gilts raised outside and fed a high-fiber diet increased ($P < 0.05$) in both frequency and duration during early gestation. All other treatments and environments showed a decrease over time of gestation for both frequency and duration of sham chewing (Figures 3 and 4).

Gilts raised outdoors spent more time drinking in the early morning than those raised indoors (Figures 5 and 6). The outside-reared gilts also had an increase in frequency of drinking ($P < 0.05$) during these early hours.

Discussion

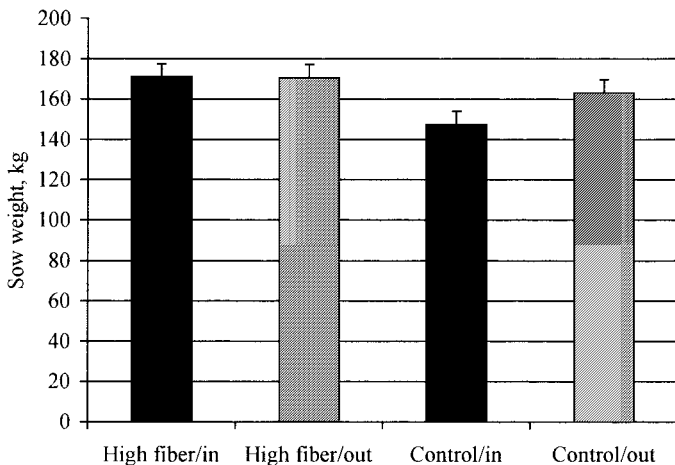Feeding the high-fiber diet had clear but transient effects on pregnant gilts' behavior. The major effect on

Figure 1. Diet by treatment effect for sow weight entering farrowing crate (n = 5, SEp = 6.51, $P = 0.04$).

gilts' behavior was observed in the first 30 d on the high-fiber diet when gilts spent less time standing (Figure 2). Overall activity levels equalized over the period from 60 to 90 d of gestation (Figure 2). Gilts on each of the four treatments (diet × rearing) had very similar behavior by the end of gestation.

Stereotyped behaviors are those behaviors that are constant in form, are repeated many times, and seem to serve no purpose (Wiepkema, 1987). Typical stereotypies for confined sows include bar-biting, bar-chewing, rubbing/rooting the bars or trough with the snout, or any other oral/nasal behavior that has no apparent function. An interesting observation is that stereotyped behaviors have not been reported for wild animals, whereas animals in confinement frequently display these behaviors (Wiepkema, 1983). Schouten and Wiepkema (1991) found that neck-tethered sows that initially resisted tethering the most had the lowest level of stereotypies, whereas low-resisting sows had higher levels of stereotypies. They suggested that the increase in stereotypies for the low-resisting sows may be a coping mechanism.

Recently, we demonstrated that sows have a drive to express oral/nasal/facial behaviors that is fairly constant over environments. In Dailey and McGlone, (1997) we reported that sows housed indoors in crates showed the same total duration of chewing, licking, and rooting in their environment as outdoor-housed sows spent manipulating their environment. In our view, such tactile behaviors should not be considered "abnormal" unless the frequency or duration of these behaviors is abnormally high or low or if the behaviors are harmful to the animal or its neighbors. To avoid inappropriate interpretations and to be more objective in our description of the behaviors, we prefer to call them oral/nasal/facial behaviors rather than stereotypies or stereotyped behaviors. An alternative view is that chewing straw can prevent chain and bar chewing

Table 3. Immune measures (least squares means ± SE) and plasma cortisol concentrations
for gilts averaged over 30, 60 and 90 d

Measure	Treatment		Developing environment		P-value		
	Control	High fiber	In	Out	Diet	Env	D × E
Number of gilts	23	19	23	19	—	—	—
White blood cells × 10⁶ cells/mL	16.4 ± 0.56	18.4 ± 0.622	17.5 ± 0.54	17.0 ± 0.63	0.04	0.55	0.43
Hemoglobin g/dL	12.8 ± 0.19	12.4 ± 0.22	12.8 ± 0.19	12.5 ± 0.30	0.18	0.34	0.92
Neutrophil × 10⁶ cells/mL	40.5 ± 1.95	38.0 ± 2.18	37.6 ± 1.90	40.9 ± 2.23	0.40	0.26	0.51
Lymphocyte × 10⁶ cells/mL	55.4 ± 2.07	58.3 ± 2.32	59.0 ± 2.02	54.6 ± 2.36	0.35	0.17	0.78
Neutrophil: lymphocyte ratio	0.86 ± 0.087	0.75 ± 0.10	0.72 ± 0.08	0.88 ± 0.10	0.39	0.21	0.27
Monocyte × 10⁶ cells	1.96 ± 0.19	1.93 ± 0.21	1.84 ± 0.18	2.05 ± 0.21	0.90	0.48	0.85
LTA at 20 μg/mL pHA[a]	106,730 ± 5,718	109,953 ± 6,390	114,520 ± 5,574	102,163 ± 6.517	0.71	0.16	0.24
Natural killer cell % cytotoxicity[b]	7.1 ± 0.79	6.4 ± 0.88	6.9 ± 0.77	6.6 ± 0.90	0.55	0.84	0.94
Chemotaxis, cells/field	413.7 ± 50.51	356.6 ± 64.93	326.0 ± 49.11	444.5 ± 65.99	0.50	0.16	0.45
Chemokinesis, cells/field	168.2 ± 25.05	143.7 ± 32.21	156.6 ± 24.36	155.3 ± 32.74	0.56	0.98	0.70
Cortisol, ng/mL	35.0 ± 2.93	34.8 ± 3.06	37.5 ± 2.79	32.3 ± 3.30	0.41	0.38	0.89

[a]Lymphocyte transformation assay. Data for 2.0, 0.2, and 0 μg/mL also not influenced by treatments.
[b]Data for 50:1, 25:1, and 12.5:1 also not influenced by treatments. Data presented are at an effector:target ratio of 100.

(Spoolder et al., 1995), an implication that chewing one substrate is "better" than chewing another. We do not believe that chewing low-nutrient-dense materials has much more apparent function than chewing a non-nutrient (such as a bar). We hypothesize that if the pig has a "need" to chew, then that need may be satisfied by a number of substrates, including straw or a metal bar.

One behavior that certain gilts expressed was sham chewing. Sham chewing represents overt chewing by the gilts or sows with no apparent feed in their mouth (Dailey and McGlone, 1997). For sham chewing, the frequency and duration of sham chewing had a significant day × treatment × developmental environment interaction (Figures 2 and 3). Outdoor-reared gilts showed more sham chewing overall than indoor-reared gilts. However, gilts fed the high-fiber diet that had been reared outdoors increased their sham chewing over gestation, whereas all other treatment groups (in-door-reared regardless of diet) decreased their sham chewing as gestation progressed. The simplest interpretation of these data is that gilts normally adapt well to the crate environment as defined by decreasing sham chewing over time. The gilts developed outdoors and fed the high-fiber diets, however, did not adapt as well, shown by the fact that their rate of sham chewing increased over time.

The three-way interaction (gestation stage × diet × rearing environment) for sham chewing was the only component of oral/nasal/facial stereotypies that was significantly affected by treatments (Figures 3 and 4). The overall level of oral/nasal/facial behavior was not different among treatments (Table 4). This important finding conflicts, in part, with earlier published reports. Robert et al. (1997) found less chain manipulation for lactating sows fed a high-fiber diet than for sows fed a more traditional diet. The Robert et al. (1997) data may
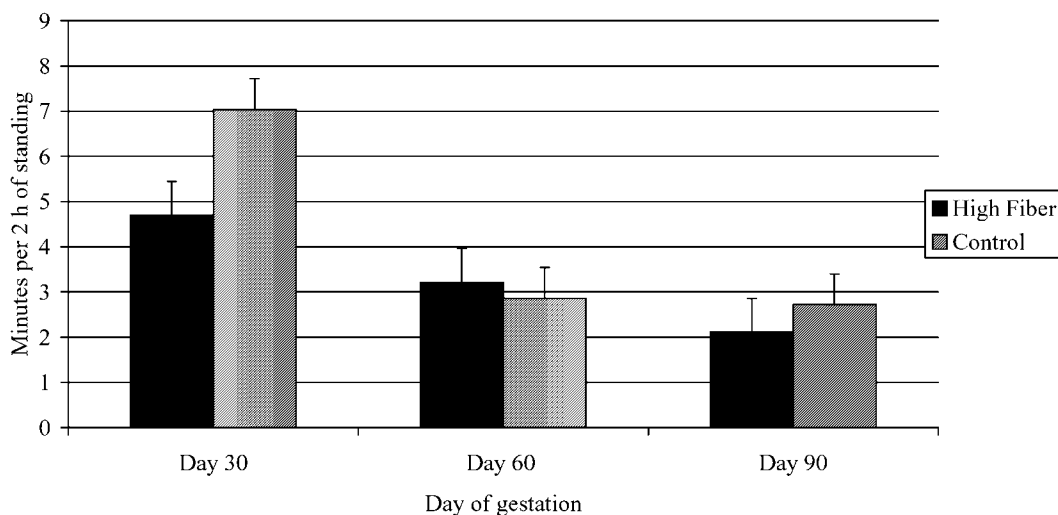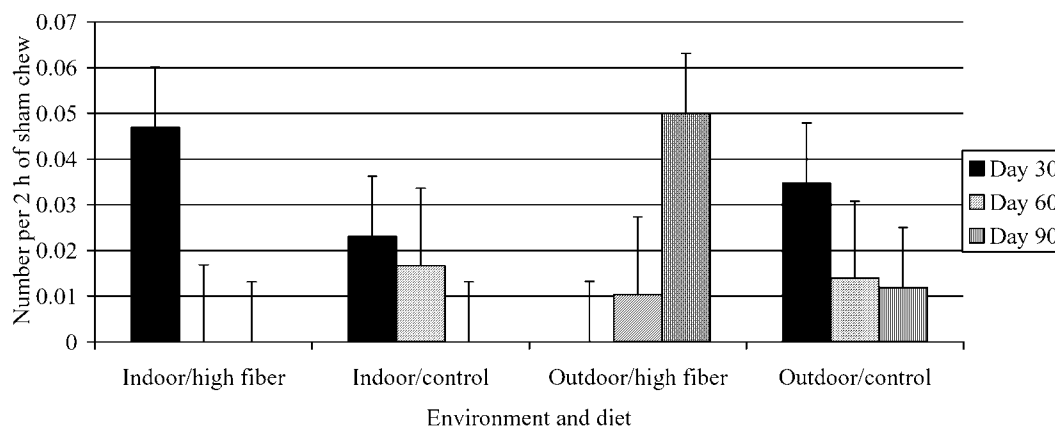

Figure 2. Day by treatment effects for duration (seconds/2-h period) of standing (n = 19 for high fiber and 23 for control, SE P = 1.62, P < 0.02).

Table 4. Main effects for behavioral measures (least squares mean ± SE)
averaged per 2-h period taken over a 24-h period

Measure	Treatment		Environment		P-value		
	High fiber	Control	In	Out	Diet	Environment	D × E
Pregnant gilts, no.	19	23	25	17	—	—	—
Frequency, no./2h							
Feed	0.20 ± 0.03	0.23 ± 0.02	0.23 ± 0.02	0.19 ± 0.03	1.00	0.30	0.37
Drink	0.42 ± 0.13	0.53 ± 0.12	0.54 ± 0.12	0.40 ± 0.13	0.28	0.27	0.79
Stand	0.92 ± 0.17	1.18 ± 0.15	1.16 ± 0.15	0.93 ± 0.17	0.11	0.05	0.87
Sit	0.005 ± 0.005	0.008 ± 0.004	0.002 ± 0.004	0.01 ± 0.005	0.40	0.14	0.31
Oral/nasal	0.63 ± 0.09	0.72 ± 0.08	0.70 ± 0.08	0.69 ± 0.09	0.17	0.48	0.84
Head weave	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.01	0.05 ± 0.01	0.92	0.09	0.86
Sham chew	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.63	0.45	0.67
Lying	0.12 ± 0.07	0.21 ± 0.06	0.18 ± 0.06	0.15 ± 0.07	0.38	0.78	0.09
All oral/nasal/facial	0.88 ± 0.09	1.04 ± 0.08	0.93 ± 0.07	1.00 ± 0.09	0.10	0.42	0.96
Duration, min/2h							
Feed	0.58 ± 0.13	0.49 ± 0.11	0.64 ± 0.11	0.37 ± 0.13	0.29	0.03	0.84
Drink	0.63 ± 0.19	0.72 ± 0.17	0.78 ± 0.16	0.54 ± 0.19	0.67	0.31	0.81
Stand	3.52 ± 0.84	3.43 ± 0.77	4.43 ± 0.75	3.36 ± 0.86	0.21	0.02	0.51
Sit	0.002 ± 0.01	0.02 ± 0.01	0.0008 ± 0.009	0.02 ± 0.01	0.14	0.12	0.34
Oral/nasal	4.19 ± 0.80	5.19 ± 0.72	5.03 ± 0.71	4.35 ± 0.81	0.16	0.42	0.92
Head weave	0.05 ± 0.02	0.06 ± 0.02	0.07 ± 0.02	0.05 ± 0.02	0.82	0.57	0.98
Sham chew	0.05 ± 0.08	0.01 ± 0.07	0.02 ± 0.07	0.04 ± 0.08	0.82	0.43	0.93
Lying	107.6 ± 1.66	105.5 ± 1.51	105.4 ± 1.47	108.0 ± 1.69	0.16	0.05	0.82
Feed total	3.87 ± 0.27	4.12 ± 0.24	4.22 ± 0.24	3.72 ± 0.27	0.86	0.07	0.88
All oral/nasal/facial	7.64 ± 0.79	8.92 ± 0.24	8.75 ± 0.70	7.80 ± 0.80	0.17	0.35	0.92

not relate to stereotypies because it could be considered toy manipulation. Brouns and Edwards (1994) and Spoolder et al. (1995) reported less feeding motivation when sows were fed a high-fiber diet than when sows were fed a more conventional diet. Their sows were in groups on straw bedding. Their finding was not replicated in our work, in which sows were housed individually on concrete slats without bedding. Perhaps being housed on straw bedding affects the expression of oral/nasal/facial behaviors more than does the dietary fiber content. In addition, in the previous studies that reported a reduction in oral/nasal/facial behaviors, the effect was much greater in the second parity than in the first parity. In these past studies, measures of physiology were not reported.

Our results clearly suggest that the feeding of high-fiber diets did not reduce oral/nasal facial behaviors among pregnant gilts. Use of high-fiber diets would probably not improve the feeling of satiation among pregnant gilts (due to lack of digestible nutrients in the beet pulp), and it caused no measurable, sustained change in behavioral measures. In a previous report, feeding 4.5 kg/d (rather than the 2.67 kg that we fed) reduced oral/nasal/facial behaviors (Bergeron et al., 2000). Two important differences between the past work and our work are first, that Bergeron et al. (2000) fed high-fiber diets containing oat hulls and alfalfa, which was probably more palatable than the water-absorbing beet pulp we fed, and thus total mass of intake was greater in their study than in ours. Second,

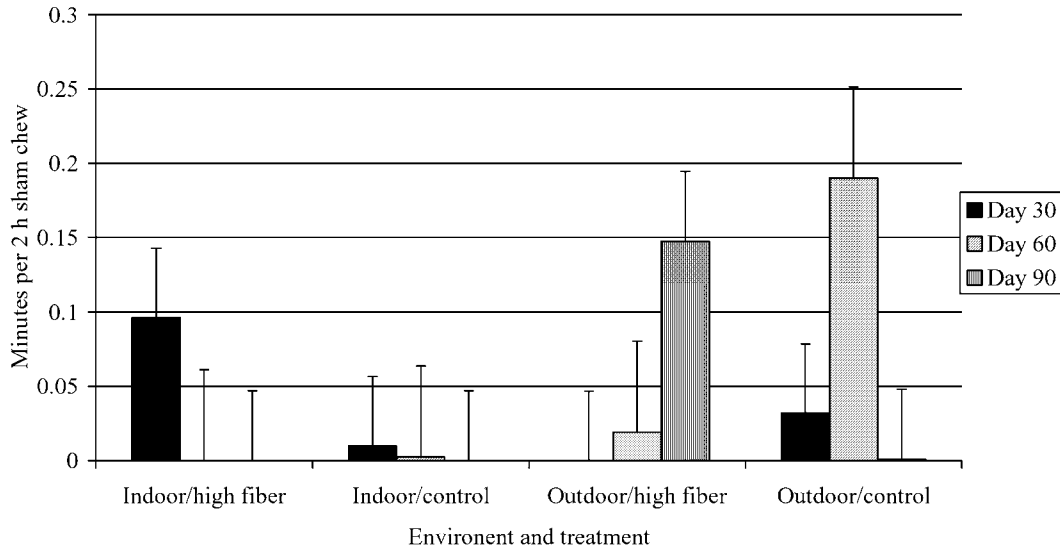**Figure 3**. Day by treatment by environment effect for frequency of sham chewing (n = 4–11, SEp = 0.038, P = 0.003).

Figure 4. Day by treatment by environment effect for duration (seconds/2-h period) of sham chewing (n = 4–11, SEp 0.007, *P* = 0.037).

Bergeron et al. (2000) recorded sows' behavior for only 2 h after feeding, and we do not know whether the total 24-h oral/nasal/facial behaviors might have been altered. Based on our work and the other recently published work one cannot assume that feeding any sort of high-fiber diet would reduce oral/nasal/facial stereotyped behaviors over the 24-h day.

In addition, feeding high-fiber diets is expected to generate a large mass of manure, which creates an environmental challenge. Therefore, based on the lack of documented behavioral or physiological improvements and given the added environmental burden, feeding high-fiber diets to pregnant gilts kept in gestation crates should not be encouraged. Indeed, for pregnant gilts reared outdoors, feeding high-fiber diets may compromise well-being, because sham chewing increased as gestation progressed.

Outdoor-reared gilts had an increase in both frequency and duration of drinking (*P* < 0.05), especially

during the early hours after feeding (Figures 5 and 6). Outdoor-reared gilts may have been frustrated with the indoor crate environment and may have used the waterer to express oral/nasal manipulations. Considering behavioral measures, outdoor-reared gilts showed more behavioral (but not physiological) adaptations to the crate than indoor-reared gilts.

The term *stress* has been used in a broad sense to explain the effects of external and internal stimuli on homeostasis. Many authors (Ewbank, 1978; Curtis, 1983; Moberg, 1985) concluded that *stress* is a vague term, but stress is generally considered to be present when environmental stimuli are responded to with any combination of a series of local and general anatomical, biochemical, physiological, and(or) behavioral changes. When these physiological changes are successful, the animal is able to maintain homeostasis. If the stress continues and the animal is unable to adapt physiologically, then the stress is considered nonadaptive and harmful to the animal's well-being (Moberg, 1985;
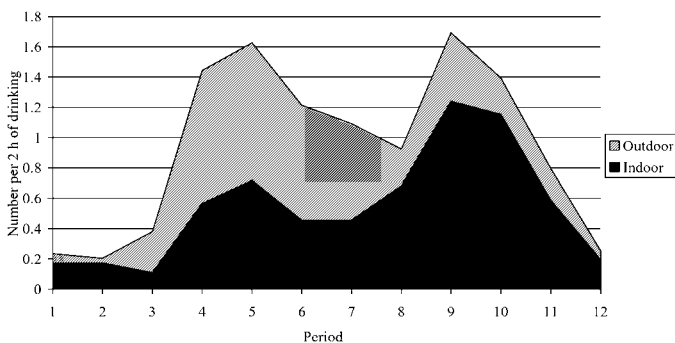

Figure 5. Period by environment effect for frequency of drinking (n = 25 for in and 17 for out, SEp = 0.27, *P* = 0.038). Period 1 = midnight to 0200 h and each period thereafter is 2 h until 24 h is completed.
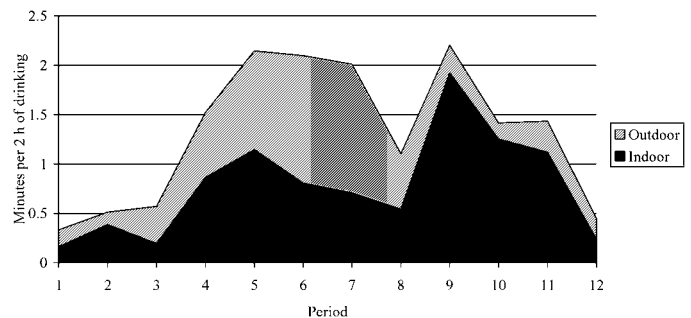

Figure 6. Period by environment effect for duration of drinking (n = 25 for in and 17 for out, SEp = 0.43, *P* = 0.02). Period 1 = midnight to 0200 h and each period thereafter is 2 h until 24 h is completed.

McGlone, 1993). If sows are penned in crates and fed a limited daily ration and if these practices are stressful to the sow, then one should be able to demonstrate physiological signs of stress. Absent a physiological stress response, the sow crate and limited ration could not be considered stressful (at least in terms of physiology).

The measure of WBC numbers was the only immune measure that was influenced by treatments. Gilts fed the high-fiber diet had elevated WBC numbers. Numbers of WBC can be elevated during infection or extreme stress when neutrophils demarginate (increase in circulation by loss of adherence to vessel walls). Because we did not find an increase in numbers of circulating neutrophils, the gilts fed high fiber were probably not stressed. Nor can we say that pregnant gilts fed conventional diets were stressed based on lower WBC numbers. Use of total WBC numbers as an indication of stress is not appropriate. Other measures such as lymphocyte proliferation under mitogen, NK activity, and neutrophil chemotaxis are known to be sensitive measures of stress in the pig (Salak-Johnson et al., 1997).

The reproductive, immune, and plasma cortisol measures did not show many significant treatment effects (Tables 2 and 3). These results can only be interpreted as indicating that pregnant gilts in any of the four treatments were not under any more or less stress to the point that their physiology changed. That gilts showed few physiological signs of stress can be interpreted as either that all treatments were not stressful or that all treatments were stressful. Clearly, the feeding of high-fiber diets did not change physiological measures. Given that immune and reproductive measures were all in the normal range for our facility (see, for example, McGlone et al., 1994), we conclude that the environments are all supportive of normal physiology. Further studies are needed to address the welfare concerns, based on both behavioral and physiological measures, of pregnant pigs in group pens compared with individual crates.

Implications

The use of gestation crates and limiting feed intake such that animals are hungry for part of most days raise animal welfare concerns. This study shows clearly that (1) pregnant gilts fed a high-fiber diet adapt to the diet and show few signs that oral/nasal/facial behaviors are effected by the end of gestation, (2) gilts from diverse developmental environments housed in gestation crates and fed conventional diets or high-fiber diets showed few physiological signs of stress, and (3) outdoor-reared gilts required more time to behaviorally adapt to the individual gestation crate. Finally, because a potential animal welfare advantage (given measures of reproduction, behavior, and immunity) of feeding high-fiber diets could not be demonstrated, and because of the potential negative environmental impact of adding a large amount of fiber to effluent systems, feeding high-fiber diets to pregnant gilts in an attempt to improve welfare is not recommended at this time.

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