

JOURNAL OF ANIMAL SCIENCE

The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Intensive indoor versus outdoor swine production systems: genotype and supplemental iron effects on blood hemoglobin and selected immune measures in young pigs

S. N. Kleinbeck and J. J. McGlone

J Anim Sci 1999. 77:2384-2390.

The online version of this article, along with updated information and services, is located on the World Wide Web at:

<http://jas.fass.org>



American Society of Animal Science

www.asas.org

Intensive Indoor Versus Outdoor Swine Production Systems: Genotype and Supplemental Iron Effects on Blood Hemoglobin and Selected Immune Measures in Young Pigs¹

Samara N. Kleinbeck* and John J. McGlone*,†,2

*Department of Animal Science and Food Technology, Texas Tech University, Lubbock 79409 and

†Department of Cell Biology and Biochemistry, Texas Tech Health Science Center, Lubbock 79430

ABSTRACT: The objectives of Exp. 1 were to determine the effects of production system and genotype on pig performance and health. Sows were bred, gestated, farrowed, and lactated in either an intensive indoor or an intensive outdoor production system. The three dam genotypes of pigs used in each environment were PIC Camborough-15 (C-15), PIC Camborough Blue (CB), and Yorkshire × Landrace (YL). All pigs received 100 mg of iron dextran at d 3 of age. Pigs raised in the outdoor unit had higher blood hemoglobin (Hb) concentrations on d 28 of age than pigs raised indoors ($11.5 \pm .22$ vs $8.16 \pm .26$ g/dL, $P < .0001$). Outdoor-reared pigs had more white blood cells (WBC) on d 3 than indoor-reared pigs ($9.7 \pm .38$ vs $8.04 \pm .38$ cells/ $\mu\text{L} \times 10^3$, $P < .05$), but outdoor pigs had fewer WBC on d 28 of age than indoor-reared pigs ($9.8 \pm .5$ vs $11.1 \pm .45$ cells/ $\mu\text{L} \times 10^3$, $P < .05$). Genetic lines did not differ in plasma immunoglobulin G (IgG) concentrations at 3 or 28 d of age. Environment and age influenced pig Hb levels and WBC numbers.

The objectives for Exp. 2 were to determine whether C-15-405 pigs reared outdoors or indoors needed supplemental iron or whether they would receive enough environmental iron, and how the lack of supplemental iron may impact pig Hb and immunity. Indoor and outdoor pigs received either no supplemental iron, 100 mg, or 400 mg of iron dextran on d 3 of age. Blood percentage neutrophils and neutrophil: lymphocyte ratio were lower ($P < .05$) indoors, and natural killer cell (NK) activity was greater ($P < .05$) among indoor- than outdoor-reared pigs (NK % cytotoxicity: 15.6 ± 2.3 vs 9.7 ± 2.3). Outdoor-reared pigs that received no injected iron had similar Hb at d 28 of age as indoor-reared pigs that received 100 mg of iron dextran ($11.1 \pm .36$ vs $10.7 \pm .4$ g/dL, $P = .59$). Supplemental iron may not be necessary in an outdoor production system. Outdoor-reared pigs had lower values for some immune measures, but they had similar survival rates as indoor-reared litters.

Key Words: Pigs, Immunity, Natural Killer Cells, Hemoglobin, Iron

©1999 American Society of Animal Science. All rights reserved.

J. Anim. Sci. 1999. 77:2384–2390

Introduction

Pigs can become anemic in the first few weeks of life even though they produce iron-rich red blood cells (Sansom, 1984), but primarily consume an iron-deficient milk diet (Miller and Ullrey, 1977). Pigs require daily iron of approximately 7 mg to maintain normal blood hemoglobin levels (Miller and Ullrey, 1977). Pigs reared outdoors can obtain iron through

the soil, bedding, plants, sow feed, or through sow feces. Indoor pigs typically do not have access to soil, bedding, or plants that may allow for sufficient iron intake. Anemic pigs may show poor health, possibly due to lower immune responses to disease (Miller and Ullrey, 1977). Therefore, indoor-reared pigs commonly receive at least 100 mg of iron dextran in the first few days of life to prevent anemia (Mayrose et al., 1988). Pigs that have not been given supplemental iron have had lower weight gains than pigs given 200 mg of supplemental iron (Pollmann et al., 1983).

Newer production methods for outdoor pigs have been developed in recent years (Thornton, 1990). In the new-style outdoor system, sow and litter productivity can equal the productivity of sows and litters from indoor units. However, among modern genotypes and in the improved outdoor environment, many genotypes and management practices must be reevaluated. Most modern genotypes of sows have

¹This work was supported by the state of Texas research line item for efficient pork production. The authors thank Mr. Stanley Harris for care of experimental animals and Ms. Theresa Hall and Ms. Carliss Fumuso for technical assistance. Texas Tech University manuscript number T-5-365.

²To whom correspondence should be addressed (phone: 806/742-2826; fax: 806/742-2335; E-mail: jmcglone@ttu.edu).

Received July 2, 1998.

Accepted January 27, 1999.

been developed for many generations in indoor systems. Whether these genotypes may do as well outdoors is an important question. Many management practices, such as provision of supplemental iron, must also be reevaluated for the newer outdoor systems.

In this investigation, three genotypes in two environments were used to determine their effects on pig blood hemoglobin (**Hb**) concentrations, selected immune measures, and pig performance. Contemporary, age-matched sows and pigs were evaluated in intensive indoor and intensive outdoor systems.

Materials and Methods

Experiment 1: Three Genotypes in Indoor vs Outdoor Environments

A total of 329 pigs were used from 39 litters. Three genotypes were raised in either an indoor or an outdoor unit. Two of the three genotypes in each environment were produced by PIC, USA, Inc., (Franklin, KY): PIC Camborough-15 (**C-15**) and PIC Camborough Blue (**CB**). The C-15 is a commercial-style sow with Large White, Landrace, and Duroc breeds. The CB had Wessex Saddleback in addition to the other breeds. The CB was originally intended as an outdoor sow line. The other genotype evaluated was a Yorkshire \times Landrace (**YL**) obtained at the Texas Tech University Research Farm by mating purebred Yorkshire sows to purebred Landrace boars (lines from Birchwood Genetics, OH). All maternal lines were mated to PIC 405 boars (a lean crossbred terminal sire).

Gilts of CB and C-15 genotypes arrived from a common source and were placed in quarantine as a group. Gilts had a common health status at the start of the study and maintained a similar high-health status both indoor and outdoors. At the end of the 60-d quarantine, gilts of each genotype were randomly assigned to either the indoor or outdoor system. At this time, and throughout the study, the three genotypes were housed together, assuring a common health status by the time litters were born. They were then bred and moved to the given treatment environment where they remained for two parities. Indoor and outdoor sows were bred and gestated in indoor (concrete slatted floors, mechanical ventilation) or outdoor paddocks (seven sows per acre). Sows and pigs remained in their treatment environment throughout the studies. Seven litters were randomly selected from each genotype in each environment for the first study, and 10 litters were randomly selected per treatment indoors and outdoors.

Pigs were weighed and bled on d 3 and 28 of age. All pigs received 100 mg of iron dextran intramuscularly on d 3 of age. All pigs were handled only at 3 d of age and weaning. At 3 d of age, needle teeth were clipped, ears were notched, tails were docked, boars were castrated, and pigs were weighed. Approximately

3 mL of blood was taken by venipuncture over sodium heparin at 3 and 28 d of age.

Gilts, sows, and pigs of each genotype were kept in multigenotype breeding groups. Each breeding and farrowing group were contemporaries, with each genotype represented in each breeding and farrowing batch. Breeding and farrowing groups had a target composition of 16 dams. The farrowing accommodation housed, respectively, 16 lactating sows indoors and outdoors per batch.

Pigs indoors were born and raised in a 1.5×2.15 m sow crate until 28 d of age. Pigs had access to creep feed at 14 d of age. Flooring was totally slotted and no bedding was provided. An under-floor water flush provided for removal of waste. Farrowing rooms were operated on an all-in-all-out basis. Mechanical ventilation was provided, and heaters kept room temperature above 23°C. A heat lamp (250 W) was provided in each farrowing crate.

Pigs outdoors were farrowed and raised in sow huts measuring 1.2×2.15 m (Porta Huts, Storm Lake, IA) on a dirt lot/pasture until 28 d of age. The farrowing paddock accommodated 7 sows per .4/ha. They had free access to the surrounding soil and grass. Huts were bedded with wheat straw and had a fender to prevent pigs from leaving for 7 to 14 d (when they could leap over the fender).

Assays performed on the blood samples were white blood cell (**WBC**) counts, Hb, and a validated IgG ELISA. The WBC and Hb concentration were determined at a 1:500 dilution of blood in Isolyse using a Coulter cell counter (Coulter Electronics, Hialeah, FL). A full description and validation of the IgG ELISA were presented by Morrow-Tesch et al. (1994).

Statistical analyses were performed using SAS software (SAS, 1988). Analysis of variance was used in a completely random, split plot design. Litter was the experimental unit for all analyses. Data were collected on 39 litters and 329 individual pigs. The model examined effects of genotype, environment, genotype \times environment interaction, age, and age interactions with each main plot effect.

Experiment 2: Iron Level Effects on Indoor vs Outdoor Reared Pigs

A total of 108 pigs were used from 20 PIC C-15-405 litters raised in the indoor or outdoor unit. Pigs were weighed on d 3 and 28 of age. Pigs within each litter were randomly given one of three doses of iron dextran on d 3 of age. The three doses were 0 mg (no injection), 100 mg, or 400 mg per pig. On d 28 of age, approximately 8 mL of blood was taken by jugular venipuncture over sodium heparin. Pigs were enumerated on d 3 and 28, and mortality between these two times was determined. Indoor and outdoor pigs were raised in the same environments as the pigs in Exp. 1.

Assays performed on the blood samples were WBC counts, differential leukocyte counts, Hb concentra-

tion, plasma IgG ELISA, and natural killer cell (NK) activity assays. Blood smears were made using whole blood. The smears were fixed in methanol and stained with Hemo-3 (Biochemical Sciences, Bridgeport, NJ) for differential leukocyte counts. One hundred cells were counted per slide.

The NK assay was performed as previously described for porcine NK cell activity (Lumpkin and McGlone, 1992; McGlone et al., 1993). Briefly, nonadherent splenic lymphocytes were isolated and used at effector:target (E:T) ratios of 100, 50, 25, and 12.5:1. The K562 cells (American Type Culture Collection; Rockville, MD) were used as the target cell. Target cells were labeled with inorganic ^{51}Cr ($\text{Na}_2 \text{ } ^{51}\text{CrO}_4$). A constant 10^4 target cells were used in each culture well. Maximum ^{51}Cr release was determined by adding 7.5% Triton-X detergent (Sigma Chemical Corp., St. Louis, MO) to lyse all targets. Spontaneous ^{51}Cr release was determined by adding culture media to target cells and measuring radioactive decay in the supernatant. Effector and target cells were incubated in a 5% CO_2 humidified chamber for 18 h. Supernatants were collected by pipette and were counted for 1 min on a gamma counter. Percentage cytotoxicity was calculated using the following formula:

$$\% \text{ NK cytotoxicity} = \frac{\text{experimental release cpm} - \text{spontaneous release cpm}}{\text{maximum release cpm} - \text{spontaneous release cpm}}$$

In this study, the experimental design was a randomized complete block. Litters served as blocks, and treatments were assigned within each litter. Pigs were bled only on d 28 of age. Treatment effects included iron dose, environment (indoor or outdoor), and iron \times environment interaction. The block \times treatment effect served as the error term.

Results

Experiment 1: Three Genotypes in Indoor vs Outdoor Environments

The environment \times genotype interaction was significant ($P < .01$) for d 3 weight and weaning weight (Table 1). Day-3 weights were greater ($P < .05$) among outdoor pigs than indoor pigs from C-15 and CB genotypes, but for YL litters, indoor and outdoor d-3 pig weights were similar.

The genotype \times environment interaction was significant ($P < .0001$) for weaning weights. The YL litters were the lightest outdoors but had the heaviest weaning weights when housed indoors (Table 1). The C-15 pigs had the lightest weaning weights indoors but were the heaviest when housed outdoors.

The genotype \times environment interaction was significant ($P < .0001$) for weight gain. The YL litters had

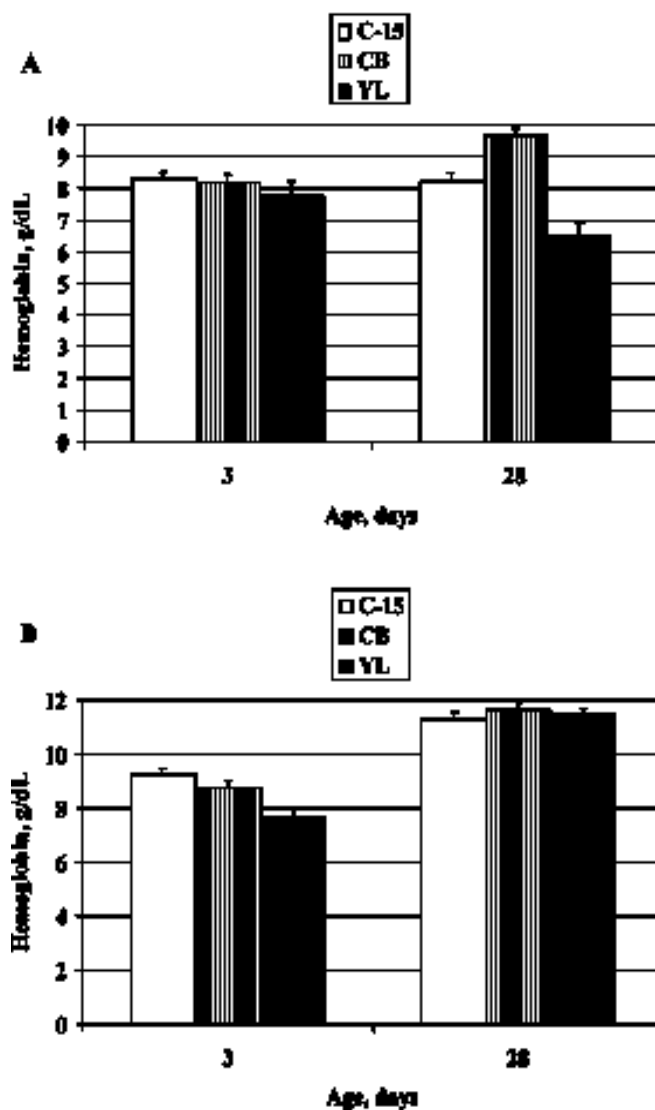


Figure 1. Environment \times genotype \times age interaction ($n = 14$ to 63 pigs per mean; $P < .01$) for hemoglobin concentration for pigs reared A) indoors and B) outdoors (Exp. 1).

the highest weight gain when housed indoors, and the C-15 litters had the highest weight gain when housed outdoors (Table 1).

A genotype effect ($P < .0004$) was seen for WBC numbers on d 3 of age. On d 3, C-15 litters had higher numbers of WBC compared to the CB and YL litters ($10.4 \pm .46$ vs $9.29 \pm .45$ and $6.92 \pm .49$ cells/ $\mu\text{L} \times 10^3$, respectively).

The YL pigs had lower ($P < .001$) WBC numbers at 28 d compared to the C-15 and CB pigs ($7.9 \pm .40$ vs $10.3 \pm .38$ and $10.8 \pm .37$ cells/ $\mu\text{L} \times 10^3$, respectively). Overall, the YL litters had lower WBC numbers on d 3 and 28 of age compared to the CB and C-15 litters.

The environment \times age interaction was significant ($P < .01$) for WBC numbers (Figure 1). Pigs indoors had higher ($P < .01$) WBC numbers on d 28 than on d

Table 1. Selected least squares means and standard errors for pig performance and white blood cell (WBC) measures in indoor and outdoor pigs of three genotypes (Experiment 1)

Measure	Indoor			Outdoor			<i>P</i> -Values ^a		
	C-15 ^b	CB ^c	YL ^d	C-15 ^b	CB ^c	YL ^d	E	G	E × G
Number of pigs	70	61	34	52	47	65			
Number of litters	7	7	7	7	7	7			
Weight d 3, kg	1.77 ± .12	1.80 ± .13	2.00 ± .17	2.05 ± .15	1.98 ± .15	1.95 ± .14	.002	.23	.008
Weaning weight, kg	6.16 ± .53	6.67 ± .76	7.50 ± .75	9.10 ± .71	6.67 ± .76	5.62 ± .62	.15	.01	.0001
Weight gain, kg/d	4.33 ± .52	4.45 ± .59	5.52 ± .73	6.93 ± .70	4.71 ± .75	3.59 ± .61	.36	.02	.0001
WBC, d 3, cells/ μ L × 10 ³	9.57 ± .56	8.29 ± .62	6.27 ± .77	11.20 ± .73	10.30 ± .66	7.58 ± .61	.02	.0001	.88
WBC, d 28, cells/ μ L × 10 ³	11.00 ± .68	12.70 ± .73	9.58 ± .90	9.50 ± .99	11.70 ± .82	8.18 ± .77	.93	.001	.20

^aProbability values for effects of environment (E), genotype (G), or the environment × genotype interaction (E × G).

^bC-15 is PIC Camborough-15.

^cCB is PIC Camborough Blue.

^dYL is Yorkshire × Landrace.

3 ($11.1 \pm .45$ and $8.0 \pm .38 \times 10^3/\mu\text{L}$, respectively). Pigs reared outdoors had similar WBC numbers on d 3 and 28. Indoor pigs had lower ($P < .01$) numbers of WBC on d 3 of age than did pigs outdoors ($8.0 \pm .38$ and $9.7 \pm .39 \times 10^3/\mu\text{L}$, respectively).

The genotype × age interaction was significant ($P < .01$) for WBC numbers. On d 3, WBC numbers for YL, C-15, and CB were $6.9 \pm .49$, $10.4 \pm .46$, and $9.3 \pm .45 \times 10^3/\mu\text{L}$, respectively. On d 28, WBC numbers for YL, C-15, and CB were $8.9 \pm .59$, $10.2 \pm .60$, and $12.2 \pm .55 \times 10^3/\mu\text{L}$, respectively.

The environment × genotype × age interaction was significant ($P < .01$) for Hb concentrations (Figure 1 a,b). Pigs reared outdoors had greater ($P < .05$) Hb concentrations on d 3 of age than did indoor-reared pigs ($8.6 \pm .15$ vs $8.1 \pm .19$ g/dL, respectively). The C-15 pigs had overall higher levels of Hb on d 3 than CB or YL pigs ($8.7 \pm .17$ vs $8.5 \pm .18$ and $7.8 \pm .26$ g/dL, respectively). The CB pigs had higher ($P < .0004$) levels of Hb on d 28 compared to C-15 and YL pigs ($10.7 \pm .26$ vs $9.8 \pm .26$ and $9.1 \pm .36$ g/dL, respectively). On d 28, outdoor pigs had 41% greater Hb than indoor pigs ($8.2 \pm .26$ g/dL indoors vs $11.5 \pm .22$ g/dL outdoors, $P < .0001$). Indoor-reared YL litters had lower ($P < .05$) Hb than C-15 or CB genotypes on d 28 ($6.5 \pm .62$, $8.3 \pm .30$, and $9.7 \pm .33$ g/dL, respectively). The environment × genotype interaction was significant ($P < .05$) for Hb concentrations on d 28. The CB pigs had the highest concentrations of Hb indoors and outdoors (Figure 1 a,b).

All genotypes had similar IgG concentrations on d 3 and 28 of age. There were no significant effects of environment, genotype, or environment × genotype on IgG concentrations on d 3 or 28 of age.

Experiment 2: Iron Level Effects on Indoor vs Outdoor Reared Pigs

In Exp. 2, a treatment × environment interaction was present ($P < .0001$) for blood Hb concentration (Figure 3). Pigs raised in the outdoor unit had higher

($P < .01$) levels of Hb than pigs raised in the indoor unit ($12.0 \pm .22$ g/dL outdoors vs $9.9 \pm .22$ g/dL indoors). Pigs given 400 mg of iron dextran had higher ($P < .0001$) Hb concentrations compared to the pigs given 0 or 100 mg iron dextran ($12.3 \pm .26$, $9.0 \pm .27$, and $11.5 \pm .29$ g/dL, respectively). Pigs given no iron outdoors had higher Hb levels at d 28 of age than pigs given no supplemental iron indoors ($11.1 \pm .36$ g/dL outdoors vs $6.9 \pm .40$ g/dL indoors). Pigs outdoors had statistically similar levels of Hb over the three iron treatment levels (Fig. 3). Pigs housed indoors showed ($P < .01$) increases in Hb with the increase in dose of supplemental iron.

A treatment × environment interaction was observed ($P < .01$) for WBC numbers. Indoor-reared pigs given increasing levels of iron showed increasing

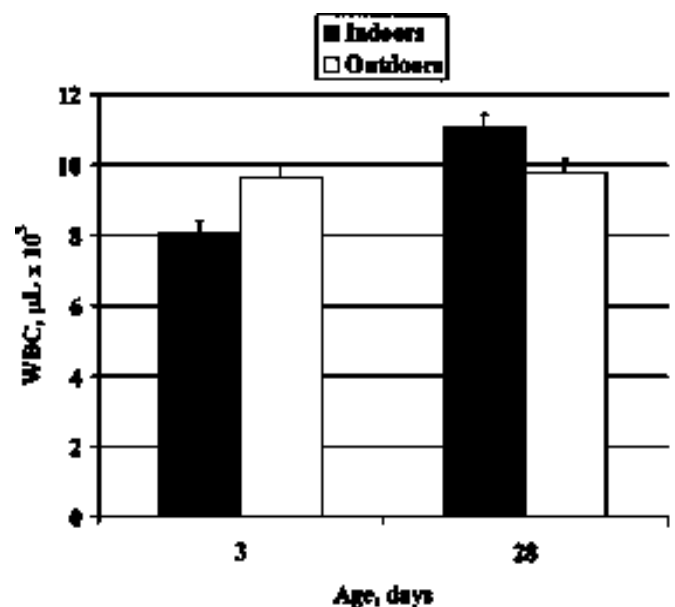


Figure 2. Environment × age interaction ($n = 95$ to 150 pigs per mean; $P < .0005$) for white blood cell (WBC) numbers for pigs reared indoors or outdoors (Exp. 1).

levels of WBC numbers (Table 2). Outdoor-reared pigs given no supplemental iron showed greater WBC numbers compared to the pigs given 100 mg of iron dextran.

An environment effect was present for neutrophil ($P < .02$) and lymphocyte ($P < .01$) numbers (Table 2). Pigs raised outdoors showed increased numbers of neutrophils ($43.4 \pm 1.98\%$ outdoors vs $37.0 \pm 1.98\%$ indoors) and decreased numbers of lymphocytes ($51.64\% \pm 2.1$ outdoors vs $59.31\% \pm 2.1$ indoors) compared to pigs raised indoors. There was an environment effect ($P < .02$) for the neutrophil:lymphocyte ratio. Indoor-reared pigs had a lower neutrophil:lymphocyte ratio than the outdoor-reared piglets ($.73 \pm .11$ indoors vs $1.1 \pm .11$ outdoors). The percentage of monocytes decreased ($P < .05$) from pigs treated with no supplemental iron to pigs treated with 100 mg of iron dextran ($3.53\% \pm .25$ vs $2.52\% \pm .25$, respectively).

A treatment \times environment interaction was observed ($P < .05$) for NK activity. Outdoor-reared pigs generally had lower NK activity compared with pigs in all other indoor rearing treatments (Figure 4).

There were no significant effects of environment, treatment, or environment \times treatment on birth weight, weaning weight, pig survival, IgG concentrations, or average daily gain (Table 2).

Discussion

Outdoor pigs had higher d-3 weights than indoor pigs. The C-15 and CB litters outdoors had heavier d-3 weights than indoor-born pigs. The YL litters indoors and outdoors had similar d 3 weights. Weaning weights were higher for C-15 pigs overall than for CB and YL pigs. The YL litters had the lightest weaning weights outdoors, but the heaviest indoors. The CB litters had similar weaning weights outdoors and indoors. These results show that the YL litters grew better indoors than outdoors. The C-15 pigs showed the best weight gain overall, but the YL litters had greater weight gains indoors than the C-15 indoors. These results show that the C-15 line may perform better over the other two genotypes outdoors, but that the YL litters gained best indoors. All genotypes and each environment supported reasonable growth of pigs during nursing.

Hemoglobin concentrations were greater on d 3 in outdoor-reared pigs than the indoor-reared pigs (Figure 1 a,b). The C-15 pigs had higher levels of Hb on d 3 than the YL or CB pigs. This may correlate with the observation that they had improved weight gain. The outdoor pigs had higher levels of Hb than the indoor pigs on d 28. This is likely due to their access to soil, plants, bedding, sow feed, and feces, whereas the indoor pigs had limited access to sow feed and feces and no access to soil. Much early research

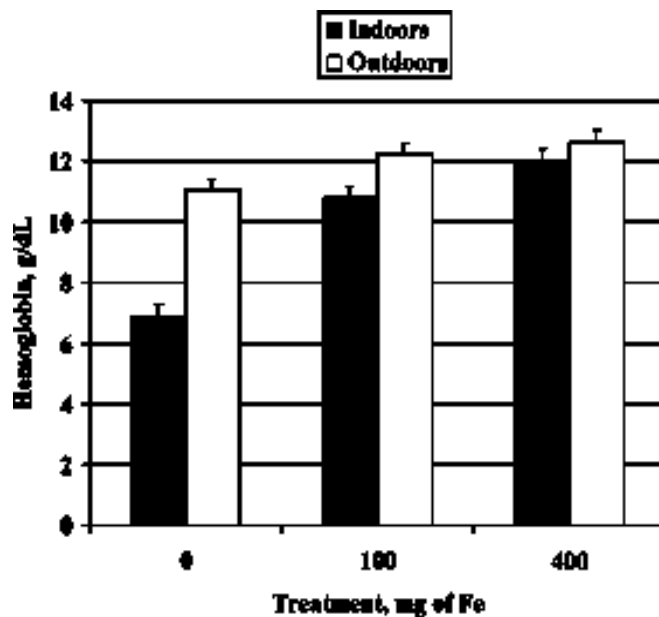


Figure 3. Treatment \times environment interaction ($n = 15$ to 20 pigs per mean; $P < .0001$) for hemoglobin for pigs raised indoors and outdoors given one of three iron treatments (Exp. 2; all C-15-405 pigs).

found outdoor pigs of older-style genotypes had higher Hb than indoor-reared pigs (Pond, 1959). These results show that outdoor-reared pigs may not need supplemental iron if they have access to sources of environmental iron. A report by Brown et al. (1996) showed that outdoor-reared pigs that received no supplemental iron were not anemic. Even though they did not report Hb values from indoor pigs in their work, our results and the Scottish work (Brown et al., 1996) are in complete agreement that supplemental iron is not necessary among outdoor-reared pigs.

The YL litters indoors and outdoors had lower WBC numbers on d 3 and 28 compared to the other genotypes. Outdoor pigs had similar WBC on d 3 and 28 of age. Indoor pigs had lower WBC numbers on d 3 than on d 28 of age. The CB litters indoors had more WBC on d 28 of age than C-15 or YL litters. Indoor pigs may have a rise in WBC numbers, possibly because there was an increased microbial load, whereas the outdoor pigs may be exposed to a more dilute microbial load. The genotype effect seen in WBC numbers may be due to how different genetic lines react to particular opportunistic disease organisms in our herd. This agrees with King (1971) who stated that differences in performance, susceptibility, or resistance between breeds of pigs may be altered in the presence or absence of a particular disease.

In Exp. 2, more WBC were seen among indoor-reared pigs than outdoor-reared pigs at 28 d of age. Again, this may be due to a greater level of microbes in the indoor environment. Indoor-reared pigs given 400 mg of iron had more WBC than did pigs given 100

Table 2. Selected least squares means and standard errors for immune measures and performance measures for each level of iron treatment among indoor and outdoor pigs (Exp. 2). All animals were C-15-405 crossbred pigs

Measure	Indoor						Outdoor						P-Values ^a		
	0 mg Fe		100 mg Fe		400 mg Fe		0 mg Fe		100 mg Fe		400 mg Fe		E	T	E × T
	17	10	17	10	19	10	20	10	15	10	50	10			
Number of pigs, d 8	17	10	17	10	19	10	20	10	15	10	50	10			
Number of litters	2.00 ± .09	1.96 ± .09	1.96 ± .09	1.96 ± .09	1.96 ± .09	1.96 ± .09	2.02 ± .08	2.02 ± .08	2.10 ± .10	2.10 ± .10	2.31 ± .08	2.31 ± .08	.09	.66	.40
Weight d 8, kg	5.85 ± .37	6.44 ± .37	6.44 ± .37	6.87 ± .36	6.87 ± .36	6.87 ± .36	6.31 ± .34	6.31 ± .34	6.89 ± .40	6.89 ± .40	6.84 ± .34	6.84 ± .34	.32	.12	.89
Wearing weight, kg	12.4 ± .70	14.8 ± .71	14.8 ± .71	16.1 ± .66	16.1 ± .66	16.1 ± .66	13.1 ± .64	13.1 ± .64	11.9 ± .76	11.9 ± .76	13.0 ± .64	13.0 ± .64	.003	.02	.01
WBC, d 28, cells/ μ L, $\times 10^3$	28.5 ± 5.0	29.8 ± 5.3	29.8 ± 5.3	43.2 ± 3.8	43.2 ± 3.8	43.2 ± 3.8	25.0 ± 5.4	25.0 ± 5.4	21.4 ± 6.9	21.4 ± 6.9	20.6 ± 6.9	20.6 ± 6.9	.56	.30	.55
IgG, d 28, mg/ml	31.8 ± 3.5	36.1 ± 3.6	36.1 ± 3.6	63.7 ± 3.4	63.7 ± 3.4	63.7 ± 3.4	44.7 ± 3.5	44.7 ± 3.5	42.7 ± 3.8	42.7 ± 3.8	42.8 ± 3.3	42.8 ± 3.3	.02	.33	.14
Neutrophil, %	63.7 ± 3.6	60.5 ± 3.7	60.5 ± 3.7	63.7 ± 3.4	63.7 ± 3.4	63.7 ± 3.4	60.1 ± 3.4	60.1 ± 3.4	53.0 ± 4.0	53.0 ± 4.0	61.9 ± 3.3	61.9 ± 3.3	.01	.40	.24
Lymphocyte, %	3.21 ± .44	1.86 ± .45	1.86 ± .45	2.68 ± .42	2.68 ± .42	2.68 ± .42	3.84 ± .42	3.84 ± .42	3.06 ± .49	3.06 ± .49	3.06 ± .41	3.06 ± .41	.07	.04	.75
Monocyte, %	1.24 ± .50	1.48 ± .50	1.48 ± .50	1.09 ± .47	1.09 ± .47	1.09 ± .47	1.37 ± .47	1.37 ± .47	1.15 ± .54	1.15 ± .54	2.30 ± .45	2.30 ± .45	.40	.64	.39
Other cells, %	.618 ± .19	.668 ± .19	.668 ± .19	.908 ± .18	.908 ± .18	.908 ± .18	1.01 ± .18	1.01 ± .18	1.22 ± .31	1.22 ± .31	1.08 ± .17	1.08 ± .17	.02	.59	.88
Neutrophil:lymphocyte	1.44 ± .01	1.68 ± .01	1.68 ± .01	1.77 ± .01	1.77 ± .01	1.77 ± .01	1.69 ± .01	1.69 ± .01	1.89 ± .01	1.89 ± .01	1.81 ± .01	1.81 ± .01	.10	.11	.67
Average daily gain, kg/d	38.5 ± 7.4	89.4 ± 7.4	89.4 ± 7.4	96.9 ± 7.4	96.9 ± 7.4	96.9 ± 7.4	90.0 ± 8.6	90.0 ± 8.6	84.6 ± 6.5	84.6 ± 6.5	88.8 ± 6.6	88.8 ± 6.6	.51	.33	.88
Pigs survived, %															

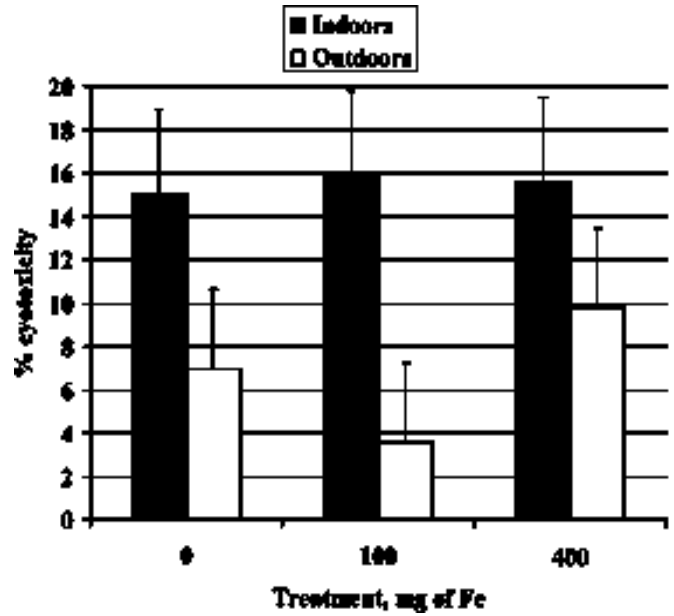


Figure 4. Natural killer cell (NK) activity (effector: target ratio of 100:1) for pigs raised indoors and outdoors given one of three iron treatments (Exp. 2; all pigs C-15-405 genotype). The environment \times iron dose interaction was significant ($P < .036$).

mg of iron dextran or no supplemental iron. The indoor pigs showed increasing numbers of WBC with the increase in iron level. These results may indicate that the increase in iron treatment levels stimulated the production of WBC, much as Hb synthesis and red blood cell formation increase with supplemental iron. Humbert and Moore (1983) report that the lack of iron decreases lymphocyte responses, decreases of the formation of humoral antibodies, and causes dysfunctional neutrophils. The outdoor pigs given no supplemental iron had more WBC than the indoor pigs given 100 mg of iron dextran. At 0 mg of iron dextran, indoor pigs had similar numbers of WBC compared to the outdoor pigs. At 100 and 400 mg of iron dextran, indoor pigs had more WBC than did outdoor pigs. If the indoor environment had a greater microbial load, pigs may require 100 mg of iron dextran to increase WBC numbers. According to this hypothesis, outdoor pigs with excess iron (100 or 400 mg plus environmental iron), did not have an increase in WBC numbers because the microbial load was less.

All genotypes had similar IgG on d 3 and 28 of age. Galán et al. (1988) reported that there is reduced serum IgG levels in iron-deficient children; however, other studies showed no effect on serum IgG levels (Brock, 1993). In our pig study, iron status did not influence plasma IgG concentrations.

Outdoor pigs had a higher blood neutrophil percentage and neutrophil:lymphocyte ratio than indoor pigs. The outdoor pigs also had decreased lymphocyte numbers compared to the indoor pigs. Brock (1993)

reported that lymphocyte and neutrophil numbers were not affected by iron deficiency; however, with iron overload, neutrophil activity was impaired. Chandra (1981) reported that iron deficiency impaired the numbers of lymphocytes and reduces neutrophil activity. Our results either did not confirm this hypothesis (if one assumes very high iron status among outdoor-reared pigs), or our pigs may not have shown excessive iron loading.

Outdoor pigs had lower NK activity than indoor pigs. Indoor pigs on each treatment level all had similar levels of NK cell activity. Outdoor pigs given 100 mg of iron had lower NK activity than all pigs on other treatments. Sherman and Lockwood (1987) reported that iron-deficient rats had significantly impaired splenic NK cell activity. However, our outdoor pigs were clearly not iron-deficient.

One might conclude that outdoor-reared pigs show signs of stress. Signs suggesting a stress response among outdoor pigs include decreased NK activity, increased percent of blood neutrophils, and increased an neutrophil:lymphocyte ratio. However, with increased gain and Hb concentrations, it seems unlikely that they were more than mildly stressed. That a lower microbial exposure may cause lower WBC numbers and lower NK activity is a more plausible explanation than that outdoor pigs showed signs of stress-induced immunosuppression. The outdoor pigs' immune status and performance are consistent with the segregated early weaning model that includes low microbial load and high performance in an early-weaned, stressed animal.

Implications

Production of weaned pigs outdoors is a viable alternative to traditional indoor production. Indoor and outdoor pigs generally had similar productivity. However, sow and pig productivity showed significant genotype \times environment interactions, suggesting that some genotypes may perform better indoors or outdoors. Outdoor pigs do not require supplemental iron to attain the same, or greater, blood hemoglobin concentrations. Differences in immune measures

among indoor and outdoor pigs require further study for both mechanisms and implications for practical pig production.

Literature Cited

- Brock, J. H. 1993. Iron and immunity. *J. Nutr. Immunol.* 2:47-106.
- Brown, J.M.E., S. A. Edwards, W. J. Smith, E. Thompson, and J. Duncan. 1996. Welfare and production implications of teeth clipping and iron injections of piglets in outdoor systems in Scotland. *Prev. Vet. Med.* 27:95-105.
- Chandra, R. K. 1981. Iron, immunity, and infection: Is there a casual link? *Food Nutr. Bull.* 3:49-52.
- Galán, P., M. Mekki, N. Hereberg, and S. Hereberg. 1988. Iron deficiency, inflammatory processes and humoral immunity in children. *Int. J. Vitam. Nutr. Res.* 58:225-230.
- Humbert, J. R., and L. L. Moore. 1983. Iron deficiency and infection: A dilemma. *J. Pediatr. Gastroenterol. Nutr.* 2:403-406.
- King, J.W.B. 1971. The interaction of genotype and environment in pig production. *Nottingham Univ. Easter School Agric. Sci. Programs.* 18:21-36.
- Lumpkin, E. A., and J. J. McGlone. 1992. A ^{51}Cr release assay for the determination of natural killer cell cytotoxicity. *J. Nutr. Immunol.* 1:63-74.
- Mayrose, V. B., A. Hogg, L. Phillips, and J. Phillips. 1988. Processing baby pigs. *Pork Ind. Handb.* 114:1-8.
- McGlone, J. J., J. L. Salak, E. A. Lumpkin, R. I. Nicholson, M. Gibson, and R. L. Norman. 1993. Shipping stress and social status effects on pig performance, plasma cortisol, natural killer cell activity, and leukocyte numbers. *J. Anim. Sci.* 71:888-896.
- Miller, E. R., and D. E. Ullrey. 1977. Baby pig anemia. *Pork Ind. Handb.* 34:1-4.
- Morrow-Tesch, J. L., J. J. McGlone, and J. L. Salak-Johnson. 1994. Heat and social stress effects on pig immune measures. *J. Anim. Sci.* 72:2599-2609.
- Pollmann, D. S., J. E. Smith, J. S. Stevenson, D. A. Schoneweis, and R. H. Hines. 1983. Comparison of gleptoferron with iron dextran for anemia prevention in young pigs. *J. Anim. Sci.* 56:640-644.
- Pond, W. G. 1959. Prevention of baby-pig anemia. *Cornell Exp. Stn. Bull.* 939:1-14.
- Sansom, B. F. 1984. The iron requirements of young pigs. *Pig Vet. Soc.* 11:67-75.
- SAS. 1988. *SAS User's Guide: Statistics (Version 5 Ed.)*. SAS Inst. Inc., Cary, NC.
- Sherman, A. R., and J. F. Lockwood. 1987. Impaired natural killer cells activity in iron-deficient rat pups. *J. Nutr.* 117:567-571.
- Thornton, K. 1990. *Outdoor Pig Production*. Farming Press, Ipswich, U.K.

Citations

This article has been cited by 2 HighWire-hosted articles:
<http://jas.fass.org#otherarticles>