Environmental effects on pig performance, meat quality, and muscle characteristics[1]

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ABSTRACT: The objective of this experiment was to determine the effect of diverse production systems on pig performance, muscle characteristics, and their relation to pork quality measures. Birth and rearing conditions were evaluated using 48 barrows during the fall/winter months. Pigs were farrowed in either indoor crates or outdoor huts. At weaning, indoor- and outdoor-born pigs were allotted randomly to treatments arranged in a 2 × 2 factorial design with two birth (indoor vs. outdoor) and rearing (indoor vs. outdoor) environments. Pigs housed indoors were on concrete-slatted flooring (1.2 m^2/pig), and pigs housed outdoors were on an alfalfa pasture (212 m^2/pig). Body weight data were collected. Muscle samples were removed within 1 h postmortem from the longissimus (LM) and semimembranosus (SM) muscles. Muscle samples were stained histochemically to identify type I, IIA, and IIB/X muscle fibers. Boneless loins were collected from the left side of each carcass and aged for 14 d. Objective and subjective color measurements were taken on the longissimus muscle at the 10th rib on d 14 postmortem. Loin chops were evaluated for sensory attributes, shear force, and retail display features. Pigs born outdoors were heavier and had a greater ADG at most growth intervals postweaning (d 28, 56, and 112; $P < 0.05$) than pigs born indoors. Pigs reared outdoors were heavier ($P = 0.02$) at d 140 (120.1 vs. 112.9 ± 4.9 kg), and had higher ($P = 0.01$) ADG (2.2 vs. 1.9 kg/d) and gain:feed ratios (0.41 vs. 0.37) than did pigs reared indoors. Birth × rearing environment interactions were not significant ($P > 0.10$) for most measures. Carcass and meat quality measures did not differ ($P > 0.05$) among treatment groups, but loin chops from outdoor born or reared pigs had higher ($P < 0.05$) a* values than chops from pigs born or reared indoors. The LM muscle of pigs born outdoors had a higher ($P < 0.01$) percentage of type I, and a lower ($P < 0.05$) percentage of type IIA fibers than did pigs born indoors. Pigs reared outdoors had a higher ($P < 0.01$) percentage of IIA fibers and a lower ($P < 0.05$) percentage of IIB/X fibers than did pigs reared indoors for the LM and SM muscles. Outdoor production systems may influence growth, pork color, and muscle fiber types.

Key Words: Environment, Meat Quality, Muscle Fibers, Pigs

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Introduction

Awareness of animal welfare issues and interest in niche retail marketing opportunities have contributed to increased interest in alternative production systems for livestock species. Many studies of housing system effects on pig performance and meat quality have yielded widely differing conclusions (Warris et al., 1983; Enfält et al., 1997; Sather et al., 1997).

Muscle fiber type percentages are influenced by environmental factors (Andersen and Henriksson, 1977; Petersen et al., 1997a), genetics (Ruusunen and Puolanne, 1997; Brocks et al., 1998), nutrition (Essén-Gustavsson and Jensen-Waern, 1993; Karlsson et al., 1994), and exercise (Petersen et al., 1998). The relationship between muscle fiber types and meat quality is not fully understood in pigs (Essén-Gustavsson and Jensen-Waern, 1993; Swatland, 1994), and muscle fiber type composition is highly variable (Lefaucher and Gerrard, 2000). Petersen et al. (1998) found that pigs' physical activity in large pens increased cross-sectional area of muscle fibers, but found no effect of physical activity

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on sensory quality of meat cuts from the ham and loin (Petersen et al., 1997a). Several researchers have determined that meat from pigs reared in outdoor pens had reduced tenderness (Warriss et al., 1983; Enfält et al., 1997), whereas others reported no differences in meat quality of pigs reared outdoors or indoors (Barton-Gade and Blaabjerg, 1989; Van der Wal, 1991; Jones et al., 1994). Therefore, the objective of this experiment was to determine the effects of diverse birth (outdoors on pasture with farrowing huts vs. indoors in crates) and rearing (outdoors on alfalfa pasture vs. indoors on slats) production systems on pig growth, meat quality, and muscle fiber type characteristics.

Materials and Methods

Animal Selection and Processing

Newsham barrows (Colorado Springs, CO; n = 48) were randomly selected from a group of pigs born indoors or outdoors that were weaned on the same day. Dams of pigs in the present study gestated indoors or outdoors. This birth environment refers to the system in which sows gestated and lactated and in which the pigs suckled. All pigs included in the study had a high health status and were porcine reproductive and respiratory syndrome negative. The production systems used in the present study were previously described in detail by Johnson et al. (2001). Littermates were weaned at 21 d and placed in one of the growing and finishing environments (indoors or outdoors). Pigs were allotted so that each pen comprised animals of similar average weaning weights.

Pigs were placed in one of two finishing environments: indoors on concrete slatted flooring (1.2 m^2/pig) or outdoors on an alfalfa pasture (212 m^2/pig and this finishing system was described by Gentry et al., 2002b). For the performance measures, four pens per finishing environment were used and six barrows were placed in each pen. Each pen consisted of three indoor-born and three outdoor-born pigs. All pens were equipped with a single three-hole feeder and a nipple waterer. Animals were afforded ad libitum access to a milo-soybean meal diet (starter: 43% milo, 26% SBM; finisher: 71% milo, 22% SBM, as-fed basis) that met, or exceeded, nutrient requirements (NRC, 1998). Feed disappearance (per pen) was measured throughout the experiment. Pigs were fed a starter ration up to 20 kg and then fed a series of five finishing diets. Feed and water were located on opposite ends of the long pens for the outdoor group, and pigs and feeders were weighed at weaning and 28, 56, 112, and 140 d postweaning on a common scale (Toledo Honest Weight 169371, Mettler Toledo, Inc., Columbus, OH). Animals were housed in accordance with the Guide for the Care and Use of Agriculture Animals in Agricultural Research and Teaching (FASS, 1999), and the Texas Tech University Animal Care and Use Committee approved the project.

Pigs were placed in their pens on October 31, 2000, and processed on one of four dates starting on March 20 and ending on April 4, 2001, at the Texas Tech University Meat Laboratory. For carcass and meat quality measures, four pigs/pen (two indoor-born and two outdoor-born) were processed (n = 32) at an average live weight of 115 kg. Pigs from each of the four treatment groups were processed on each of the four processing dates. The average air temperature for the outdoor pigs during the trial was 5°C (range: –3 to 15°C) and the relative humidity was 74% during the experiment. Indoor pigs were placed in a temperature-controlled building and temperatures did not decline below 18°C.

Sample Collection and Color Evaluation

Pigs were stunned using an electrical stunner (2 to 2.5 A and 250 to 300 V). Carcasses were chilled for 24 h to an internal temperature of 4°C or less, as measured in the center of the ham. Temperature and pH decline of the carcasses were measured at 1, 6, and 24 h postmortem in the area of the 10th and 11th ribs. Temperature was measured with a Hantover model TM99A-H digital thermometer with a 10-cm stem (Hantover, Atlanta, GA), whereas pH decline was monitored using an IQ Scientific 150 pH meter (IQ Scientific Instruments, Inc., San Diego, CA) with a stainless steel pH probe that housed a silicon chip sensor.

Carcass measurements collected in the cooler included midline backfat (first rib, last rib, and last lumbar vertebra) depths, carcass length, and ham muscle score (1 = thin, 2 = average, and 3 = thick). Carcasses were fabricated into wholesale cuts after 48-h chilling to determine the percentage of four leans cuts (Boston butt, picnic, loin, and ham) trimmed to 0.6 cm. The left side of each carcass was ribbed between the 10th and 11th ribs and allowed to bloom for 30 min. Color was evaluated at the 10th-rib interface on the longissimus muscle for Commission Internationale de l'Eclairage (CIE, Wien, Austria) L* (lightness), a* (redness), and b* (yellowness) values using a Minolta spectrophotometer (model CM-2002; Minolta Camera Co., LTD, Osaka, Japan) with illuminant D_{65} and a 1-cm diameter aperture. The instrument was calibrated according to manufacturer instructions before each use. Loins were deboned, vacuum-packaged in oxygen-impermeable bags (Cryovac Sealed Air Corp., Duncan, SC), and stored at 2°C until 14 d postmortem.

Color (1 = pale pinkish-gray to white to 6 = dark purplish-red), marbling (1 = devoid to 10 = moderately abundant, or greater), and firmness (1 = very soft and very watery to 5 = very firm and very dry) were assigned to each loin on d 14 postmortem by trained personnel (NPPC, 1999). A 2.5 × 2.5 cm sample was obtained from each loin, weighed, placed in a drip loss tube (meat juice containers; C. Christensen Laboratory, Hillerød, Denmark), and held at 2°C for 24 h. Then, samples were reweighed to determine percentage of drip loss. To measure purge loss, loins were removed from the package and allowed to air dry for 20 min. Any excess

moisture was removed with a paper towel. Loins were then reweighed, and the difference between pre- and postpackaged loin weights was divided by the prepackaged loin weight to determine purge loss percentage. Loins were subsequently cut into 2.5-cm-thick chops at d 14 postmortem, vacuum-packaged, and frozen at –40°C until shear force and sensory panel analysis were performed.

Sensory and Shear Force Analyses

Two chops from each loin were used for sensory and shear force determination. All chops were thawed overnight in a refrigerator to an internal temperature of 2 to 5°C, and cooked on a belt-grill (model TBG-60 Magigrill; MagiKitch'n, Inc., Quakertown, PA) to an internal temperature of 71°C (AMSA, 1995), as previously described (Gentry et al., 2002b). Cores were removed parallel to the muscle fiber orientation. Each core for shear force analysis was sheared once through the center with a United testing machine (model SSTM-500 with a tension attachment, United Calibration Corp., Huntington Beach, CA). Shear force values for each animal were determined by averaging the six cores (n = three from each chop). The remaining two cooked chops were cut into 1.3 × 1.3 × 2.5 cm pieces for sensory evaluation. Samples were served warm to a six- to eight-member panel selected and trained according to Cross et al. (1978). Panelists evaluated the samples on an eight-point scale for juiciness, tenderness, flavor intensity, pork flavor, and overall mouthfeel (8 = extremely juicy, tender, intense, and characteristic pork mouthfeel and 1 = extremely dry, tough, bland, unsavory, and uncharacteristic mouthfeel, respectively).

Retail Display

One chop from each pork carcass was placed on a tray and overwrapped with Reynolds 914 plastic wrap for display in a retail case for 4 d at 4°C. Two lamps, each containing two bulbs of 30 SPX and providing 1,000 lumens each, were placed over the retail case. The chops were randomly placed in the display case (model DGC6, Tyler Refrigeration Co., Niles, MI) and continually illuminated during the 4-d display period. Objective color (L*, a*, and b*) values were taken through the plastic wrapping initially, and then at 24-h intervals. A trained, six-member panel evaluated the chops each day for color (8 = extremely bright grayish pink and 1 = extremely dark grayish-pink), color uniformity (5 = extreme two-toning and 1 = uniform), surface discoloration (7 = 100% discolored and 1 = 0% discolored), and browning (6 = dark brown and 1 = none) according to AMSA (1991) guidelines.

Muscle Fiber Typing

Muscle samples were removed within 1 h postmortem from the longissimus muscle (**LM**) at the last rib location and semimembranosus (**SM**) just below the gracilis muscle. Samples were immediately cut into 1 × 1 cm pieces (parallel to the muscle fibers) and frozen in isopentane that was cooled using liquid nitrogen. Samples were stored in a –80°C ultracold freezer (Revco Ultima II, GS Laboratory Equipment, Asheville, NC) until analysis. Muscle samples were cut (12-μm-thick) on a cryostat (Leica CM 1800-3, Leica Instruments GmbH, Nussloch, Germany) at –20°C, and placed on silane-treated microscope slides. Sections were treated with an acid preincubation at pH 4.35 followed by an alkaline treatment at pH 7.8. Sections were treated with a combination histochemical staining procedure of reduced nicotinamide adenine dinucleotide-tetrazolium reductase for metabolic capacity and acid myofibrillar ATPase (Solomon and Dunn, 1988) to identify type I, IIA, and IIB/X muscle fiber types (Brooke and Kaiser, 1970). Samples were viewed using a Leitz (Wetzlar, Germany) diavert inverted phase contrast-fluorescence microscope with a magnification of 160×. Images were taken using a Spot 2 Slider (model 1.4.0, Diagnostic Instruments, Inc.) camera. At least 500 myofibers on four viewing frames per sample were counted for the determination of fiber type percentages. The percentage of each of the three fiber types (I, IIA, and IIB/X) was calculated by counting the total number of fibers, and then multiplying the quotient by 100. Cross-sectional area (**CSA**; μm^2) was calculated using IPLab scientific imaging software (Scanalytics, Inc., Fairfax, VA). Three sections were analyzed for each muscle sample. From each section, at least 10 muscle fibers/type (I, IIA, and IIB/X) were measured and then averaged for the determination of CSA.

Statistical Analyses

Data were analyzed using SAS (SAS Inst., Inc., Cary, NC). Growth and carcass data were analyzed as a completely randomized design, with a 2 × 2 factorial arrangement of treatments using GLM procedures of SAS with pen as the experimental unit. Birth and rearing environments and their interactions were the main plots and were evaluated against the replicate within treatment effect. Hot carcass weight and processing date were included as covariates in the analysis for all carcass measures. Retail display data were analyzed as repeated measures with pen variance used as the error term to test the main effects, and the treatment × display day interaction was tested using the residual error term. Least squares means were separated by a protected predicted difference test within SAS GLM procedures. For muscle fiber types, all data were expressed as percentages and were subjected to a square-root arcsine transformation to achieve a normalized distribution before ANOVA. Correlation coefficients were calculated to examine relationships between muscle fiber type percentages and meat quality measures.

Results

Growth Characteristics

Pigs born outdoors were heavier after 28 ($P = 0.04$), 56 ($P = 0.02$), and 112 ($P = 0.03$) d on feed than indoor-

Table 1. Performance traits of pigs born and reared either indoors or outdoors[a]

	Birth environment[b]		Rearing environment[c]			*P*-value[d]		
Measure	Indoor	Outdoor	Indoor	Outdoor	SEM	B	R	B × R
No. of pigs	12	12	12	12				
No. of pens	4		4					
Weaning weight, kg	8.4	7.6	8.0	8.0	1.05	0.25	0.95	0.91
28-d weight, kg	17.4	19.7	18.9	18.2	1.35	0.04	0.38	0.20
56-d weight, kg	32.0	36.9	34.2	34.7	2.40	0.02	0.69	0.26
112-d weight, kg	86.9	94.6	88.4	93.0	4.16	0.03	0.08	0.45
140-d weight, kg	116.9	116.2	112.9	120.1	4.86	0.82	0.02	0.60
ADG, kg/d	0.76	0.81	0.77	0.80	0.04	0.21	0.21	0.30
ADFI, kg/d	—	—	1.90	2.19	0.11	—	0.01	—
Gain:feed	—	—	0.41	0.37	0.04	—	0.01	—
Hot carcass weight, kg	87.5	87.8	84.9	90.4	3.64	0.87	0.01	0.35

[a]Pigs were housed outdoors from November until March.
[b]Pig birth environments: indoors (sows housed in farrowing crates) or outdoors (sows kept on pasture and farrowed in huts).
[c]Pig finishing environments: indoors on concrete slatted-flooring or outdoors on alfalfa pasture.
[d]*P* values for birth environment (B), rearing environment (R), and interaction effects (B × R).

born pigs, but 140-d live weight and ADG were not ($P = 0.21$) different between birth environments (Table 1). At the end of the finishing period (140 d), pigs reared outdoors were heavier ($P = 0.02$) and produced heavier ($P = 0.01$) hot carcass weights than pigs reared indoors. Even though there were no ($P > 0.20$) birth × rearing environment interactions for any performance trait (nor was there an effect ($P > 0.21$) of rearing environment on ADG), gain:feed (**G:F**) was lower ($P = 0.01$) for pigs finished outdoors compared to pigs finished indoors. The reduction in G:F is a direct effect of pigs reared outdoors having higher ($P = 0.01$) ADFI than pigs reared indoors.

Carcass Traits

Carcasses from outdoor-born pigs had greater ($P < 0.05$) backfat depths measured at the first and last ribs than indoor-born pigs; however, backfat depths did not ($P > 0.09$) differ between carcasses of outdoor- and indoor-reared pigs (Table 2). Pigs reared outdoors had similar ($P > 0.05$) backfat measurements to pigs reared indoors. A birth × rearing environment interaction was noted for backfat depths at the last rib ($P = 0.05$), with the greatest effect attributed to fat deposition during the birth environment. No differences ($P = 0.09$) were detected in carcass length, ham muscle score, longissimus muscle area, or percentage of four lean cuts between the main effects of pig birth and rearing environments.

Muscle Characteristics

Loin measurements, including muscle pH, temperature, and purge loss percentage were not ($P > 0.25$) different for the main effects of pig birth and rearing environments; however, loins from pigs born and reared outdoors were redder (higher a* value; $P = 0.03$ and 0.02, respectively) than those from pigs born and reared indoors (Table 2). Even though birth environment had no ($P = 0.96$) affect on marbling scores, loins from pigs reared indoors had more ($P = 0.05$) marbling than loins from pigs reared outdoors. Additionally, neither birth nor rearing environment impacted ($P > 0.13$) color and firmness scores or L* and b* values.

Loin Palatability and Retail Display

In the retail display case, Minolta a* values were higher ($P < 0.01$) for loin chops from pigs born outdoors compared with loin chops from pigs born indoors (Table 3). Yellowness (b*) values were higher ($P < 0.05$) for loin chops from outdoor-born pigs compared to loin chops from indoor-born pigs. Moreover, loin chops from pigs reared outdoors had higher a* values and lower visual color scores ($P < 0.05$) than chops from pigs reared indoors. Birth × rearing environment interactions were not significant for retail display measures. Differences were not ($P > 0.05$) detected between treatments for any sensory panel scores or shear force values for cooked loin chops (data not shown).

Muscle Fiber Types

Muscle cross-sections depicting three muscle fiber types (I, IIA, and IIB/X) from pigs reared either indoors or outdoors are illustrated in Figure 1. There were no ($P > 0.10$) birth × rearing environment interactions for muscle fiber type percentages. Although pigs born outdoors had a higher ($P < 0.01$) percentage of type I fibers and a lower ($P < 0.05$) percentage of type IIA fibers in the LM, pig birth environment did not ($P > 0.35$) affect muscle fiber type percentages in the SM (Table 4). Additionally, pigs finished in the outdoor environment had a higher ($P < 0.01$) percentage of IIA fibers and a lower ($P < 0.05$) percentage of IIB/X fibers in the LM and SM than pigs finished indoors.

Table 2. Carcass and loin measures of pigs born and reared either indoors or outdoors[a]

	Birth environment		Rearing environment			*P*-value[b]		
Measure	Indoor	Outdoor	Indoor	Outdoor	SEM	B	R	B × R
No. of pigs	8	8	8	8				
No. of pens	4		4					
First-rib backfat, cm	3.9	4.3	4.1	4.2	0.04	0.02	0.53	0.17
Last-rib backfat, cm	2.1	2.5	2.2	2.4	0.04	<0.01	0.10	0.04
Last lumbar backfat, cm	1.8	2.1	1.8	2.1	0.05	0.08	0.09	0.05
Loin muscle area, cm^2	43.5	40.2	42.7	40.9	0.32	0.17	0.55	0.99
Four lean cuts, %[c]	65.0	65.9	65.8	65.0	1.15	0.49	0.65	0.50
24-h pH	5.6	5.6	5.6	5.6	0.02	0.66	0.88	0.07
24-h temperature, °C	3.7	3.4	3.7	3.4	0.41	0.50	0.78	0.27
Purge, %	5.7	4.8	4.9	5.6	0.72	0.25	0.52	0.73
Color score[d]	2.8	2.9	2.7	3.0	0.22	0.69	0.34	0.34
Marbling score[e]	1.3	1.3	1.5	1.1	0.13	0.96	0.05	0.31
Firmness score[f]	3.0	2.9	3.0	2.9	0.21	0.69	0.72	0.51
Minolta L*[g]	47.3	47.8	47.9	47.2	1.50	0.73	0.77	0.89
Minolta a*[g]	3.2	4.3	3.0	4.6	0.42	0.03	0.02	0.08
Minolta b*[g]	12.1	13.3	12.0	13.4	0.62	0.13	0.13	0.29

[a]Hot carcass weight and processing date were included as covariates in this analysis.
[b]*P*-values for birth environment (B), rearing environment (R), and interaction effects (B × R).
[c]Four lean cuts was determined by weighing the Boston butt, picnic, loin, and ham trimmed to 0.6 cm.
[d]Color scores: 1 = pale, pinkish-gray to 6 = dark, purplish-red.
[e]Marbling scores: 1 = devoid to 10 = moderately abundant or greater.
[f]Firmness scores: 1 = very soft and watery to 5 = very firm and dry.
[g]L* values are a measure of darkness to lightness (higher L* value indicates a lighter color); a* values are a measure of the green to red spectrum (higher a* value indicates a redder color); and b* values are a measure of the blue to yellow spectrum (higher b* value indicates a more yellow color).

Pig birth environment had no ($P > 0.05$) effect on CSA (data not shown); however, pigs reared outdoors had larger ($P = 0.02$) CSA for type IIB/X fibers (7,065 vs. 5,992 ± 281 μm^2) than did pigs reared indoors (Figure 2). In the SM, type I and IIA CSA measurements from pigs finished outdoors were smaller (type I: 3516 vs. 4187 ± 130 μm^2; type IIA: 4237 vs. 5159 ± 271 μm^2; $P < 0.05$) than the SM from pigs finished indoors; however, no ($P > 0.05$) differences in CSA were detected for IIB/X fibers in the SM, nor was there any birth × rearing interactions detected for CSA, regardless of muscle.

Relationships between muscle fiber type percentages and pork quality measures were small (Table 5). A positive correlation was found between type I fiber percentage and a* ($r = 0.44$, $P < 0.05$) in the LM, indicating that as type I fiber numbers increased, a more red color was observed in the pork. A negative correlation was found between type I fibers (LM) and ultimate pH ($r = -0.46$, $P < 0.01$).

Discussion

Climatic conditions can play a significant role in pig performance in an outdoor production system. Researchers have reported that pigs finished indoors grew faster than pigs finished outdoors in both summer and

Table 3. Retail display characteristics of loin chops from pigs born and reared either indoors or outdoors

	Birth environment		Rearing environment			*P*-value[a]		
Measure	Indoor	Outdoor	Indoor	Outdoor	SEM	B	R	B × R
Color[b]	5.4	5.6	5.8	5.4	0.08	0.53	0.004	0.05
Uniformity[c]	1.4	1.6	1.4	1.6	0.11	0.15	0.32	0.21
Discoloration[d]	1.3	1.5	1.3	1.5	0.12	0.18	0.14	0.06
Browning[e]	1.3	1.5	1.3	1.5	0.10	0.18	0.13	0.08
Minolta L*	53.6	55.0	54.9	53.8	0.75	0.20	0.33	0.24
Minolta a*	4.2	5.0	4.2	5.0	0.15	0.004	0.003	0.64
Minolta b*	8.9	9.8	9.2	9.6	0.22	0.015	0.22	0.70

[a]*P*-values for birth environment (B), rearing environment (R), and interaction effects (B × R).
[b]Color scores: 1 = extremely dark grayish-pink to 8 = extremely bright grayish-pink.
[c]Uniformity scores: 1 = uniform to 5 = extreme two-toning.
[d]Discoloration scores: 1 = 0% discoloration to 7 = 100% discoloration.
[e]Browning scores: 1 = none to 6 = dark brown.

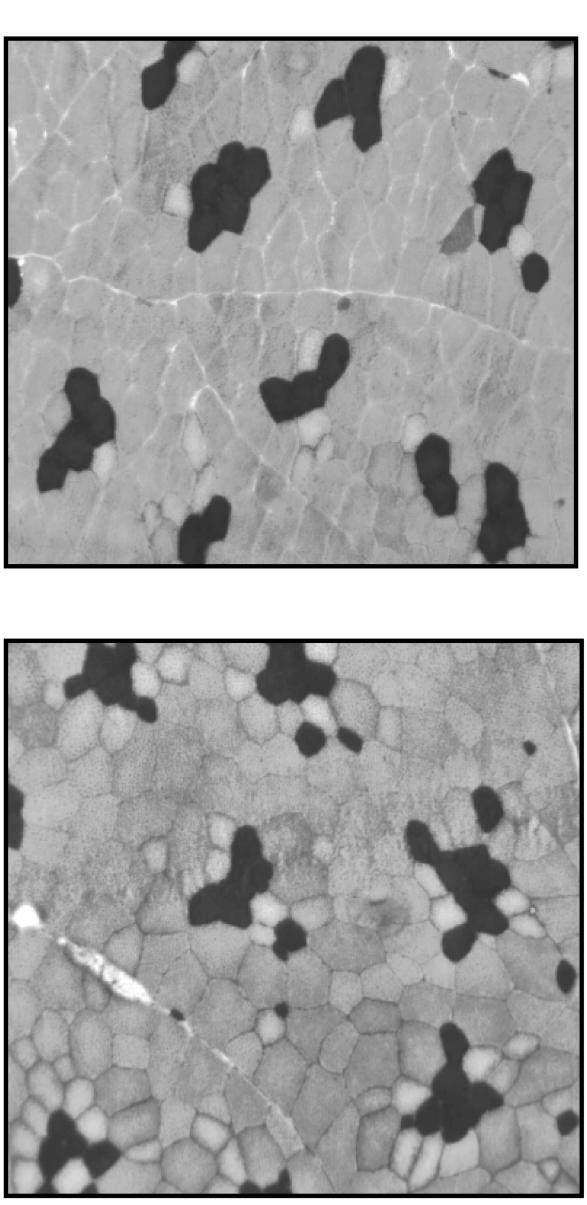

Figure 1. Photomicrograph of semimembranosus muscle from: (a) pig reared indoors and (b) pig reared outdoors. The dark-stained fibers are type I fibers (red, slow contracting, oxidative), the light gray fibers are type IIA fibers (intermediate, fast contracting, oxidative), and the darker-gray fibers are type IIB/X fibers (white, fast contracting, glycolytic).

winter seasons (Enfält et al., 1997; Sather et al., 1997). The present experiment was conducted during the winter months, and our laboratory has also reported positive performance results for pigs finished outdoors during the spring and summer months (Gentry et al., 2002b). Moreover, the outdoor climate evaluated in this experiment (generally mild and semiarid) may be more favorable than more northern climates evaluated by other researchers (Sather et al., 1997; Enfält et al., 1997).

Beattie et al. (2000) reported that pigs finished in enriched environments (3.5 m^2/pig, solid flooring with straw bedding) had greater growth rates during the last stage of finishing (15 to 21 wk) compared with pigs finished in a barren environment (0.76 m^2/pig, concrete slats). In agreement, pigs finished outdoors in this experiment also were heavier during the last month of the finishing period than pigs finished indoors.

Pigs reared in the outdoor pens had poorer G:F and higher ADFI. Factors including a cool climate and increased activity levels required to eat and drink, may have contributed to the reduced feed efficiency of the pigs reared outdoors. Feed efficiency was calculated considering only the supplied feed to the pigs, not the forage that may have been consumed in the outdoor environment and the pigs in the outdoor pasture consumed forage as well as the supplied feed.

We have determined that carcasses of pigs reared outdoors during the summer months had more backfat at the last rib than carcasses of pigs reared indoors (Gentry et al., 2002b). In this experiment, no differences were detected in backfat measurements for pig rearing environment when weight was held constant in the analysis. However, pigs born outdoors were fatter than pigs born indoors. Seasonal differences play a large part in fat deposition in an outdoor finishing system. Variation in climatic conditions between the present study and the previous study from our laboratory (Gentry et al., 2002b) may explain the lack of any treatment effects on last-rib backfat depth in the present study. Others have reported that outdoor-reared pigs had less backfat compared to pigs reared indoors (Warriss et al., 1983; Enfält et al., 1997), but these experiments did not examine the pig birth environment.

Birth and rearing developmental environments resulted in an advantage in pork color in this experiment and is in agreement with our previously reported work (Gentry et al., 2002b). When pigs were both born or finished outdoors, the pork was more red than was pork from pigs born indoors or reared indoors. Components (space, soil, or vegetation) of the diverse production system that caused the desirable increase in red color remains to be determined. In another experiment using indoor-born pigs, we evaluated the impact of spontaneous exercise on pig performance and muscle fiber characteristics (Gentry et al., 2002a). Increasing space allowance 10-fold in an indoor finishing facility did not result in any differences in pork color or muscle fiber types compared to muscle from pigs that were housed with the 0.9 m^2 space allowance. Perhaps the other factors, such as the outdoor birth environment and the presence of vegetation or ground cover, have more impact on pork color than increasing space allowance. Kleinbeck and McGlone (1999) documented that pigs produced outdoors do not require supplemental iron to attain the same, or greater, blood hemoglobin concentrations as indoor pigs. Blood hemoglobin levels were not measured in this study, but authors recognize that it is possible that pigs reared outdoors could have a

Table 4. Percentage of muscle fiber types from pigs born and reared either indoors or outdoors

	Birth environment[a]		Rearing environment[b]			*P*-value[c]		
Measure	Indoor	Outdoor	Indoor	Outdoor	SEM	B	R	B × R
Longissimus muscle, %								
Type I	17.3	21.5	19.3	19.4	0.83	0.01	0.84	0.11
Type IIA	16.0	12.7	12.4	16.4	0.91	0.04	0.01	0.84
Type IIB/X	66.7	65.8	68.3	64.2	1.18	0.57	0.02	0.15
Semimembranosus muscle, %								
Type I	17.1	18.4	17.0	18.5	1.17	0.46	0.34	0.59
Type IIA	20.6	18.8	15.7	23.6	1.21	0.35	0.01	0.17
Type IIB/X	62.3	62.8	67.3	57.9	0.93	0.77	0.01	0.15

[a]Pigs were born indoors in a farrowing crate or outdoors in a farrowing hut.
[b]Pigs were reared indoors on concrete-slatted flooring or outdoors on alfalfa pasture.
[c]*P*-values for birth environment (B), rearing environment (R), and interaction effects (B × R).

higher plasma iron content than pigs reared indoors in this study.

Researchers have reported no differences in pork eating quality measurements comparing pork from indoor- and outdoor-reared pigs (Barton-Gade and Blaabjerg, 1989; Van der Wal, 1991). However, Enfält et al. (1997) reported reduced tenderness and juiciness in the loin muscle of outdoor-reared pigs during the winter months. Muscle characteristics, including fiber type frequency, may be a source of variation in eating quality (Seideman et al., 1986; Karlsson et al., 1994; Koch et al., 1995). Maltin et al. (1997) examined muscle fiber type characteristics of longissimus muscle from pigs of eight major breeding stock companies and determined that variation existed in fiber size and fiber type among the populations of pigs. Those differences did not significantly contribute to differences in sensory quality measures, such as juiciness or pork flavor. In this experiment, no differences were found in sensory attributes or shear force of the loin between the treatments evaluated. Because we did not measure color or eating quality traits of the ham in this experiment, future research examining color and sensory qualities of ham, particularly cured ham products, should be conducted to further understand environmental effects on pork color.

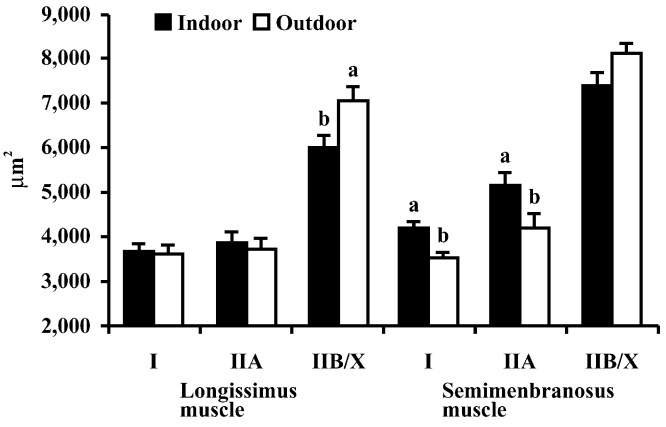

Figure 2. Cross-sectional area (CSA) of muscle fiber types from pigs reared either indoors on concrete slatted flooring or outdoors on alfalfa pasture. Significant effects were observed in the following muscle fiber types: longissimus muscle type IIB/X: $P = 0.02$; semimembranosus muscle type I: $P = 0.003$; semimembranosus muscle type IIA: $P = 0.02$).

Pigs are born with a predominance of type I (darker red) fibers and, as they develop, fibers shift to type IIA and IIB/X fibers. In general, increased activity leads to a shift of muscle fibers from IIB to IIX to IIA to I, and decreased activity levels lead to a reverse of this pathway (Lefaucheur and Gerrard, 2000). Previous literature suggests that spontaneous activity significantly increased the ratio of type IIA to IIB/X fibers in longissimus muscle (Petersen et al., 1998), but the chemical composition of the meat was not altered (Lewis et al., 1989; Enfält et al., 1997; Petersen et al., 1997b) by increased exercise. Fitts et al. (1976) determined that exercise training during a 7-mo period had no effect on muscle or body composition of miniature pigs. However, muscle fiber adaptations during exercise training are not comparable with effects of spontaneous exercise occurring in outdoor or free-range systems (Petersen et al., 1997a).

At processng, pigs born outdoors in this experiment had more type I and less IIA fibers in the LL than pigs born indoors. Furthermore, pigs reared outdoors had more type IIA and less IIB/X fibers in both muscles (LM and SM) than did pigs reared indoors, indicating an effect of pig finishing environment on muscle fiber type development. Pigs reared outdoors produced pork that had a higher a* value (redder color) compared with pork from pigs reared indoors. Outdoor rearing may delay or prevent the shift in muscle fibers from type IIA to type IIB/X.

For both the LM and SM muscles, pigs reared outdoors had more IIA fibers and less IIB/X fibers than pigs reared indoors, which may have been influenced

Table 5. Simple correlation coefficients between muscle fiber type percentages and loin muscle quality measures

	Longissimus muscle			Semimembranosus muscle		
Measure	Type I	Type IIA	Type IIB/X	Type I	Type IIA	Type IIB/X
Minolta L*	0.02	–0.01	–0.01	0.18	–0.16	0.04
Minolta a*	0.44*	–0.10	–0.27	0.26	0.10	–0.25
Minolta b*	0.29	0.04	–0.27	0.27	0.04	–0.20
Ultimate pH	–0.46**	0.14	0.26	–0.19	0.15	–0.03
Shear force	–0.34	0.01	0.26	0.01	–0.03	0.02
Initial tenderness	–0.06	0.05	0.01	–0.09	0.07	–0.01
Sustained tenderness	–0.13	0.12	0.01	–0.08	–0.01	0.05
Initial juiciness	–0.01	0.09	–0.07	0.06	–0.24	0.18
Sustained juiciness	0.06	0.06	–0.10	0.05	–0.22	0.17
Flavor intensity	–0.35	–0.01	0.28	–0.18	–0.04	0.14

*$P < 0.05$.
**$P < 0.01$.

by increased spontaneous exercise for pigs finished in the larger pens (Gentry et al., 2002a). These results are in agreement with Jurie et al. (1998), who reported that bulls housed loose (vs. tied) had a higher percentage of IIA fibers and a lower percentage of IIB/X fibers in the semitendinosus muscle. Petersen et al. (1998) also demonstrated that pigs reared in large pens with spontaneous activity (36-m^2 pens, 40 pigs/pen) had more IIA and fewer IIB/X, fibers than pigs reared either individually with a 2.5-m^2 space allowance or individually with treadmill training (5 d/wk for 70 d). Increased exercise levels associated with loose housing of animals may result in a slower conversion of IIA to IIB/X fibers in muscle, because type IIB/X fibers are larger in diameter (Ashmore, 1974; Miller et al., 1975). A slower conversion rate of type II fibers could result in an advantage in meat tenderness; however, no differences in tenderness were detected in this experiment.

Values for the percentage of myofibers reported in our experiments were similar to those previously reported (Solomon et al., 1990; Lefaucheur et al., 1991; Larzul et al., 1997). Several histochemical methods for the identification of muscle fiber types have been reported in the literature. There is a lack of uniformity in the classification, and this is caused mainly by the lack of correspondence between type II subgroups (Nemeth et al., 1979; Green et al., 1982). Because of this lack of uniformity, it is difficult to compare fiber type results of different studies. Brocks et al. (1998) determined that a combination of ATPase (after acid preincubation at pH 4.6) and succinate dehydrogenase staining separated type II fibers into three clearly distinguishable groups. Fiber types were separated into only two subgroups (type IIA and type IIB/X) in our experiment.

Larzul et al. (1997) determined that phenotypic correlations of muscle fiber composition to other traits were low. They suggested that selection for a decreased percentage of IIB/X fibers would result in decreased cross-sectional area of the muscle fibers, which may lead to improved meat quality by decreasing the rate and extent of postmortem pH decline in the longissimus muscle. Correlations between muscle fiber type percentages and loin color, pH, water-holding capacity, shear force, and sensory panel scores were low in the present experiment. Overall, the relationships between muscle fiber type percentages and loin muscle characteristics were variable. Research is needed to provide a better understanding of the physiological mechanisms of muscle fiber types and to explain the conflicting results in studies that have been reported thus far.

Implications

Suckling pig birth environment plays a significant role in growth throughout the finishing period. Although all the pigs produced in the indoor system had acceptable performance and pork quality measures, outdoor pig production was a suitable alternative. When using an outdoor finishing system as described in this paper, one can expect similar growth rates and pork quality of loins compared to more conventional production systems. The opportunity to improve pork color, without altering palatability attributes, may be found by providing more quantity or quality of space during the neonatal and/or finishing periods.

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