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Diverse birth and rearing environment effects on pig growth and meat quality[1]

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ABSTRACT: Birth and rearing conditions were evaluated for their effects on pig growth, body composition, and pork quality using 48 barrows during the spring and summer months. Pigs were either farrowed in indoor crates or outdoor huts. At weaning, indoor-born and outdoor-born pigs were randomly allotted to indoor or outdoor treatments for growing/finishing. Body weight data were collected. Pigs were transported 5 h to a commercial processing plant, allowed 2 h of rest, and then processed as a group under commercial conditions. 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 greater ADG at all growth intervals after weaning (d 28, 56, 112, and final weight, $P < 0.05$) than pigs born indoors. Outdoor-born pigs had heavier carcass weights (91.2 vs 81.3 ± 3.4 kg, $P < 0.001$), larger loineye areas (54.6 vs 49.7 ± 0.2 cm^2, $P < 0.05$), and higher pork flavor intensity scores (6.5 vs 6.1 ± 0.10, $P < 0.01$) than indoor-born pigs. Birth × rearing environment interactions were not significant for most measures. Backfat measurements at the last rib were greater (3.2 vs 2.8 ± 0.05 cm, $P < 0.05$) for the pigs reared outdoors than for the pigs reared indoors. Pigs finished outdoors had more reddish pink color scores, lower shear force values, and lower L* values, indicating darker-colored pork, compared with pigs finished indoors ($P < 0.05$). Pig birth environment played a significant role in improving growth rates of outdoor-born pigs and increasing pork flavor intensity scores of loin chops from pigs born outdoors. Finishing pigs outdoors may improve pork color and tenderness but also may increase backfat thickness when they are fed conventional diets.

Key Words: Environment, Meat Quality, Pigs, Pork

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Introduction

Intensive outdoor pig production systems have been considered in recent years in some parts of the world. These alternatives to traditional slatted-floor indoor systems may become more common as environmental or animal welfare regulations become more intense. Outdoor pig production systems have lower capital costs, which can vary from 40 to 70% of the cost for conventional indoor systems (Thornton, 1988), but currently fewer than 6% of the pigs finished in the United States are housed on pasture or dirt pens (USDA, 2001). Awareness of animal welfare issues and interest in niche retail marketing opportunities has contributed to increased interest in alternative production systems.

Many studies of housing system effects on pig performance and pork quality have yielded widely differing conclusions. Researchers determined that pigs finished outdoors had less backfat than pigs finished indoors (Warriss et al., 1983; Enfält et al., 1997; Sather et al., 1997). Beattie et al. (2000) determined that pigs finished in an enriched environment had higher growth rates and more backfat than pigs finished on concrete slats. Some researchers determined that meat from pigs reared outdoors had reduced water-holding capacity, lower ultimate pH, and(or) higher shear force values than meat from pigs reared indoors (Barton-Gade and Blaabjerg, 1989; Enfält et al., 1997), whereas others reported no commercially important differences in meat quality of pigs reared outdoors compared to pigs reared indoors (van der Wal, 1991; van der Wal et al., 1993; Sather et al., 1997). To date, the effects of diverse birth

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and rearing environments on pig growth and pork quality have not been carefully or completely examined.

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 pastures vs indoors on slats) production systems on pig growth, meat quality, and retail display characteristics.

Materials and Methods

Animal Selection and Processing. Newsham (Colorado Springs, CO) barrows (n = 48) were randomly selected from a group of pigs born indoors or outdoors that were weaned on the same day. Newsham is a white-line breeding female containing Yorkshire, Landrace, and Duroc breeds. The Newsham sire is a crossbred, dark-skinned sire. The barrows' dams had gestated indoors or outdoors. This birth environment refers to the system in which sows gestated and lactated and in which the pigs suckled. The indoor and outdoor systems were recently described by Johnson et al. (2001). Pigs were from a herd that has a high health status and is PRRS-negative. Littermates were weaned at 21 d and placed in each of the growing and finishing environments (indoors or outdoors). Pigs were allotted so that each pen consisted of animals with 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). Four pens per finishing environment were used and six barrows were placed in each pen (n = 48). Each pen consisted of three indoor-born pigs and three outdoor-born pigs. All pens had one three-hole feeder and one nipple waterer. Feed and water were located on opposite ends of the long pens for the outdoor group. Pigs were placed on trial on February 25, 2000, and were slaughtered on July 19, 2000. 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. The average air temperature for the outdoor pigs during the trial was 19°C and the percentage relative humidity was 53.6 during the trial. Indoor pigs were placed in a temperature-controlled building in which temperatures did not fall below 18°C. Pigs were weighed at weaning and at 28, 56, 112, and 143 d after weaning on a common scale (Toledo Honest Weight 169371, Mettler Toledo, Columbus, OH). Animals were given ad libitum access to a milo-soybean meal diet that met nutrient requirements (NRC, 1998). Feed intake (per pen) was measured throughout the experiment. All animals were slaughtered on the same day at a common live weight of approximately 114 kg. Pigs were transported for 5 h to the packing plant and allowed to rest for 2 h before slaughter. Animals were slaughtered using commercial practices in Guymon, OK.

Sample Collection and Loin Measurements. Temperature and pH decline of the carcasses were measured at 1, 6, and 24 h postmortem the 10th and 11th rib interface. Temperature was measured with a Hantover Model TM99A-H Digital Thermometer with a 10-cm stem (Hantover, Atlanta, GA). The pH decline was monitored using an IQ Scientific 150 pH meter (IQ Scientific Instruments, San Diego, CA) with a stainless steel pH probe that housed a silicon chip sensor.

Carcass measurements collected in the cooler included backfat (first rib, last rib, and last lumbar vertebra), carcass length, and ham muscle score (1 = thin, 2 = average, and 3 = thick). After 24 h of chilling, the carcasses were fabricated into wholesale cuts. Loins were cut into boneless loins (Institutional Meat Purchasing Specification No. 413), vacuum-packaged in a plastic Cryovac bag (Cryovac Sealed Air Corp., Duncan, SC), and transported under refrigeration to the Texas Tech University meat laboratory for further analysis. Loins were stored at 2°C until d 14 postmortem. Loin color was evaluated at 14 d postmortem at the 10th rib interface for Commission Internationale de l'Eclairage (CIE, Wien, Austria) L* (muscle lightness), a* (muscle redness), and b* (muscle yellowness) values devised in 1976 by CIE using a Minolta Spectrophotometer Meter model CM-2002 with a D_{65} illuminant with a 1-cm-diameter aperture (Minolta Camera Co., LTD, Osaka, Japan). L* values range from 1 to 100 (1 = pure black and 100 = pure white). Minolta a* values represent the amount of red to green colors and a higher value indicates a redder color. Minolta b* values represent the amount of blue to yellow color and a higher b* value indicates a more yellow color. Visual color, marbling, and firmness scores were also assigned to each loin by trained personnel that were blind to the treatment groups (NPPC, 1999). Color was scored on a 6-point scale with 6 = dark purplish-red, 3 = reddish-pink, and 1 = pale pinkish-gray to white. Marbling scores were assigned on a 10-point scale where 10 = moderately abundant or greater and 1 = devoid. Firmness was scored on a 5-point scale where 5 = very firm and dry, 3 = slightly firm and moist, and 1 = very soft and very watery. A core sample (2.5 × 2.5 cm) was obtained from the loin to determine drip loss. Samples were weighed, placed in a drip loss tube (meat juice containers, C. Christensen Laboratory, Denmark), and held at 2°C for 24 h. Samples were reweighed at 24 h to determine percentage drip loss. Loin purge was determined by weighing the vacuum-packaged loin. The loin was then 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 to determine purge loss. Loins were cut into 2.5-cm chops at d 14 postmortem for shear force and sensory analysis. Chops were vacuum-packed and frozen at −40°C until further analysis. A sample from each loin was analyzed to determine the percentage of moisture, fat, and protein using AOAC (1990) approved methods.

Sensory and Shear Force Analyses. Chops from each loin (n = two per analysis) 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 then cooked on a belt grill (Model TBG-60 Magigrill, MagiKitch'n, Quakertown, PA) to an internal temperature of 71°C (AMSA, 1995). The belt grill settings (top heat and bottom heat = 163°C, preheat = disconnected, height = 0.3 cm, and cook time = 5.4 min) were set to reach an internal temperature of 71°C. The final internal temperature was recorded with a needle thermocouple meat thermometer (Model #91100, Cole-Parmer, Vernon Hills, IL). The chops for shear force analysis were cooled to room temperature, wrapped with polyvinyl chloride film to prevent dehydration, and stored overnight at 2°C (AMSA, 1995). Three 1.3-cm-diameter cores were removed parallel to the muscle fiber orientation from each chop for shear force determination. Each core was sheared once through the center with a United Testing Machine (Model #SSTM-500 with a tension attachment, United Calibration Corp., Huntington Beach, CA). The crosshead speed was set at 200 mm/min as suggested from previous literature (AMSA, 1995; Wheeler et al., 1997). Shear force values for each animal were determined by averaging the six cores (n = 3 for each chop). The other two cooked chops were cut into 1.3- × 1.3- × 2.5-cm pieces for sensory evaluation. Samples were served warm to an eight-member panel selected and trained according to Cross et al. (1978). Panelists evaluated the samples on an 8-point scale for juiciness, tenderness, flavor intensity, pork flavor, and overall mouthfeel (8 = extremely juicy, tender, intense, and characteristic pork mouthfeel; 1 = extremely dry, tough, bland, unsavory, and uncharacteristic mouthfeel, respectively). The samples were served under red lights to mask color differences. The panelists were served water and apple juice to rinse their palates between samples. Individual panelist scores were averaged and mean scores from each sample were used for the statistical analysis.

Retail Display. One chop from each animal was placed on a tray and overwrapped with Reynolds 914 saran 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 lm 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. CIE L*, a*, and b* values were taken initially and at 24-h intervals over the saran wrapping on the loin chop. 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).

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. The pen was the experimental unit. Birth and rearing environments and their interaction were the main plots and were evaluated against the replicate within treatment effect. Retail display data were analyzed as repeated measures over time. Treatment by time was tested using the residual error term. Least squares means were separated by a protected predicted difference test within SAS GLM procedures.

Results

Growth Characteristics. Birth × environmental interactions were not significant for growth measures. Outdoor-born pigs were heavier ($P < 0.05$) than indoor-born pigs when weighed at d 28, 56, 112 and at the final weighing (Table 1). Final weights for indoor- and outdoor-born groups were 112.5 and 124.4 kg, respectively, and the outdoor-born pigs reached a heavier ($P < 0.05$) end weight than the indoor-born pigs. Rearing environment did not affect pig growth. Pigs finished outdoors had a lower ($P < 0.05$) gain:feed ratio than pigs finished indoors. No differences were detected in ADFI of pigs in the two rearing environments. Outdoor-born pigs had a greater ($P < 0.05$) ADG and heavier ($P < 0.05$) hot carcass weights than indoor-born pigs.

Carcass Traits. Pig birth environment did not affect backfat measurements, carcass length, or ham muscle scores (Table 2). Outdoor-born pigs had larger ($P < 0.05$) loineye measurements (54.6 vs 49.7 ± 0.21 cm^2) than indoor-born pigs. Larger loineyes from the outdoor-born pigs may have contributed to the heavier carcass weights of the outdoor-born pigs. When hot carcass weight was included in the model as a covariate, no differences in loineye area were detected between the birth environment treatments.

Pigs reared outdoors from weaning to finishing had hot carcass weights, loineye areas, and first rib backfat measurements similar to those of pigs reared indoors. However, last rib backfat measurements were greater ($P < 0.05$) for pigs reared outdoors (3.2 vs 2.8 ± 0.05 cm) than for pigs reared indoors.

Muscle Characteristics. No differences were detected in loin pH, purge, or drip loss between the birth and rearing main effects (Table 2). Loins from indoor-born pigs had a higher ($P < 0.05$) temperature measured 1 h postmortem than loins from outdoor-born pigs. Outdoor-born pigs had a higher loin temperature at 6 and 24 h postmortem than indoor-born pigs ($P < 0.05$).

Visual color, marbling, and firmness scores of the loin were not different between the groups born indoors and those born outdoors. Minolta a* values were 1.4 and 2.4 ± 0.23 for the indoor- and outdoor-born groups, respectively. Loins from the outdoor-reared pigs had higher ($P < 0.05$) a* values than loins from the indoor-reared pigs. Minolta b* values were 10.21 and 10.94 ± 0.19 for the indoor-born and outdoor-born groups, respectively. Loins from outdoor-born pigs were redder

Table 1. Growth traits of 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
No. of pigs	24	24	24	24				
Weaning wt, kg	9.1	9.0	9.0	8.9	1.00	0.89	0.93	0.47
28-d wt, kg	19.2	23.8	21.4	21.1	2.40	0.01	0.85	0.68
56-d wt, kg	39.0	45.7	42.7	41.2	4.63	0.04	0.62	0.92
112-d wt, kg	87.3	98.4	90.0	93.8	3.95	0.01	0.16	0.10
Final wt, kg (d 143)	112.5	124.4	115.4	119.0	5.33	0.01	0.31	0.31
ADG, kg/d	0.72	0.81	0.74	0.77	0.03	0.01	0.24	0.31
ADFI, kg/d	—	—	2.0	2.0	0.06	—	0.56	—
G:F Ratio	—	—	0.37	0.35	0.003	—	0.02	—
Hot carcass wt, kg	81.3	91.2	83.5	87.2	3.37	0.01	0.11	0.07

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

($P < 0.05$) and more yellow ($P < 0.05$) in color than loins from the indoor-born group. Figures 1 a, b, and c include the simple effects of L*, a*, and b* values of pork loins for the treatment least squares means.

Visual color scores of the loin were higher ($P < 0.05$) for the outdoor-reared pigs (3.5 vs 3.0 ± 0.10) than for the indoor-reared pigs (Table 2). Minolta L* values were lower ($P < 0.05$) for loin chops from pigs reared outdoors than for loin chops from pigs reared indoors. Loins from the outdoor finished pigs were darker in color, as indicated by the color scores and L* values. There were no significant differences in a* or b* values between the

Table 2. Carcass traits of 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
No. of pigs	24	24	24	24				
First rib backfat, cm	3.8	3.7	3.8	3.7	0.05	0.29	0.71	0.07
Last rib backfat, cm	2.5	3.1	2.8	3.6	0.05	0.10	0.04	0.66
Last lumbar backfat, cm	2.5	2.8	2.7	2.7	0.05	0.10	0.75	0.61
Carcass length, cm	76.6	86.2	81.5	81.3	1.45	0.08	0.96	0.95
Ham muscle score[d]	3.3	2.2	2.4	3.1	0.57	0.47	0.35	0.48
Loin measurements								
Loineye area, cm^2	49.7	54.6	51.3	52.9	0.21	0.02	0.41	0.71
1-h temperature, °C	39.0	38.4	38.6	38.8	0.18	0.04	0.54	0.99
6-h temperature, °C	3.3	5.5	4.1	4.7	0.42	0.01	0.37	0.27
24-h temperature, °C	0.61	0.9	0.75	0.8	0.07	0.02	0.93	0.06
1-h pH	6.4	6.5	6.5	6.4	0.07	0.19	0.21	0.43
6-h pH	6.1	6.1	6.1	6.1	0.02	0.67	0.08	0.32
24-h pH	5.8	5.7	5.7	5.8	0.04	0.10	0.68	0.35
Drip loss, %	0.6	0.4	0.4	0.7	0.08	0.06	0.22	0.30
Purge, %	3.1	3.2	3.4	3.0	0.29	0.91	0.35	0.24
Color score[e]	3.1	3.4	3.0	3.5	0.10	0.09	0.01	0.35
Marbling score[f]	2.3	2.7	2.5	2.5	0.16	0.18	0.82	0.27
Firmness score[g]	3.1	3.3	3.2	3.2	0.09	0.38	0.77	0.77
Minolta L*[h]	49.5	49.2	50.5	48.1	0.50	0.70	0.01	0.28
Minolta a*[i]	1.4	2.4	1.6	2.2	0.23	0.01	0.06	0.83
Minolta b*[j]	10.2	10.9	10.5	10.7	0.19	0.02	0.58	0.64

[a]Pig birth environments: indoors (sows housed in farrowing crates) or outdoors (sows kept on pasture, farrowed in huts).
[b]Pig finishing environments: indoors on concrete slatted-flooring or outdoors on alfalfa pasture.
[c]*P*-values for birth environment (B), rearing environment (R), and interaction effects.
[d]Ham muscle scores are 1 = thin, 2 = average, and 3 = thick.
[e]Color scores range from 1 to 6, 1 = pale, pinkish gray and 6 = dark, purplish red.
[f]Marbling scores range from 1 to 10, 1 = devoid and 10 = moderately abundant or greater.
[g]Firmness scores range from 1 to 5, with 1 = very soft and very watery and 5 = very firm and very dry.
[h]L* values range from 1 to 100 with 1 = pure black and 100 = pure white.
[i]a* values represent the amount of red to green colors and a higher value indicates a redder color.
[j]b* values represent the amount of blue to yellow color in the meat and a higher b* value indicates more yellow.

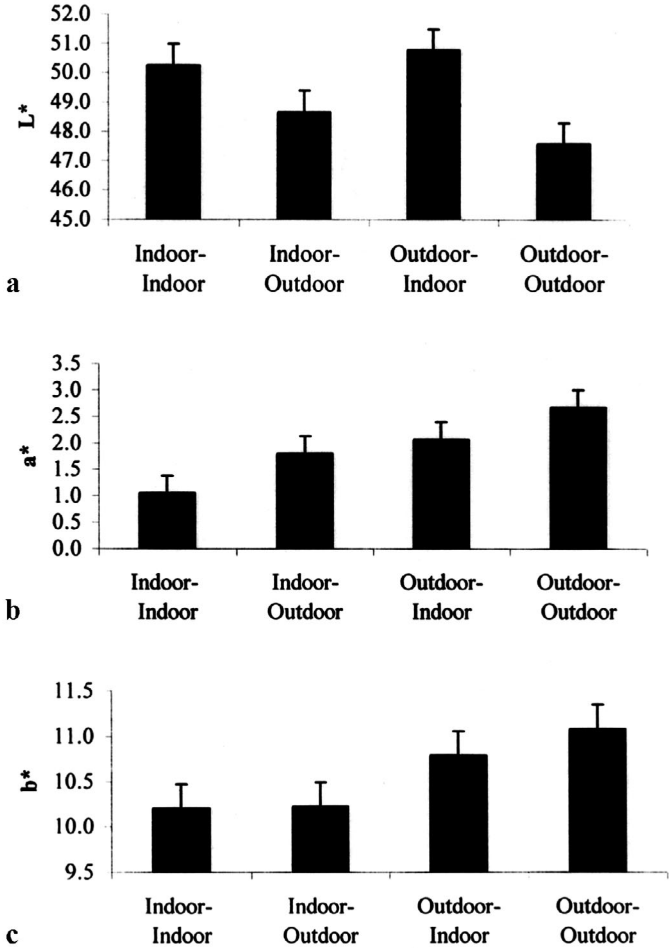

Figure 1. Objective color patterns from sampled pork listed by simple effects of pig birth (top line) and rearing environment. (a) L* values, (b) b* values, and (c) a* values (n = 11 or 12 loins/treatment). Birth environment effect ($P < 0.05$) for a* and b*, rearing environment effect ($P < 0.01$) for L*.

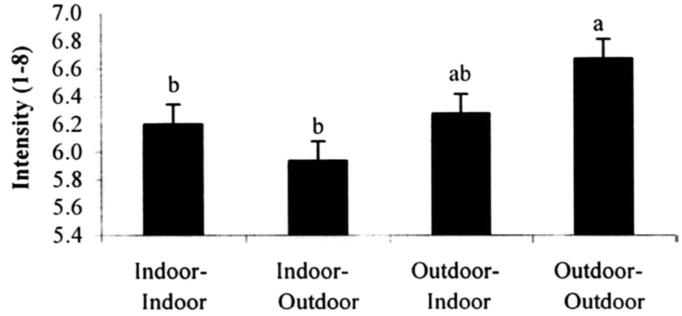

Figure 2. Flavor intensity of pork loin chops categorized by pig birth (top line) and rearing environments (n = 11 or 12 chops/treatment). Means are simple effects. Pork flavor intensity score 1 = extremely bland and 8 = extremely intense pork flavor intensity. ^{a,b}Means with different superscripts differ ($P < 0.05$).

rearing environment treatments. No differences were detected in the percentage of moisture, fat, or protein between the birth and rearing environment treatments (data not shown).

Loin Palatability. Listed in Table 3 are least squares means for sensory and shear force values by pig birth and rearing environments. No differences were detected in juiciness or tenderness scores of pork from the indoor-born and outdoor-born pigs in sensory panel evaluations. Means for pork flavor intensity for the indoor-born and outdoor-born pigs were 6.1 and 6.5 ± 0.10, respectively. Loins from outdoor-born pigs scored higher ($P < 0.05$) for pork flavor intensity than loins from the indoor-born pigs. Pork flavor intensity scores listed by simple effects are presented in Figure 2. Loin chops from the outdoor-born/outdoor-reared pigs had higher ($P < 0.05$) scores for flavor intensity than chops from the indoor-born/indoor-reared and indoor-born/outdoor-reared groups. Backfat was included in a preliminary analysis as a covariate to determine the effects of fat on flavor intensity. Backfat did not have a significant effect on flavor intensity and therefore was not included as a covariate in the final analysis.

No difference was detected in any of the sensory panel scores for pig rearing environment effects. Shear force values were greater ($P < 0.05$) for the indoor-finished group than for the outdoor-finished group (2.2 and 2.0 ± 0.06, respectively). Shear force values listed by simple effects are presented in Figure 3. Outdoor-reared pigs had more ($P < 0.05$) tender pork; however, both means were acceptable in pork tenderness and no differences were detected in sensory panel tenderness scores.

Retail Display. Birth × rearing environmental interactions were not significant for retail display features. Differences in retail display characteristics for pig birth and rearing main effects were observed and are given in Table 4. Visual color scores were higher ($P < 0.05$) for chops from pigs born indoors than for chops from pigs born outdoors, which is a lighter and more brightly colored chop. Chops from outdoor-born pigs had higher ($P < 0.05$) a* values during the 4-d display period and higher b* values on d 1 and 4 than chops from indoor-born pigs.

Objective color measurements of the loin muscle were greater ($P < 0.05$) for indoor-reared pigs than for outdoor-reared pigs, indicating a more brightly colored pork chop. Color scores were greater ($P < 0.05$) for the indoor-reared group throughout the 4-d retail case period. No differences were found in color uniformity until d 3 of the trial. On d 3, the chops from the outdoor-reared group had more ($P < 0.05$) two-toning than chops from the indoor-reared group. Discoloration scores for the groups were similar during the first 2 d of the trial. On d 3, chops from outdoor-reared pigs had more ($P < 0.05$) discoloration than chops from the indoor-reared pigs. On d 4, chops had discoloration scores of 2.6 and 2.2 ± 0.10 ($P < 0.05$) for the indoor-reared and outdoor-reared groups, respectively. No differences between the groups were observed in browning scores throughout the 4-d period. L* values were higher ($P < 0.05$) for the

Table 3. Sensory and shear force values of longissimus muscle listed by pig birth and rearing environments

	Birth environment[a]		Rearing environment[b]			*P*-value[c]		
Measure	Indoor	Outdoor	Indoor	Outdoor	SEM	B	R	B × R
No. of loins	23	22	22	23				
Initial juiciness[d]	6.2	5.9	6.1	6.1	0.11	0.10	1.00	0.29
Sustained juiciness[d]	6.2	6.2	6.2	6.2	0.11	0.59	0.83	0.09
Initial tenderness[d]	6.1	6.2	6.0	6.4	0.15	0.65	0.10	0.96
Sustained tenderness[d]	6.2	6.3	6.1	6.5	0.14	0.58	0.09	0.77
Pork flavor intensity[d]	6.1	6.5	6.2	6.3	0.10	0.01	0.65	0.03
Pork flavor[d]	6.3	6.6	6.4	6.5	0.11	0.06	0.56	0.05
Overall mouthfeel[d]	6.0	6.2	6.0	6.2	0.14	0.47	0.26	0.42
Off-flavor[e]	1.0	1.0	1.0	1.0	0.01	0.24	0.55	0.55
Shear force, kg	2.1	2.1	2.2	2.0	0.06	0.53	0.04	0.07

[a]Pig birth environments: indoors (sows housed in farrowing crates) or outdoors (sows kept on pasture, farrowed in huts).
[b]Pig finishing environments: indoors on concrete slatted-flooring or outdoors on alfalfa pasture.
[c]*P* values for birth environment (B), rearing environment (R), and interaction effects.
[d]Sensory panel scores for initial and sustained juiciness, initial and sustained tenderness, flavor intensity, pork flavor, and overall mouthfeel range from 1 to 8 with 1 = extremely dry, tough, bland, unsavory, and uncharacteristic mouthfeel, and 8 = extremely juicy, tender, intense, savory, and characteristic mouthfeel.
[e]Scores for off-flavor are 1 = no off-flavor 5 = extreme off-flavor.

indoor-reared group on each day during the 4-d trial. Loin chops from the indoor-reared pigs were lighter in color and also had lower a* values. The a* values were higher for the outdoor-reared group, which is a redder pork chop.

Discussion

Pigs born outdoors clearly grew faster. We did not anticipate finding an advantage in growth rates due to an outdoor birth environment. This finding led us to hypothesize that the 3-wk period from birth to weaning played a significant role in the development of muscle and other tissues of these pigs. The outdoor environment has many components and some or all of these individual components may be responsible for the observed effects. Unique components of the outdoor system (compared with conventional indoor systems) include more space, a different floor or ground substrate, sunshine, and a more enriched environment. Birth environment played a critical role in pig growth and development, regardless of whether pigs were placed indoors on slats or in an outdoor environment on alfalfa pasture.

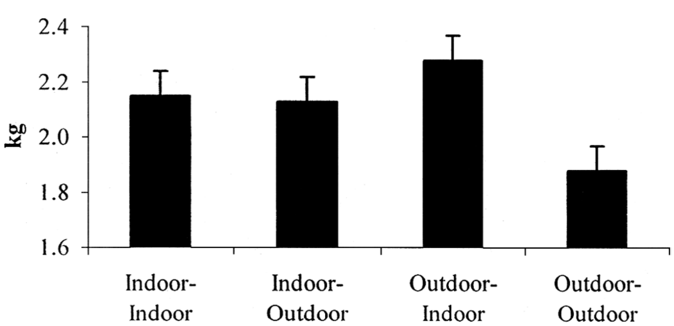

Figure 3. Shear force of loin chops categorized by pig birth (top line) and rearing environments (n = 11 or 12 chops/treatment). Means are simple effects. Rearing environment effect, $P < 0.05$. Birth × rearing interaction, $P = 0.07$.

Studies on environmental enrichment for pigs have shown that earth-like material is an effective enriching agent (Beattie et al., 1998). In the past, environmental enrichment was only incorporated after weaning (Warriss et al., 1983; Pearce and Paterson, 1993), but Hessing et al. (1993) found that characteristics such as stress responsiveness (which can affect pig performance and meat quality) are established earlier in life. Beattie et al. (2000) reported that pigs finished in enriched environments (3.5 m^2/pig, solid flooring with straw bedding) had greater ($P < 0.001$) 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).

Other researchers have reported that indoor-finished pigs grew faster than outdoor-finished pigs in both the summer and winter seasons (Enfält et al., 1997; Sather et al., 1997). However, climatic conditions can play a significant role in pig performance in an outdoor production system. Outdoor systems in west Texas may be more favorable than those in more northern climates evaluated in previous research.

Conflicting findings have been reported for pork carcass measurements of pigs finished in alternative housing systems. Pigs finished on straw bedding in an enriched environment had greater levels of backfat and heavier carcass weights than pigs finished in a barren environment (Beattie et al., 2000). Others have found that environmental enrichment resulted in no improvement in productivity (Pearce and Paterson, 1993; Blackshaw et al., 1997). The nature of the enrichment and

Table 4. Retail display characteristics of loin chops listed by pig birth and rearing environments

		Birth environment[a]		Rearing environment[b]			*P*-value[c]		
Item	Day	Indoor	Outdoor	Indoor	Outdoor	SEM	B	R	B × R
Color[d]	1	7.0	6.9	7.2	6.8	0.08	0.48	0.01	0.13
	2	6.9	6.6	6.9	6.5	0.08	0.01	0.01	0.13
	3	5.7	5.2	5.7	5.1	0.08	0.01	0.01	0.13
	4	5.1	4.8	5.1	4.8	0.08	0.05	0.02	0.13
Uniformity[e]	1	1.1	1.1	1.1	1.1	0.04	0.51	0.51	0.39
	2	1.1	1.1	1.1	1.1	0.04	0.74	1.00	0.39
	3	1.5	1.5	1.4	1.6	0.04	0.91	0.01	0.39
	4	2.0	1.9	2.0	1.9	0.04	0.69	0.60	0.39
Discoloration[f]	1	1.0	1.0	1.0	1.0	0.10	1.00	1.00	0.87
	2	1.0	1.0	1.0	1.0	0.10	0.82	0.94	0.87
	3	1.6	1.9	1.6	1.9	0.10	0.04	0.03	0.87
	4	2.3	2.5	2.6	2.2	0.10	0.09	0.01	0.87
Browning[g]	1	1.0	1.0	1.0	1.0	0.08	1.00	1.00	0.98
	2	1.0	1.0	1.0	1.0	0.08	1.00	1.00	0.98
	3	1.4	1.6	1.5	1.4	0.08	0.07	0.63	0.98
	4	2.2	2.4	2.4	2.2	0.08	0.06	0.14	0.98
Minolta L*	1	51.1	51.0	51.9	50.2	0.24	0.88	0.01	0.55
	2	50.4	50.0	50.9	49.5	0.24	0.18	0.01	0.55
	3	49.9	49.8	51.0	48.7	0.24	0.63	0.01	0.55
	4	50.5	50.4	51.3	49.6	0.24	0.68	0.01	0.55
Minolta a*	1	3.5	4.4	3.8	4.1	0.10	0.01	0.03	0.98
	2	2.8	3.4	2.9	3.3	0.10	0.01	0.01	0.98
	3	1.7	2.3	1.6	2.4	0.10	0.01	0.01	0.98
	4	1.2	1.7	1.0	1.9	0.10	0.01	0.01	0.98
Minolta b*	1	9.2	9.9	9.8	9.4	0.17	0.01	0.07	0.36
	2	9.8	10.3	10.0	10.1	0.17	0.06	0.67	0.36
	3	9.2	9.5	9.2	9.6	0.17	0.23	0.11	0.36
	4	9.2	9.8	9.4	9.7	0.17	0.02	0.21	0.36

[a]Pig birth environments: indoors (sows housed in farrowing crates) or outdoors (sows kept on pasture, farrowed in huts).
[b]Pig finishing environments: indoors on concrete slatted-flooring or outdoors on alfalfa pasture.
[c]*P*-values for birth environment (B), rearing environment (R), and interaction effects.
[d]Color scores range from 1 to 6 (1= extremely dark grayish-pink; 8 = extremely bright grayish-pink).
[e]Uniformity scores range from 1 to 5 (1 = uniform, 5 = extreme two-toning).
[f]Discoloration scores range from 1 to 7 (1 = 0% discoloration, 7 = 100% discoloration).
[g]Scores for browning range from 1 to 5 (1 = none, 6 = dark brown).

the length of exposure to the enrichment may explain the conflicting findings reported thus far.

Pig finishing rations may need to be altered to reduce backfat when pigs are reared outdoors. We do not know whether the added backfat thickness changed total body composition. The best prediction at this time is that the faster weight gain and heavier weights at processing led to greater body fat. However, we do not know what might have happened if the pigs were processed at a common end weight rather than a common time on feed. We do not know whether the selected improvements in Minolta color values, pork flavor, and shear force among outdoor-born/reared pigs were dependent on the increased backfat thickness. However, when hot carcass weight was added as a covariate in the analysis, treatment differences in color, flavor intensity, and shear force were still significant. There is no evidence that the heavier carcass weights, within the ranges we reported here, would have influenced the sensory traits we collected.

Warriss et al. (1983) and Enfält et al. (1997) reported that outdoor-reared pigs had thinner backfat measurements compared with pigs reared intensively indoors. Van der wal (1991) showed that pigs reared on free range had growth and carcass compositions similar to those of littermates finished indoors, on partially slatted floors. Differences in backfat between pigs in different rearing environments may also be due in part to genetics. Newsham pigs utilized in this study may perform differently from other genetic lines when placed in an outdoor environment. Some researchers have suggested that if pigs are reared outdoors in cold conditions, then carcasses may have less fat because food is diverted from fat deposition to thermoregulation (Warriss et al., 1983; Sather et al., 1997; Edwards, 1999). This study was conducted from February to July in west Texas, where the climate was moderate to warm.

In this study, the outdoor-born pigs had heavier carcass weights and larger loineye areas. These factors may have contributed to the higher loin temperature that was observed in pigs from the outdoor-born group compared with the indoor-born group. When hot carcass weight was added in the model as a covariate, no differences were found in loin temperature between the outdoor-born and indoor-born treatments.

Previous studies have detected reduced postmortem pH values of outdoor-finished pigs (Warriss et al., 1983; Enfält et al., 1997; Sather et al., 1997); however, no studies have examined the effect of outdoor birth environments on postmortem muscle quality. No differences in water-holding capacity (pH, drip loss, or purge) were found in this study comparing the groups born and finished indoors or outdoors. Beattie et al. (2000) found no differences in pH measurements comparing pigs from enriched and barren finishing environments.

The pork flavor intensity differences discovered among outdoor-born pigs was interesting. Hansen et al. (1994) reported that pigs lying in a mixture of feces and urine in pens at high stocking rates (0.6 m^2/pig) for at least 1 wk had greater levels of skatole and indole in subcutaneous backfat than pigs kept in clean pens at low stocking rates (0.8 m^2/pig). Skatole levels were greater in the summer months than the winter months (Hansen et al., 1994). No differences were detected in visual marbling scores or fat percentage in the chemical analysis of the loins, and therefore it is doubtful that fat had an effect on flavor intensity of the pork evaluated in this experiment. Pork flavor intensity advantages for the outdoor-born group in this study may be attributed, in part, to the low stocking rates of the pigs during the birth and finishing periods. The outdoor-born/outdoor-finished group of pigs had the highest scores (most desirable) for pork flavor intensity compared with the other three groups. The stocking rates used in this project were less dense than industry recommendations of 0.74 m^2/pig for pigs from 68 kg to market weight (Fritschen and Meuhling, 1986) or 0.93 m^2/pig in confinement facilities during the late finishing phase (Arthur, 1993).

Several researchers have found no differences in pork eating quality measurements comparing pork from indoor- and outdoor-reared pigs (Barton-Gade and Blaabjerg, 1989; van der Wal, 1991). Enfält et al. (1997) reported reduced tenderness and juiciness in the loin muscle of outdoor-reared pigs during the winter months. Jonsäll et al. (2001) reported that ham from outdoor-reared pigs was less juicy and acidulous than ham from indoor-reared pigs ($P < 0.05$), but no differences were found in tenderness, odor intensity, or meat taste between the indoor- and outdoor-reared groups. Maw et al. (2001) reported that pigs housed on straw bedding produced bacon with a stronger fried meat flavor than bacon from pigs housed on concrete or slats ($P < 0.05$).

Bacon from straw-bedded pigs was darker in color than bacon from pigs raised either on contrete or slatted flooring (Maw et al., 2001). We found that birth and rearing developmental environments had significant effects on pork color (Figure 1). For red color, best measured by Minolta a* values (Figure 1b), the effects of birth and rearing environments were additive. A small increase in Minolta a* value was observed with each of outdoor birth and rearing environments compared with indoor systems. When pigs were both born and reared outdoors, the pork was clearly darker red than pork from pigs born and reared indoors. Which components (space, soil, vegetation, etc.) of the diverse production system caused the desirable increase in red color remains to be determined.

Our study found decreased shear force values in the loin for outdoor-reared pigs, indicating a small advantage in objective tenderness among pork from outdoor pigs. There was no advantage in sensory panel tenderness of loin muscle for the outdoor-born group. Loin shear force values indicated a tenderness advantage for outdoor-reared pigs; however, these results did not agree with sensory panel scores. Miller et al. (2001) determined that beef with a shear force value of 3.0 kg or less was considered acceptable by 100% of the consumers in the study. Pork chops evaluated in this study had shear force values below 2.5 kg, indicating that these samples were acceptable in tenderness. Increased exercise levels may play a role in pork tenderness; pigs were required to walk greater than 350 m from the waterer to the feeder. These results agree with Beattie et al. (2000), who found that pigs from enriched environments produced pork with a lower shear force than their counterparts from barren environments. Other researchers have found no effect of physical activity on sensory qualities of cuts from the ham and loin (Essén-Gustavsson et al., 1988; van der Wal et al., 1993; Petersen et al., 1997), but the degrees of exercise and enrichment of the environments varied.

We found no previous reports on the effects of outdoor birth and rearing environments on pork retail display characteristics. We found loin chops from outdoor-reared pigs were darker and redder in color. Loin chops from outdoor-reared pigs also had higher scores for discoloration on d 3 and 4 compared with chops from the group reared indoors. Higher discoloration scores are not desirable, but at the same time, advantages in Minolta L* and a* values were found throughout the retail display period for pork from pigs finished outdoors. However, a* color advantage was not detected with the visual scores. Although the a* values were higher for the chops from the outdoor-finished pigs, the panelists were not able to see a visual color difference on the chops. Discoloration of the chops from the outdoor-reared groups may have offset the color, and this is why the panelists did not detect any visual differences in pork color. Further work in this area is needed to determine what causes pork chops from outdoor-reared pigs to be darker and redder in color and have higher discoloration scores during d 3 and 4 in the retail case.

Implications

The birth environment of suckling pigs plays a significant role in their growth throughout the finishing period. Advantages of outdoor-born pigs include increased average daily gains and larger loineye areas. Pork color was improved (darker and redder) and had improved shear force values with outdoor rearing of pigs on alfalfa pasture in this trial. Although all the pigs produced in the indoor system had acceptable growth and pork quality, outdoor pig production may improve growth and meat quality compared with more conventional production systems. Further research is needed to determine whether these effects are observed over seasons, with different genetic lines of pigs, and whether some of the effects could be replicated in modified indoor environments.

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