Influence of rearing conditions on performance, behavioral, and physiological responses of pigs to preslaughter handling, carcass traits, and meat quality[1]

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ABSTRACT: A total of 120 crossbred [synthetic line × (Large White × Landrace)] pigs (castrated males and females) were used to evaluate the influence of rearing conditions for growing-finishing pigs on growth performance, carcass, stress reactions at slaughter, and meat eating quality. At approximately 35 kg of live weight (LW), littermates were allocated to either a conventional (fully slatted floor, 0.65 m^2/pig, considered as control, CON) or an alternative (sawdust bedding with free access to an outdoor area, 2.4 m^2/pig, OUT) system, until slaughter at approximately 110 kg of LW. Pigs had free access to standard growing and finishing diets. The trials were conducted in spring, summer, and winter, with each season involving 2 pens of 10 pigs in each system. Compared with the CON, the OUT pigs exhibited a greater growth rate (+10%, $P < 0.001$) due to their greater feed intake (+0.23 kg/d, $P < 0.01$), resulting in a greater body weight at slaughter (+7 kg, $P < 0.001$). The OUT pigs had thicker backfat (+2.4 mm, $P < 0.01$) and lower lean meat content (–2.0% points, $P < 0.001$) than the CON pigs. The OUT system did not ($P > 0.10$) influence the behavioral activities of pigs during lairage at the slaughterhouse, or the urinary levels of catecholamines and cortisol, and plasma levels of ACTH, cortisol, lactate, creatine kinase, and FFA immediately after slaughter. The OUT pigs had similar ($P > 0.10$) pH values 30 min postmortem (pH_1) in the LM, biceps femoris (BF), and semimembranosus (SM) muscles, similar ultimate pH (pH_u) in LM, but lower pH_u in SM (–0.07 unit, $P < 0.001$) and in BF (–0.03 unit, $P = 0.029$). Despite nonsignificant effects of production system on stress reactions at slaughter, assessed by urine and plasma indicators and muscle metabolism at 30 min postmortem, meat from OUT pigs had more LM drip loss after 2 (+1.0%, $P = 0.003$) and 4 (+1.1%, $P = 0.010$) d than did meat from the CON pigs. The OUT system slightly increased meat yellowness (b* value) in the LM (+0.7 unit, $P = 0.001$), BF (+0.5 unit, $P = 0.014$), and SM (+0.5, unit $P = 0.041$), whereas redness (a*) and lightness (L*) of the 3 muscles were unaffected ($P > 0.07$). Intramuscular fat content was greater in the LM (+17%, $P = 0.001$), BF (+14%, $P = 0.004$), and SM (+17%, $P = 0.003$) of the OUT pigs. Outdoor rearing during summer and winter improved meat juiciness, whereas odor, flavor, and tenderness were unaffected ($P > 0.10$). Influence of rearing conditions on all the other traits studied did not depend on the season.

Key words: behavior, hormone, housing, meat quality, muscle, pig

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INTRODUCTION

Societal concerns about conventional pig production have been increasing for a number of years in Europe. The conventional production system is generally thought to be associated with a negative environmental impact (pollution, offensive odors), and poor animal welfare due to high animal densities and bad housing conditions, and is perceived to result in reduced meat quality (Rainelli, 2001; Ngapo et al., 2003). Thus, in the near

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future, the pork industry has to propose pig production systems that satisfy consumer and citizen demands for lower environmental impact, improved animal welfare, and better meat quality.

This article focuses on the effects of the production system (alternative on bedding with free outdoor access vs. conventional on fully slatted floor) on performance, carcass traits, and pork quality. Although several studies have been published, few consider sensory meat quality and most of those only report indicators of pork quality in relation to stress reactions of pigs to the slaughtering procedure (Geverink et al., 1999; De Jong et al., 2000; Klont et al., 2001). The effects of pig rearing conditions on meat eating quality are controversial. van der Wal et al. (1993) and Gentry et al. (2002a,b) reported no effect of indoor enrichment or outdoor rearing on sensory properties, whereas Enfält et al. (1997) showed decreased pork tenderness and overall acceptance with outdoor rearing. Moreover, most studies did not take into account the direct effects of the n and RN^- alleles on meat quality (for review, see Sellier, 1998) and their possible influence on stress reactions at slaughter and subsequent meat quality (Terlouw, 2005).

Thus, this study focused on evaluating the effects of an alternative (bedding with free outdoor access) compared with a conventional (fully slatted floor) pig production system, on performance, carcass composition, behavior, and physiology at slaughter, muscle traits, and meat eating quality in pigs free of the n and RN^- alleles.

MATERIALS AND METHODS

Animals and Husbandry

The experiment was conducted following French guidelines for animal care and use (http://www.cnrs.fr/infoslabos/reglementation/expanim.htm). All people involved in the experiment have an agreement for conducting experimental procedures on animals, delivered by the Veterinary Services of French Ministry of Agriculture.

The experiment included 120 crossbred synthetic line × (Large White × Landrace) pigs (castrated males and females) from 30 litters. All pigs were free of the halothane-sensitive (n) and RN^- alleles. At the average live weight (**LW**) of 35 kg, 2 castrated males and 2 females from each litter were chosen on the basis of their LW, and growth rate from birth. One castrated male and 1 female were allocated to 1 of the 2 following systems: conventional (**CON**; fully slatted floor, 0.65 m^2/pig, controlled ambient temperature at 22°C) considered as the control system, or an alternative outdoor (**OUT**; sawdust bedding, 1.3 m^2/pig, with fluctuating ambient temperature, and with free access to an outdoor area, concrete floor, 1.1 m^2/pig) system. Pigs had ad libitum (1 feeder by pen) access to a growing diet (2.35 Mcal of NE/kg, 17.5% CP, 0.85% digestible lysine) until 70 kg of LW, and to a finishing diet thereafter (2.35 Mcal/kg of NE/kg, 15.0% CP, 0.72% digestible lysine). Animals had free access to water.

Trials were undertaken in spring (February–May), summer (June–September), and winter (November–February), with each season involving 2 pens of 10 pigs (5 castrated males and 5 females, littermates within sexes) in each system. Pigs were reared in 2 rooms (1 per system) of the same building. In CON, the average (±SD) ambient temperature was 22.8 (± 0.9) °C for the spring, 25.4 (± 1.4) °C for the summer, and 22.7 (± 0.7) °C for the winter trials. The ambient temperature was lower with greater fluctuations in the OUT system, and varied between seasons: 18.4 (± 2.1) °C for the indoor and 10.1 (± 4.1) °C for the outdoor areas during the spring trial; 22.5 (± 2.2) °C for the indoor and 18.0 (± 4.0) °C for the outdoor areas during the summer trial; and 15.6 (± 3.7) °C for the indoor and 8.0 (± 3.7) °C for the outdoor areas during the winter trial.

Pigs were weighed weekly. Feed consumption (by pen) was recorded each day.

Handling and Slaughtering

When the average LW of a batch of 5 pigs from each pen reached 110 kg, 2 batches (1 from each system) were fasted from 1600 onwards. The following day, the 2 batches of pigs were loaded on to a lorry (without mixing the batches), transported for 2 h, and kept in separate pens in lairage for 3 h at the abattoir at INRA (SENAH, Saint-Gilles, France), where they had free access to water. Afterwards, every 15 min, 1 pig from each batch (alternatively) was showered with a small water jet for 1 min, 5 min before the pig was walked to the stunning area, and then slaughtered by electrical stunning and exsanguination in compliance with the current national regulations applied in slaughterhouses. Overall, the fasting period lasted between 21 and 23 h.

For the summer and winter trials, the behavioral activity of pigs during the 3-h lairage period at the slaughterhouse was recorded continuously by video until the first pig was stunned. Each batch was video taped using a camera (Sony PC25-2230P 1/3, Tokyo, Japan) fixed 2 m above the pen. The 2 cameras were connected to a videotape recorder (Panasonic TL 500, Tokyo, Japan) via a multiplexer (Advanced Technology VideoDPX9 PAL, Tokyo, Japan), which allowed sequential recording of both cameras and pictures to be viewed on 1 screen (Sony Triniton, Tokyo, Japan). The behavioral activities were analyzed by scan sampling at 5-min intervals. The following mutually exclusive activities were recorded: walking, investigation of walls and floor of the pen, investigation of penmates, agonistic behavior, resting (lying posture), and other active behaviors. The cumulative number of 5-min scans was calculated for each behavioral activity per hour within each batch and expressed as a percentage of the total scans recorded during the hour (12 scans × 5 pigs in each batch).

After slaughter, blood temperature was recorded (Thermometer JTEK, Cole Parmer Instrument Company, Chicago, IL). Blood was collected in EDTA tubes, centrifuged immediately, and stored at –20°C before determination of plasma ACTH using a 2-site ^{125}I immunoradiometric assay (Nichols Diagnostic Institute, San Juan Capistrano, CA). The quantification limit of the assay was 6 pg/mL of plasma, and the intra- and interassay CV were 3.0 and 7.8%, respectively, at 35 pg/mL. Blood was also collected in heparinized tubes, immediately centrifuged, and stored at –20°C before determination of plasma cortisol using a competitive ^{125}I RIA kit (Immunotech, 13276 Marseille, France). The quantification limit of the assay was 8 ng/mL of plasma, and the intra- and interassay CV were 4.2 and 10.0%, respectively, at 71 ng/mL.

Plasma concentrations of glucose and lactate (bioMerieux kits, Marcy l'Etoile, France) and FFA (Wako Chemicals GmbH, Neuss, Germany) as well as creatine kinase activity (bioMerieux kit) were determined on the blood samples collected in heparinized tubes, using a multichannel spectrophotometric analyzer (Cobas Mira, Hoffmann-LaRoche, Basel, Switzerland).

Urine was collected just after slaughter, 1% (vol/vol) 6 *N* hydrochloric acid was added immediately, and the mixture was stored at –80°C until determination of cortisol, cortisone, adrenaline, and noradrenaline. Cortisol and cortisone were measured by HPLC with UV detection after extraction on reverse-phase columns (Hay and Mormède, 1997a). Adrenaline and noradrenaline were measured by HPLC with electrochemical detection after extraction on cationic columns (Hay and Mormède, 1997b). Creatinine was measured by a colorimetric method (Sigma Diagnostics, Saint Quentin Fallavier, France). Urine hormone concentrations were expressed per milligram of creatinine, to correct for urine dilution. Samples of plasma and urine from 1 replicate were analyzed within a single assay.

Carcass Traits

Just after slaughter, the hot carcass, internal fat, digestive tract and its contents were weighed. Mean backfat thickness (mean of measurements taken between the third and fourth lumbar vertebra and between the third and fourth last rib levels) and muscle depth (between the third and fourth last rib level) were measured using a Fat-O-Meater (SFK, Herlev, Denmark) to estimate lean meat content, as described by Daumas et al. (1998). After 24 h at 4°C, the weights of the fresh carcass and of wholesale cuts [ham, loin, shoulder, belly, and backfat, as described by Métayer and Daumas (1998)] of the left side were recorded. Carcass drip was calculated from hot and cold carcass weights.

Meat Quality Traits

Thirty minutes after slaughter, internal temperatures of LM, biceps femoris (**BF**), and semimembranosus (**SM**) muscles were recorded (temperature probe Pt1000, Knick, Berlin, Germany), and samples of these 3 muscles were taken, frozen immediately in liquid nitrogen, and stored at –80°C until determinations of pH 30 min postmortem ($\mathbf{pH_1}$) and glycolytic potential. The pH_1 was determined after homogenization of 2 g of muscle in 18 mL of 5 m*M* Na iodoacetate, pH 7.0 (Ingold Xerolyte electrode, Knick pH-meter, Berlin, Germany). Glycolytic potential (**GP**) was determined according to Monin and Sellier (1985), as GP = 2[(glycogen) + (glucose) + (glucose-6-phosphate)] + (lactate). After homogenization of 1 g of muscle into 10 mL of 0.55 *M* perchloric acid, glucose, and glucose-6-phosphate were determined together using an enzymatic method (glucose HK, ABX Diagnostics kit, Montpellier, France) on an automatic spectrophotometric analyzer (Cobas Mira Roche). Muscle lactate content was determined as previously described for plasma lactate. Muscle glycogen content was determined from glucose determination (see above) after hydrolysis by amyloglucosidase, as described by Talmant et al. (1989). For muscle GP determinations, samples from 1 replicate were analyzed in a single assay. Lactate, free glucose, and glucose-6-phosphate, and glucose from glycogen hydrolysis were expressed as micromoles per gram of wet tissue; GP was expressed as micromoles of equivalent lactate per gram of wet tissue.

The following day, transverse sections of LM, BF, and SM muscles were taken for direct determination of ultimate pH ($\mathbf{pH_u}$) using the same apparatus as described above. Color was also evaluated on these muscle samples through the value determination of coordinates CIE L* (lightness), a* (redness), b* (yellowness; average of 3 different determinations per sample) using a chromameter Minolta CR 300 (Osaka, Japan) with a D_{65} illuminant and a 1-cm-diameter aperture.

Muscles slices were then trimmed of external fat, minced, and freeze-dried before determination of i.m. lipid content (Folch et al., 1957). On the same day, 3 slices (1.5-cm depth) of LM muscle were taken at the last rib level, trimmed of external fat and perimysium, weighed, and kept at 4°C in plastic bags for determination of drip loss at 2 and 4 d postmortem (Honikel, 1998).

Sensory Analyses

The day after slaughter, a piece of the right loin of each carcass (between the 10th and 21st vertebrae) was trimmed of external fat, kept at 4°C for 3 subsequent days, put under vacuum, and frozen at –20°C until sensory analyses were performed at INRA-QuaPa (Theix). The frozen loins were cut into chops, individually vacuum packaged, and stored frozen. After thawing at ambient temperature, the chops were grilled with a double-contact grill at 280°C for 6 min. Samples [a third of the muscle part of the deboned chop with the remaining external fat (3- to 5-mm depth)] were assessed by a 10-member trained taste panel for odor (normal

and abnormal odors of lean and fat), tenderness, juiciness, and typical and abnormal flavors on a scale from 0 (absent) to 10 (high). The samples were served under daylight. Panelists were served water and bread to rinse their palates between samples. Four samples (2 by husbandry method and sex) from 1 season were evaluated per session. The same procedure was used for the other 2 seasons, tested in a separate series of sessions. Individual panelist scores were averaged, and mean scores from each sample were used for the statistical analysis.

Statistical Analyses

The SAS software (SAS Inst., Inc., Cary, NC) was used in all statistical evaluations. Data for growth performance and carcass traits were submitted to an ANOVA (GLM procedure) considering the rearing conditions (R), season (S), sex (G), and their interactions (first level) as fixed effects in the model. When no significant interactions were found ($P > 0.05$), the model was reduced to main effects only. Slaughter date intraseason was added to the model for the data analysis of plasma and urine components and meat quality traits. Urinary and blood hormone concentrations were analyzed after a logarithmic transformation to fit a normal distribution.

The behavioral data expressed in percentage of total scans were transformed into arcsin square root and submitted to an ANOVA (GLM procedure) with the rearing condition, season, and the hourly lairage period as fixed effects in the model, and the day of slaughter intraseason entered as a random effect. Because no significant interactions were found ($P > 0.05$), the model was reduced to main effects only.

RESULTS

Growth Performance

The rearing system significantly influenced the growth performance of the pigs. Compared with the CON pigs, the OUT pigs exhibited a greater ($P = 0.007$) ADFI during the growing-finishing period, mainly due to differences during the finishing period (Table 1). The OUT pigs grew faster ($P < 0.002$) than CON pigs during both the growing and finishing periods. Season significantly ($P < 0.001$) influenced the average growth rate of pigs, which was the greatest in winter, the lowest in summer, and intermediate but not different from the other seasons in spring. The housing system did not affect the feed conversion ratio (calculated per pen) either in the growing or in the finishing periods. On average, feed conversion ratio was 3.07, 3.27, and 3.30 kg/kg for the winter, spring, and summer trials, respectively. The greater growth rate of the OUT compared with the CON pigs led to a heavier (+7.0 kg, $P < 0.001$) LW at slaughter at the same age for OUT pigs.

Carcass Traits

Carcass and meat quality traits were recorded only on 52 pigs from the CON group, due to a technical problem for this group at the end of the spring trial.

Carcass traits were affected by pig rearing conditions (Table 2). The OUT pigs gave heavier (+5.4 kg, $P < 0.001$) hot carcasses, reflecting their greater LW at slaughter. They had thicker ($P = 0.002$) mean backfat, whereas muscle depth was not ($P = 0.13$) modified. This gave rise to a lower (–2.0 points, $P < 0.001$) lean meat content of the OUT compared with CON carcasses. On average, carcass lean meat content assessed with the Fat-O-Meater was greater ($P < 0.001$) for pigs reared in the winter (62.0%), than in the spring (58.9%) or summer (59.8%) trials. The influence of husbandry method on lean meat content assessed with the Fat-O-Meater tended ($P = 0.068$) to be more important for castrated males than for females (–3.0 and –1.4 points for castrated males and females, respectively, between the OUT and CON groups). When adjusted by covariance analysis for the same slaughter LW, differences in carcass traits between groups remained large and highly significant (20.6 vs. 18.7 mm for backfat depth, $P < 0.007$; and 59.3 vs. 61.1% for lean meat content, $P < 0.001$, for the OUT and CON pigs, respectively). Carcass dressing percentage was similar between groups, whereas carcass drip loss was lower ($P = 0.025$) in the OUT than in the CON group.

The relative weights of wholesale cuts were not significantly influenced by production system, except for the greater ($P = 0.010$) proportion of backfat for the OUT than the CON pigs. The internal fat, liver, heart, lungs, spleen, and empty gastrointestinal tract were heavier ($P \leq 0.049$) in the OUT compared with the CON pigs. When adjusted to the same slaughter LW, differences became nonsignificant ($P > 0.300$) for all traits except for the content weights of gastrointestinal tract ($P < 0.001$) and colon ($P = 0.002$), which were 2.19 and 1.27 kg for the OUT and 1.85 and 0.99 kg for the CON pigs, respectively.

Behavioral and Physiological Characteristics During the Slaughter, and Meat Quality Traits

The production system did not influence the behavioral activities of the pigs during lairage until 3 h (Figure 1). However, for both systems, pigs exhibited lower ($P < 0.001$) resting frequency and higher ($P < 0.001$) investigative activity toward the pen walls and floor during the first hour than during the last 2 h of lairage. The other behavioral activities did not vary between production systems or time of lairage (data not shown). Pigs performed no agonistic behavior during the lairage period ($P > 0.050$).

The pig production system did not ($P \geq 0.179$) influence blood temperature at exsanguination, or plasma lactate, FFA, creatine kinase, cortisol, and ACTH concentrations, whereas OUT pigs tended ($P = 0.079$) to

Table 1. Growth performance of pigs reared outdoors or in the conventional system

	Rearing conditions[1]			*P*-value[2]		
	Outdoors	Conventional	RSD	R	S	G
No. of pigs	60	60				
No. of pens	6	6				
Growth performance						
Growing period						
Initial live weight, kg	38.0	37.5	2.6	0.319	<0.001	0.396
Final live weight, kg	72.8	71.4	5.1	0.139	0.002	0.225
Feed intake, kg/d	2.76	2.57	0.18	0.108	—	—
Growth rate, g/d	1,171	1,100	122	0.002	<0.001	0.187
G:F, kg/kg	0.42	0.43	0.01	0.595	—	—
Finishing period						
Final weight, kg	119.0	110.6	5.8	<0.001	<0.001	0.927
Feed intake, kg/d	3.07	2.84	0.17	0.052	—	—
Growth rate, g/d	971	874	114	<0.001	<0.001	0.024
G:F, kg/kg	0.32	0.31	0.02	0.375	—	—
Growing-finishing period						
Feed intake, kg/d	2.94	2.71	0.11	0.007	—	—
Growth rate, kg/d	1,045	960	94	<0.001	<0.001	0.013
G:F, kg/kg	0.35	0.35	0.02	0.834	—	—
Slaughter						
Age, d	156	157	5	0.428	0.002	<0.001
Live weight,[3] kg	116.6	109.6	5.2	<0.001	<0.001	0.632

[1]Least squares means. Experimental units = pen for feed intake and feed conversion ratio, animals for live weights and growth rate.
[2]*P*-values for rearing conditions (R), season (S), and sex (G); RSD = residual SD.
[3]Interaction between rearing conditions and season was found ($P < 0.05$).

show a greater plasma glucose concentration than the CON pigs (Table 3). At slaughter, the urine levels of cortisol and cortisone, adrenaline and noradrenaline (per mg of creatinine) were not ($P \geq 0.307$) modified by the pig rearing system (Figure 2).

In the LM, BF, and SM muscles, the internal temperature and pH_1 evaluated 30 min after slaughter were not ($P \geq 0.198$) affected by the rearing system (Table 4). In the LM, pH_u, GP, and its components were similar ($P > 0.116$) between the 2 groups. However, pH_u was lower ($P \leq 0.029$) and GP was greater ($P \leq 0.031$) in the BF and SM muscles of the OUT pigs. In the LM, drip losses were greater ($P \leq 0.010$) at 2 and 4 d postmortem from the OUT than from the CON pork. Meat yellowness (b*) was increased ($P \leq 0.041$) in the LM, BF, and SM muscles of the OUT pigs, whereas differences in meat lightness (L*) and redness (a*) between OUT and CON pigs did not reach significance ($P > 0.050$). In the 3 muscles, the average a* value was lower, and average L* and b* values and drip losses after 2 and 4 d postmortem in the LM were greater ($P \leq 0.049$) in pork from the winter compared with that from the spring and the summer.

The OUT pigs had a greater ($P \leq 0.004$) lipid content in the 3 muscles than the CON pigs. Significant effect of sex × production system interaction were noticed, indicating that the effect of production system on this trait was more pronounced for castrated males than for females in the LM ($P = 0.004$) and the BF ($P = 0.052$) (data not shown). The average i.m. lipid content was greater ($P \leq 0.020$) in all 3 muscles from the pigs reared in spring and summer than in winter.

Concerning the eating quality, meat from the 2 systems did not show any abnormal odor or flavor that might have hidden the specific effects of rearing system on sensory quality (Table 5). The OUT system increased meat juiciness ($P = 0.031$) for the winter ($P < 0.01$) and summer ($P < 0.05$) trials, but not for the spring trial ($P > 0.05$). The other sensory traits of meat did not ($P \geq 0.161$) differ between the rearing systems.

DISCUSSION

Pigs reared in the OUT system exhibited better performance, particularly greater ADFI, especially during the finishing period, giving rise to greater growth rates during the growing (+6%) and finishing (+11%) periods compared with pigs reared in the CON system. The lower ambient temperature in the OUT system may explain the greater feed intake of these animals and, consequently, their greater growth rate, in accordance with the well-established increase in voluntary feed intake with the decrease in ambient temperature (Le Dividich et al., 1998). Those authors estimated that the daily feed consumption increased by 35 g/d per °C as the ambient temperature decreased from 20 to 15°C. This can explain, at least in part, the 290 g/d increase in daily feed intake (on average) of the OUT compared with the CON pigs. The variation in ambient temperature, and particularly the cold temperature levels that

Table 2. Body composition and carcass traits of pigs reared outdoors or in the conventional system

	Rearing conditions[1]			*P*-value[2]		
	Outdoors	Conventional	RSD	R	S	G
No. of pigs	60	52				
HCW,[3] kg	94.2	88.8	4.2	<0.001	<0.001	0.796
Dressing, %	80.8	81.0	1.2	0.433	0.034	0.009
Mean backfat depth, mm	20.9	18.5	3.6	0.002	0.067	<0.001
Muscle depth,[3] mm	64.4	66.0	5.0	0.130	<0.001	0.032
Lean meat content (Fat-O-Meater), %	59.2	61.2	2.8	<0.001	<0.001	<0.001
Lean meat content (cuts),[4] %	53.4	55.0	3.2	0.012	0.686	<0.001
Carcass drip loss, %	2.35	2.45	0.24	0.025	<0.001	0.020
Carcass composition,[5] %						
Ham	24.1	24.4	0.9	0.168	<0.005	<0.002
Loin	26.7	27.1	1.2	0.138	0.137	<0.001
Shoulder	24.8	24.7	0.9	0.845	0.141	0.011
Belly[3]	13.5	13.3	0.9	0.165	0.022	0.940
Backfat	8.1	7.3	1.5	0.010	0.498	<0.001
Weight of organs, kg						
Internal fat	1.48	1.23	0.31	0.004	0.487	<0.001
Liver	1.81	1.72	0.22	0.049	0.004	0.136
Heart	0.51	0.48	0.05	<0.001	<0.001	0.20
Lungs	1.65	1.56	0.20	0.017	0.582	<0.001
Spleen	0.171	0.156	0.03	0.049	0.064	0.337
Gastrointestinal tract (empty)[3]	5.52	5.14	0.51	<0.001	0.217	0.039
Stomach	0.59	0.47	0.06	<0.001	0.920	0.907
Small bowel[3]	1.92	1.70	0.26	<0.001	0.369	0.069
Colon	1.80	1.74	0.20	0.075	0.004	0.337
Gastrointestinal tract content, kg	2.27	1.76	0.52	<0.001	0.211	0.943
Stomach	0.39	0.34	0.21	0.144	0.010	0.006
Small bowel	0.52	0.46	0.19	0.102	0.022	0.508
Colon	1.31	0.94	0.40	<0.001	0.346	0.196

[1]Least squares means.
[2]*P*-values for rearing conditions (R), season (S), and sex (G); RSD = residual SD.
[3]Interaction between rearing conditions and season was found ($P < 0.05$).
[4]Calculated from the weight of cold carcass cuts (Metayer and Daumas, 1998).
[5]Proportion of left side.

were reported from time to time in the outdoor area of the OUT system, could have also increased the nutrient requirement and thus the feed intake of the pigs, because we determined that pigs spent approximately 25% of their time there over 24 h (Le Dividich et al., 1998; Bee et al., 2004). Another explanation for the greater growth rates is the greater floor space in the OUT compared with the CON system, which provides pigs easier access to the feeder, particularly at the end of the fattening period (Hamilton et al., 2003a; De-Decker et al., 2005). Finally, the greater physical activity of the OUT pigs, due to their greater space allowance, may have increased nutrient requirements and feed intake, and modified growth rate. However, Enfält et al. (1993) and Petersen et al. (1998) did not notice any significant effect of physical activity in controlled conditions (running/walking) on voluntary feed intake or growth rate of pigs. Similar greater feed intake and growth rate of pigs finished on enriched (straw, 3.5 m^2/pig) compared with barren (slatted floor, 0.76 m^2/pig) environments were reported by Beattie et al. (2000). The influence of outdoor rearing on growth performance varies between studies, because many factors that influence pig performance, such as housing, genetics, climatic conditions, space allowance, and feeding regimen (pasture) may have differed. Compared with conventional indoor rearing, Lebret et al. (2002) reported that pigs reared outdoors on courtyards with free access to a shed have a similar growth rate during the winter season, but a decreased growth rate during summer. Conflicting results have been reported concerning the effect of free-range rearing of pigs on growth performance, depending on the season and the management of animals. Decreased growth performance of outdoor-(pasture) reared pigs has been observed by Enfält et al. (1997) and Bee et al. (2004) during the winter season. Gentry et al. (2002a, b) reported no significant effect of outdoor growing-finishing in a mild climate on pig ADG, but outdoor birth and rearing significantly increased growth rate.

Compared with the CON system, the OUT system evaluated here led to fatter carcasses, independently of carcass weight, although the proportions of wholesale cuts (except backfat) were unaffected. In agreement with our findings, increased backfat thickness, decreased carcass lean meat content, or both was found

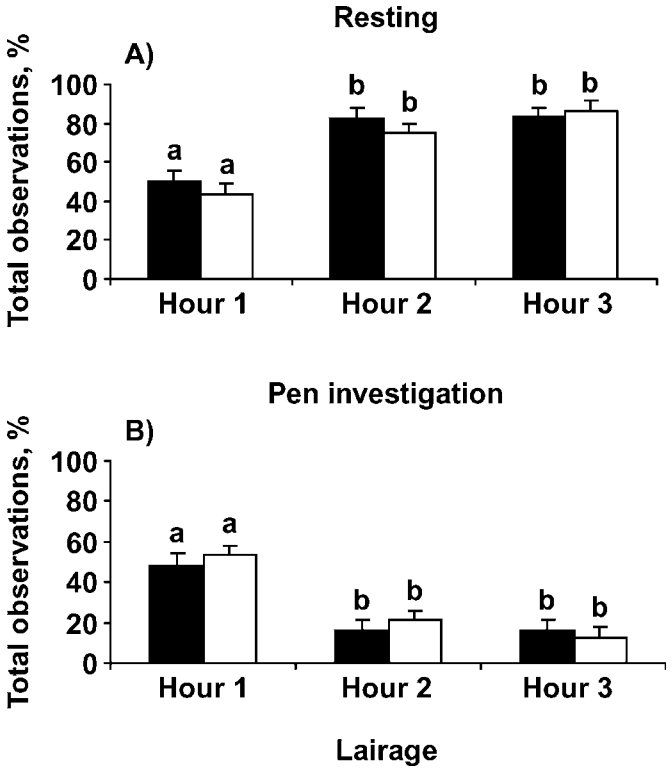

Figure 1. Influence of rearing conditions on behavioral activity of pigs per hour of lairage at the slaughterhouse. Means and SE of percentages of total observations for resting (A) and pen investigation (B) of outdoors (black bars) or conventionally (white bars) reared pigs are presented. Experimental unit = 1 batch of 5 pigs from the same home pen; n = 8 per rearing system. Within rearing condition, bars that do not have a common superscript differ, $P < 0.05$.

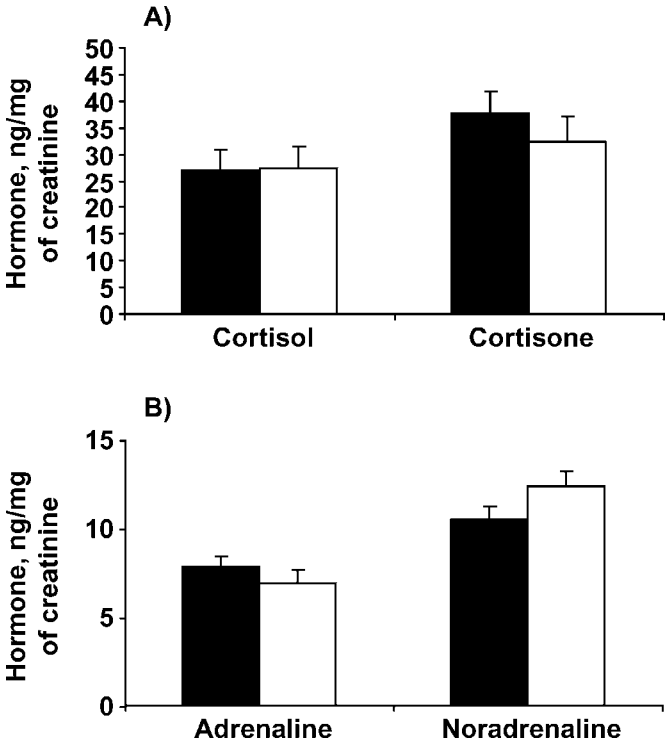

Figure 2. Concentrations (least squares means ± SE) of (A) cortisol and cortisone, and (B) adrenaline and noradrenaline in urine collected at slaughter (ng/mg of creatinine) from pigs reared in outdoors (black bars) or conventional (white bars) systems. Levels of cortisol ($P = 0.991$), cortisone ($P = 0.897$), adrenaline ($P = 0.344$), and noradrenaline ($P = 0.306$) were not affected by the pig-rearing conditions.

in pigs reared in an enriched system (extra space, straw; Beattie et al., 2000; Gentry et al., 2002b) and with free access to an outdoor courtyard (van der Wal et al., 1993) compared with a conventional environment. However, Lebret et al. (2002) did not show any significant effect of housing system on carcass muscle percentage. The effects of free-range outdoor rearing are more controversial, because this system has been shown to both increase (Gentry et al., 2002a) and decrease (Enfält et al., 1997; Bee et al., 2004) carcass fatness. The heavier gastrointestinal tract, due to heavier colon content, of our OUT pigs, could be due to the consumption of sawdust, especially during the overnight fasting period be-

Table 3. Blood temperature and concentration of plasma components at exsanguination of pigs reared outdoors or in the conventional system

	Rearing conditions[1]			*P*-value[2]		
	Outdoors	Conventional	RSD	R	S	G
No. of pigs	60	52				
Temperature, °C	39.0	38.9	0.5	0.821	0.375	0.718
Glucose, mg/mL	1.16	1.11	150	0.079	0.005	0.742
Lactate, μmol/mL	6.66	6.35	4.42	0.726	<0.001	0.590
FFA, μmol/mL	0.85	0.88	0.32	0.604	0.455	0.581
Creatine kinase, U/mL	1.99	2.13	1.03	0.477	<0.001	0.189
ACTH,[3] pg/mL	91.0	82.0	85.5	0.640	0.064	0.200
Cortisol, ng/mL	49.9	42.2	28.8	0.179	<0.001	0.838

[1]Least squares means.
[2]*P*-values for rearing conditions (R), season (S), and sex (G); RSD = residual SD.
[3]Only for replicates 2 and 3 (n = 40 pigs per group).

Table 4. Muscle traits of pigs reared outdoors or in the conventional system

	Rearing conditions[1]			*P*-value[2]		
	Outdoors	Conventional	RSD	R	S	G
No. of pigs	60	52				
Longissimus muscle						
Temperature, °C	39.3	39.3	0.9	0.942	0.015	0.469
pH, 30 min (pH_1)	6.37	6.42	0.18	0.198	0.154	0.022
Ultimate pH (pH_u)	5.50	5.49	0.20	0.942	0.617	0.178
Drip losses, %						
2 d postmortem	3.3	2.3	1.7	0.003	<0.001	0.942
4 d postmortem	5.7	4.6	2.0	0.010	<0.001	0.233
Color						
L*	55.2	54.2	3.2	0.108	0.277	0.504
a*	5.8	5.5	1.7	0.473	0.002	0.766
b*	5.7	5.0	1.0	0.001	<0.001	0.351
Lactate, μmol/g	49.2	44.9	13.8	0.116	<0.001	0.309
Free glucose and glucose-6-P, μmol/g	4.29	3.87	1.98	0.295	0.178	0.493
Glucose (glycogen),[3] μmol/g	54.6	55.0	11.2	0.861	0.200	0.393
Glycolytic potential,[4] μmol/g	167.0	162.5	14.5	0.129	0.002	0.870
i.m. fat content, %	1.68	1.44	0.36	0.001	0.002	0.011
Biceps femoris muscle						
Temperature, °C	39.2	39.4	0.7	0.198	0.007	0.549
pH_1	6.41	6.46	0.18	0.236	0.586	0.633
pH_u	5.49	5.52	0.08	0.029	0.055	0.362
Color						
L*	52.0	51.2	2.5	0.097	<0.001	0.486
a*	10.9	10.7	2.1	0.553	<0.001	0.090
b*	6.7	6.2	0.9	0.014	<0.001	0.251
Lactate, μmol/g	43.2	41.3	13.2	0.473	<0.001	0.412
Free glucose and glucose-6-P, μmol/g	3.61	3.60	1.55	0.957	0.754	0.298
Glucose (glycogen),[3] μmol/g	55.5	51.6	11.9	0.105	0.003	0.259
Glycolytic potential,[4] μmol/g	161.5	151.8	17.3	0.006	0.115	0.265
i.m. fat content,[5] %	2.23	1.96	0.49	0.004	<0.001	0.029
Semimembranosus muscle						
Temperature, °C	39.5	39.6	0.6	0.523	0.015	0.595
pH_1	6.48	6.51	0.20	0.411	0.638	0.590
pH_u	5.50	5.57	0.10	<0.001	0.737	0.741
Color						
L*	53.0	53.0	3.0	0.949	0.013	0.608
a*	9.7	9.0	1.9	0.071	<0.001	0.745
b*	6.9	6.4	1.1	0.041	<0.001	0.675
Lactate, μmol/g	43.0	38.8	16.0	0.188	<0.001	0.439
Free glucose and glucose-6-P, μmol/g	4.29	3.87	1.45	0.272	0.380	0.387
Glucose (glycogen),[3] μmol/g	59.3	58.4	13.1	0.728	0.006	0.182
Glycolytic potential,[4] μmol/g	168.5	161.8	15.4	0.031	0.871	0.101
i.m. fat content,[5] %	2.00	1.71	0.50	0.003	<0.001	0.330

[1]Least squares means.
[2]*P*-values for rearing conditions (R), season (S), and sex (G); RSD = residual SD.
[3]Glucose issued from glycogen hydrolysis.
[4]Micromoles of equivalent lactate per gram of muscle.
[5]Interaction between rearing conditions and season was found ($P < 0.05$).

fore transport. It could also be explained, at least in part, by the greater feed intake of the OUT pigs.

The positive influence of an enriched vs. conventional housing system on increased investigative activity of pigs, is now clearly established (Lyons et al., 1995; De Oliveira et al., 1999; Beattie et al., 2000) and may be interpreted as an improvement in animal welfare. The possible effects of animal behavior during the rearing period on their physiological responses to stress at transport and slaughter and, consequently, on meat quality, are of great interest. Several studies (Geverink et al., 1999; De Jong et al., 2000; Klont et al., 2001, Lambooij et al., 2004) evaluated the effect of the enrichment of indoor environment (extra space and straw vs. conventional) on pig behavior and physiology during preslaughter handling and subsequent meat quality. Although housing conditions affected animal activity during transport and salivary cortisol levels both at the home pen and during transport, these differences were generally no longer significant at the end of the lairage period. This led to small (Klont et al., 2001) or no significant effects (Geverink et al., 1999) on meat quality.

Table 5. Sensory quality traits of the LM from pigs reared outdoors or in the conventional system

	Rearing conditions[1]			*P*-value[2]		
	Outdoor	Conventional	RSD	R	S	G
No. of pigs	60	52				
Normal odor of fat	5.6	5.5	2.3	0.549	0.003	0.555
Abnormal odor of fat	0.3	0.3	0.7	0.659	0.10	0.294
Normal odor of lean	5.4	5.3	2.1	0.495	0.022	0.727
Abnormal odor of lean	0.5	0.4	1.1	0.294	0.021	0.414
Tenderness	5.5	5.3	1.7	0.161	<0.001	0.218
Juiciness	3.7	3.4	1.9	0.031	0.214	0.184
Typical flavor	5.7	5.6	1.8	0.657	<0.001	0.774
Abnormal flavor	0.5	0.6	1.0	0.746	0.009	0.677

[1]Least squares means.
[2]*P*-values for rearing conditions (R), season (S), and sex (G); RSD = residual SD.

Nevertheless, these studies did not consider outdoor rearing but only enrichment of indoor pens as alternative systems. Moreover, it is well established that pork quality largely depends on preslaughter handling conditions (Tarrant, 1993; Monin, 2003) and on the genetic background, in particular, the presence of the halothane sensitivity (n) and RN^- alleles that strongly influence meat quality (Sellier, 1998). The presence of these alleles may interact with the effects of rearing conditions on animal behavior and physiology, to determine peri- and postmortem metabolism and thus meat quality (Terlouw et al., 2001). Thus, one criterion of this study was to use pigs free of the n and RN^- alleles. In addition, the preslaughter handling conditions did not differ between the OUT and CON pigs.

In the current study, there was no influence of the pig production system on the behavioral activities of animals during lairage at the slaughterhouse. Klont et al. (2001) also reported no significant difference in the total percentage of time spent walking or fighting between enriched and barren housing conditions during the 2 h of lairage. By contrast, De Jong et al. (2000) noticed that pigs reared in an enriched environment spent less time walking and fighting during a 1-h lairage compared with pigs reared in a barren environment, even though differences between groups were slight and significant at the third 15 min in lairage. These authors did not report any significant effect of the rearing conditions in time spent lying, in agreement with the present results on resting frequencies. Similarly, the increase in resting frequency over the 3-h lairage period in our study was also observed by De Jong et al. (2000) over a 1-h period in lairage. The lack of aggressive behavior of our pigs can be explained by the fact that, within rearing treatment, pigs from different home pens were not mixed, in contrast to the study of de Jong et al. (2000) in which pigs were mixed within rearing treatment. The present results on pig behavior indicate that pigs reared under different conditions (i.e., their prior experience) cope similarly when placed in a different environment at the slaughterhouse or even after a transport period, both of which are considered potentially stress-inducing factors (Terlouw, 2005).

The physiological response to stress may be assessed through the activity of the 2 neuroendocrine systems, the hypothalamic-pituitary-adrenocortical (**HPA**) and the sympathetic (catecholaminergic) part of the autonomic nervous system. Concerning the HPA axis, cortisol is synthesized in the adrenal cortex under the control of ACTH, and released into the circulatory system with a maximum level at 20 to 30 min after an acute stimulation (Grandin, 1997; Prunier et al., 2005). The peak of ACTH occurs earlier, in the minutes after the stimulus (Prunier et al., 2005). Because urine is the major excretory pathway for cortisol and its metabolites, including cortisone, it integrates the excretion of cortisol and cortisone over the time between 2 successive emissions. In our study, plasma ACTH and cortisol, and urine cortisol and cortisone levels were similar in OUT and CON pigs. This indicates that, under our transport and slaughtering conditions, the response of the HPA axis to preslaughter stress was not influenced by the pig rearing conditions. The release of catecholamines (adrenaline and noradrenaline) in blood occurs within a few seconds after a stimulus. Their determination in urine, which integrates their excretion over time, has been used to assess the sympathetic response of pigs to the slaughtering procedure (Hay and Mormède, 1997b). The lack of any effect of the pig rearing system on the sympathetic axis activity of pigs in response to slaughtering procedure is consistent with results on the HPA axis.

Besides hormones, other metabolic variables, such as plasma glucose, FFA, and lactate concentrations, creatine kinase activity, or blood temperature may be used to assess physiological responses to stress (Warriss et al., 1994; Grandin, 1997). Plasma glucose and FFA levels, which both depend on cortisol and catecholamine levels, reflect the balance between the mobilization of energy stores and the use of energy metabolites, primarily by muscular activity. Lactic acid level reflects the intensity of anaerobic metabolism, whereas activity

of creatine kinase, a muscle intracellular enzyme, indicates cell suffering subsequent to very high muscular activity during handling and transport (Guise et al., 1998). In agreement with the similar behavioral activities of pigs during lairage and the similar plasma and urine hormone levels between rearing conditions, blood temperature, plasma glucose, FFA, and lactate concentrations, as well as muscle temperature, pH, glucose and lactate levels just after slaughter, did not differ between OUT and CON pigs. Altogether, these findings indicate that the rearing system did not influence the behavioral or physiological response of pigs to preslaughter and slaughter procedures, and thus did not influence the pattern of muscle peri- and postmortem metabolism (Warriss et al., 1994; Monin, 2003; Terlouw, 2005). In agreement with the present findings, similar levels in saliva cortisol, assessed at the end of the lairage period (De Jong et al., 2000; Klont et al., 2001) or in plasma collected at exsanguination (Geverink et al., 1999) have been reported for pigs reared in enriched compared with barren environments, even though greater levels in salivary cortisol assessed in the home pen and immediately after transport have been found for pigs in enriched systems (Geverink et al., 1999; De Jong et al., 2000; Klont et al., 2001). Saliva or plasma cortisol levels at the home pen or just after transport were not determined in our study.

The lack of any influence of the pig-rearing environment on muscle lactate, pH, and temperature 30 min after slaughter confirms results from many other studies [van der Wal et al., 1993 (LM); Geverink et al., 1999 (LM, SM); Beattie et al., 2000 (LM); Klont et al., 2001 (LM, BF)]. On the contrary, Lambooij et al. (2004) showed greater pH values and lower internal temperature and lactate content in the LM muscle 1 and 4 h after slaughter in pigs reared in enriched environmental conditions (straw bedding, 1.3 m^2/pig) compared with controls (slatted floor, 0.7 m^2/pig), whereas Gentry et al. (2002b) found lower LM pH_1 values in pigs reared on bedding compared with concrete slats.

The lower pH_u observed in the BF and SM muscles of the OUT pigs is in accordance with their greater GP at slaughter, whereas these characteristics were not modified in the LM. The greater GP in the BF and SM muscles of the OUT pigs can be explained by either greater muscle glycogen stores during rearing or lower glycogen consumption during the preslaughter procedure in these muscles, compared with the LM. Many studies also report no significant effect of the indoor rearing environment on the LM pH_u (Geverink et al., 1999; Beattie et al., 2000; Gentry et al., 2002b), even though increased (Klont et al., 2001) or decreased (van der Wal et al., 1993; Lambooij et al., 2004) pH_u values have been shown. Concerning the ham muscles, Lebret et al. (2002) reported no significant difference in SM pH_u between outdoor rearing on courtyards and indoor systems. Outdoor rearing on pasture has been shown to decrease ultimate pH in the various muscles of the ham [Enfält et al., (1997) in the quadriceps femoris, semitendinosus, gluteus and BF; Bee et al. (2004) in the semitendinosus and rectus femoris]. The effects are less (Enfält et al., 1997) or nonsignificant (Gentry et al., 2002b; Bee et al., 2004) in the LM. Clearly, the effect of pig production system on muscle glycogen store and use, and consequently, pH_u is muscle dependent, the ham muscles being more affected than the loin.

The lower pH_u in the SM and BF muscles of OUT pigs probably would have resulted in greater drip loss. The greater LM drip loss of these pigs is in accordance with Bee et al. (2004), although others studies have reported no significant effect of pig housing conditions on drip (van der Wal et al., 1993; Geverink et al., 1999; Beattie et al., 2000; Lambooij et al., 2004). The greater LM drip loss of the OUT compared with CON pigs, together with the nonsignificant effects on pH values at 30 min or 24 h postmortem, are in agreement with Hamilton et al. (2003b) for pigs reared in a spacious or a crowded environment. This can be explained by a difference between groups in the rate of muscle postmortem metabolism in the hours after slaughtering. Indeed, Klont et al. (2001) reported a greater correlation between LM drip loss 2 or 5 d after storage and pH or lactate values at 4 h, instead of 45 min or 24 h postmortem. The importance of events during the early postmortem hours in the determination of subsequent drip loss has also been demonstrated by Schäfer et al. (2002), who estimated that up to 89% of the variation in drip could be explained by the pH value at 2 h together with muscle temperature at 1 min postmortem. In the current study, we found a high correlation between LM lactate at 30 min and drip loss at 2 ($r = 0.81$, $P < 0.001$) and at 4 ($r = 0.77$, $P < 0.001$) d postmortem, confirming the importance of early postmortem muscle metabolism in governing meat drip loss. Pig production system had a small effect on meat color. In the LM, BF, and SM, meat from OUT pigs had slightly greater yellowness values than that from CON pigs; rearing conditions did not affect lightness and redness. Indoor housing systems have been shown to have no influence on LM or BF color parameters (van der Wal et al., 1993; Beattie et al., 2000; Klont et al., 2001; Lambooij et al., 2004) although rectus femoris, but not LM, was yellower in meat from pigs reared outdoors (Bee et al., 2004). Therefore, overall, there is little or no effect of pig rearing conditions on meat color.

The greater i.m. lipid content of the OUT compared with the CON pigs is consistent with the greater carcass fatness of the OUT pigs, in accordance with most studies showing a similar variation in carcass and i.m. lipid content due to rearing conditions (Lebret et al., 1999 for review) and the positive genetic correlation (+0.30) between these 2 traits (Sellier, 1998). Indeed, we found highly significant correlations between i.m. lipid content and mean backfat thickness in our study ($r = 0.59$, $P > 0.001$ in LM; $r = 0.46$, $P > 0.001$ in BF; $r = 0.33$, $P > 0.001$ in SM). In agreement with the present results, Lebret et al. (2002) reported a slight increase in the lipid content of the SM from pigs offered outdoor access

during the summer season compared with pigs reared indoors; however, van der Wal et al. (1993) found no effect. By contrast, decreased i.m. lipid content and a leaner carcass have been reported in outdoor- (free-range) reared pigs (Enfält et al., 1997; Bee et al., 2004).

The juicier meat from outdoor-reared pigs may have resulted from its greater i.m. fat content (Hodgson et al., 1991; Eikelenboom et al., 1996; Fernandez et al., 1999). In other studies, the rearing conditions yielded inconsistent results on pork quality. Maw et al. (2001), assessing meat produced from different farms in Scotland, demonstrated that bacon from pigs reared on bedding (straw) had greater greasiness score and superior eating quality, particularly in flavor, compared with that from pigs reared on slatted or concrete floors without bedding. By contrast, van der Wal et al. (1993) reported similar juiciness and tenderness of meat from pigs reared in an enriched system with free outdoor access compared with controls. Gentry et al. (2002b) showed no significant effect of indoor enrichment (space, straw) or outdoor rearing on pasture on sensory scores for fresh pork. Enfält et al. (1997) noted decreased tenderness and overall acceptance of meat from pigs reared outdoors during the cold season; this was related to its lower pH_u or i.m. lipid content. Thus, we cannot generalize about the influence of rearing environment on eating quality of pork, because it would depend on the effects of rearing conditions on muscle and meat composition. Variations in muscle composition would depend mainly on the effects of housing and feeding systems on carcass composition and in vivo muscle metabolism, and meat composition would be affected by peri- and postmortem metabolism, which are, in turn, determined by the stress reactions of pigs to transport and slaughtering procedures.

IMPLICATIONS

Compared with the conventional rearing system (indoor housing on fully slatted floor and high animal density), an alternative production system on sawdust bedding with free outdoor access increased growth performance of pigs, indicating that the conventional system is not optimal for growth rate. Physiological and behavioral responses of pigs to stress at slaughter were not influenced by the rearing conditions. The alternative system led to fatter carcasses and increased pork drip loss, but also improved loin meat juiciness. The advantages of alternative production systems for pork are sufficient to warrant further trials assessing the benefits to the commercial producer and to the consumer.

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