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Physiological traits and meat quality of pigs as affected by genotype and housing system

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ABSTRACT

The influence of pig housing system: alternative (bedding with outdoor area, BO) *vs.* conventional (slatted floor, SF) on growth performance, reactivity to pre-slaughter handling and meat quality was evaluated in two genotypes differing in the sire line, Duroc (CD) or synthetic (CS) with 40 pigs/genotype.
Animal response to housing did not differ between genotypes. BO pigs had higher growth rate and feed intake, but similar carcass composition to SF pigs. Levels of stress related hormones and plasma metabolites at slaughter were not different between BO and SF pigs, suggesting that housing did not influence pig reactivity to pre-slaughter handling. Similar (*Longissimus lumborum* and *Biceps femoris*) or slightly reduced (*Semimembranosus*) pH values, higher drip, lipid content and juiciness were observed in BO compared with SF pork. CD pigs had more tender meat than CS. In conclusion, the BO system resulted in higher feed intake, faster growth rate, increased intramuscular fat, and improved eating quality in both genotypes.

1. Introduction

Livestock production systems can influence the various dimensions of food production: eating quality of products, animal welfare, environmental impact, and production costs. In pig production, a wide variety of production systems, aimed at differentiating between these various dimensions, currently exists in Europe (Bonneau et al., 2009). Regarding eating quality of pork and pork products, differences between production systems have been demonstrated (Bonneau & Lebret, 2010). However, the effects of alternative production systems on pork quality often differ between studies, possibly due to differences in feeding and housing conditions, pig genotype, and behavioural and physiological responses of pigs to preslaughter handling, that all influence pork quality (Lebret, 2008).

A previous comparative study on pig rearing conditions showed that sawdust-shave bedding with free outdoor access (total space 2.4 m^2/pig) improved feed intake, growth performance and pork eating quality as measured by juiciness scores, compared to the conventional housing system on slatted floor (Lebret et al., 2006). In addition, this alternative system had positive impacts on other dimensions of pig production such as a decrease in the level of offensive odours in pig buildings and an improvement in animal welfare and health (lower severity scores of respiratory tract pathologies) (Dourmad et al., 2009; Meunier-Salaün, Dourmad, & Lebret, 2006). However, the pig responses to this alternative system as compared to the conventional one in terms of growth performance, carcass composition, physiological and metabolic traits as well as stress reactions during slaughter and meat quality, may also depend on pig genotype (Brandt, Werner, Baulain, Brade, & Weissmann, 2010; Terlouw, 2005). The aim of the present study was to evaluate the influence of two different housing systems on growth performance, carcass composition, physiological response to stress, muscle composition and meat quality in two genotypes of pigs differing in their sire line, synthetic or Duroc.

2. Materials and methods

2.1. Animals and husbandry

The experiment was conducted following French guidelines for animal care and use (http://ethique.ipbs.fr/sdv/charteexpeanimale.pdf). All people involved in the experimentation have an agreement for conducting experimental procedures on animals, delivered by the Veterinary Services of the French Ministry of Agriculture.

The experiment included a total of 80 pigs (40 castrated males (M) and 40 females (F)) born from Large White × Landrace dams inseminated either with semen from a Duroc (CD, n = 40) or a synthetic line (CS, n = 40). Synthetic line is the P76 line (Pen Ar Lan breeding company, Maxent, France, www.penarlan.fr) issued from the Laconie (created from Hampshire, Pietrain and Large White) and

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Penshire (created from Hampshire, Large White and Duroc) lines. All pigs were free of the halothane-sensitivity (n) and RN$^-$ alleles. In each genotype, at the average live weight (LW) of 35 kg, 2 M and 2 F from each litter were chosen on the basis of their LW, and growth rate from birth. In each litter, one piglet from each sex was allocated to one of the two following housing systems: conventional (totally slatted floor, 0.65 m^2/pig: industry standard for conventional housing system, controlled ambient temperature at 22 °C) considered as the control (SF), or an alternative housing system including an indoor area on sawdust-shave bedding (1.3 m^2/pig) with fluctuating ambient temperature and permanent free access to an outdoor area on concrete floor (1.1 m^2/pig) (BO). These indoor and outdoor animal densities fit with requirements for organic pig production and for the French "Label Rouge" (high quality) pork. Pigs were fed *ad libitum* (one feeder 30 cm wide per pen) with a growing diet up to 70 kg LW (2.35 Mcal of NE/kg, 17.5% crude protein, 0.85% digestible lysine) and a finishing diet thereafter (2.35 Mcal of NE/kg, 15.0% crude protein, 0.72% digestible lysine). Animals had free access to water.

Trials were conducted in spring (March to June) and winter (December to March), each replicate involving one pen of 10 pigs (5 M and 5 F) per genotype and per system (i.e. 40 pigs per season). For each replicate, pigs were reared in two different rooms (one per system) of the same building. In the SF housing system, the average ambient temperature (calculated from measurements every 15 min) was 22.2 ± 1.1 °C. It was cooler, with higher fluctuations in the BO system, in particular during the winter replicate. During the spring replicate, the average ambient temperature was 17.8 ± 2.7 °C and 15.0 ± 4.2 °C in the indoor and outdoor areas, respectively whilst during the winter season it was 15.2 ± 2.9 °C and 6.8 ± 3.6 °C in the indoor and outdoor areas, respectively.

Pigs were weighed weekly. Feed consumption (per pen) was recorded each day. Therefore, in both housing systems, animals were submitted to similar daily human interactions.

2.2. Physiological observations during the rearing period

The activity of 2 neuroendocrine systems, the hypothalamic–pituitary–adrenal (HPA) axis and the sympathetic part of the autonomous system (SNS), considered as markers of the physiological response to stress, was evaluated during the rearing period. At the average LW of 70 kg, after overnight fasting, urine was collected from each pig, on the same day for the 40 pigs. At 7 a.m., 2 people entered each of the 4 experimental pens and collected at least 20 ml of urine per pig at spontaneous urination. The whole sampling procedure took between 60 and 90 min. Just after sample collection, urine was adjusted to pH = 2.0 with the addition of 6 N hydrochloric acid and stored at −20 °C until determination of cortisol, cortisone, adrenaline and noradrenaline. Cortisol and cortisone were measured by HPLC with UV detection after extraction on a reverse-phase column (Hay & Mormède, 1997a), and adrenaline and noradrenaline were measured by HPLC with electrochemical detection after extraction on cationic columns (Hay & Mormède, 1997b). Creatinine was measured using a colorimetric method (Sigma Diagnostics, Saint-Quentin Fallavier, France). Concentrations of hormones in urine were expressed per mg of creatinine, to correct for urine dilution. Samples of urine from one experimental replicate were analyzed within a single assay.

2.3. Handling and slaughtering

Pigs were slaughtered at the experimental slaughterhouse of INRA (UMR SENAH, Saint-Gilles, France). The experiment was designed to slaughter the same number of pigs of each housing system on the same day. When the average LW of the 5 heaviest pigs of one pen reached 110 kg, it was decided to slaughter these pigs and the 5 heaviest pigs of the other housing system but same genotype. Animals from the other genotype were slaughtered within 4 d. In each group of 5 pigs per system and genotype, there were both castrated males and females. The 40 pigs were slaughtered over a 14-d interval. At each slaughtering session, all pigs of the pen were fasted overnight; afterwards, the 5 pigs to be slaughtered were sorted, weighed, and loaded on to a lorry without mixing the two experimental groups, transported for 2 h (approximal surface of 1.4 m^2/pig during transport), and kept in separate pens in lairage for 3 h at the slaughterhouse where they had free access to water. Afterwards, every 15 min, one pig from each group (alternatively) was showered with a small water jet for 1 min, 5 min before the pig was walked approximately 10 m to the stunning area, and then slaughtered by electrical stunning (350 V — 4 A; stunner C. Bernadet, 64 Orthez, France) and exsanguination, in compliance with the current national regulations applied in slaughterhouses. Overall, the fasting period lasted between 21 and 23 h.

At slaughter, blood was collected in heparinized tubes, centrifuged immediately and stored at −20 °C. Plasma ACTH (two-site ^{125}I immunoradiometric assay, Nichols Institute Diagnostic, San Juan Capitiano, CA, USA) and cortisol (competitive ^{125}I RIA kit, Immunotech, 13276 Marseille, France), were determined using radioimmunoassay as described by Prunier, Mounier, and Hay (2005). Plasma concentration of glucose was determined enzymatically using glucose hexokinase and glucose-6-phosphate dehydrogenase (Glucose HK, ABX Diagnostics kit, 34187 Montpellier, France). Plasma lactate was determined enzymatically using lactate oxidase and peroxidase (Lactate PAP kit, Biomerieux, 69280 Marcy l'Etoile, France). Glucose and lactate assays were performed with a multichannel spectrophotometric analyzer (Cobas Mira, Hoffmann-Roche, Basel, Switzerland). Creatine kinase (CK) activity was assayed by a kinetic determination after reactivation by N-acetylcysteine (Enzyline CK NAC kit, Biomerieux, 69280 Marcy l'Etoile, France) using the same multichannel spectrophotometric analyzer.

Urine was collected after slaughter at bladder removal, adjusted to pH = 2.0 with addition of 6 N HCl and stored at −20 °C until determinations of cortisol, cortisone, adrenaline, noradrenaline and creatinine, as described above.

2.4. Carcass traits

Just after slaughter, hot carcass and internal fat weights were recorded. Mean back fat depth (mean of measurements taken between the 3rd and 4th lumbar vertebra and the 3rd and 4th last rib levels) and muscle depth (between the 3rd and 4th last rib level) were measured using a Fat-O-Meater (FOM) (SFK, Herlev, Denmark) to estimate lean meat content (LMC FOM) as described by Daumas, Causeur, Dhorne, and Schollhammer (1998). After 24 h at 4 °C, the weights of the fresh carcass and wholesale cuts (ham, loin, shoulder, belly and backfat) of the left side were recorded, and used to calculate LMC from carcass cuts (Métayer & Daumas, 1998). Carcass drip loss (using hot and cold carcass weights) and composition (proportion of wholesale cuts to the left side) were calculated.

2.5. Muscle and meat quality traits

Twenty-five minutes after slaughter, from right side of each carcass, muscles samples (around 20 g) were taken on *Longissimus lumborum* (LL, 2nd lumbar vertebra level), *Biceps femoris* (BF, external side of the ham, at 4–5 cm depth in the muscle) and *Semimembranosus* (SM, internal side of the ham, 4–5 cm from the ilium bone towards the leg and at 2–3 cm depth in the muscle), immediately frozen in liquid nitrogen and stored at −80 °C before subsequent determination of pH_1 and glycolytic potential (GP). The pH_1 was determined after homogenisation of 2 g of muscle in 18 ml of 5 mM Na iodoacetate (Ingold Xerolyte electrode, Knick pH-meter, Berlin, Germany). GP was determined as GP = 2([glycogen] + [glucose] + [glucose-6-phosphate]) + [lactate], as

previously described (Lebret, Meunier-Salaün, et al., 2006). Briefly, muscle glucose and glucose-6-phosphate (G-6-P) were determined altogether enzymatically as described above for plasma glucose, and muscle lactate was also determined enzymatically, as described above for plasma lactate. Muscle glycogen content was determined from glucose determination (above) after hydrolysis by amyloglucosidase. GP was expressed as μmol equivalent lactate/g of wet tissue. For muscle pH_1 and GP determinations, samples from one replicate were analyzed within single assays.

The following day, from the right carcass side, muscle transverse sections of LL (first lumbar vertebra level, approximately 2-cm thick and 150 g), BF and SM (transverse to the ham, approximately 2-cm thick and 200 g) were taken for direct determination of ultimate pH (pH_u) (Ingold Xerolyte electrode, Knick pH-meter, Berlin, Germany). Meat colour was evaluated through coordinates CIE L*: lightness, a*: redness, b*: yellowness, C*: saturation (chroma) and h°: hue (average values 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.

Muscle slices were then trimmed of external fat, minced and freeze-dried before determination of lipid content (Folch, Lee, & Stanley, 1957). Muscle water content was determined from the weight of minced muscles before and after freeze-drying, and used for calculation of lipid content per gram of fresh muscle. The day after slaughter, three other slices (1.5 cm depth) of the LL 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 days *post mortem* (*p.m.*) (Honikel, 1998).

2.6. Meat eating quality

On all pigs from the second (winter) replicate (n = 40), a piece of the right loin of each carcass (between the 10th and 21st vertebrae, approximately 4 kg) was taken the day after slaughter, partially trimmed of external fat and kept at 4 °C for 3 subsequent days. They were then stored under vacuum and frozen at −20 °C until sensory analyses performed at INRA-QuaPA. After thawing at ambient temperature, chops (approximately 1.5 cm-thick) were cut and grilled (double contact grill, 280 °C for 6 min). Samples (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 odour (normal and abnormal odours of lean and fat), tenderness, juiciness, and typical and abnormal flavours on a scale from 0 (absent) to 10 (high). Four samples, i.e. one sample per housing system and genotype, from the same sex, were evaluated per session. Individual panelist scores were averaged and mean scores from each sample were used for the statistical analysis.

2.7. Statistical analyses

Data of growth performance and carcass traits were submitted to an analysis of variance (GLM procedure, SAS) using a model including the fixed effects of housing system (H), genotype (G), replicate (R) and sex (S), and their interactions (first level). When no significant interactions were found ($p>0.05$) the model was reduced to main effects only. Slaughter session (intra-replicate and genotype) was included in the model for the analysis of plasma and urine components at slaughter, and meat quality traits. Urinary and plasma hormone concentrations were analyzed after a logarithmic transformation to fit a normal distribution. For sensory analyses (winter replicate only) the model included the fixed effects of housing system, genotype, session, and their interactions (first level) when significant ($p<0.05$). Pearson's correlation coefficients were calculated between carcass and physiological traits, as well as between muscle and meat quality traits (CORR procedure, SAS). Pen was used as experimental unit for average feed intake and feed conversion ratio, and individual animal was used as the experimental unit for remaining growth performance parameters, carcass traits, plasma, muscle and meat quality parameters, as well as eating quality traits.

3. Results and discussion

Since no significant interactions between housing system and genotype were found on any of the traits evaluated, only the average values (lsmeans) of these main effects are presented.

3.1. Animal growth performance

The housing system influenced significantly the growth performance of animals. Compared with the SF pigs, the BO pigs had higher average feed intake (+6%, $p<0.01$) and growth rate (+6%, $p<0.01$) during the growing–finishing period, and were thus 5 kg heavier at slaughter (Table 1). Feed conversion ratio was similar between groups. CS and CD pigs exhibited similar average growth performance. Average initial live weight was lower in the winter than in spring replicate (33.8 *vs.* 36.5 kg, $p<0.01$) whereas average final live weight was higher in the winter than in spring replicate (116.9 *vs.* 113.2 kg, $p<0.01$). Pigs reared during the winter season also had higher growth rate (+6%, $p<0.01$) compared with pigs reared during spring, but

Table 1
Growth performance and carcass traits.

	Housing system[a]		Genotype[b]		Rsd	Sign[c]			
	BO	SF	CD	CS		H	G	R	S
Growth performance									
Initial live weight, kg	35.3	35.1	35.0	35.4	2.6	ns	ns	***	*
Final live weight, kg	117.7	112.4	115.4	114.7	6.1	***	ns	**	ns
Average feed intake, kg/d	2.82	2.65	2.77	2.70	0.08	**	–	ns	–
Growth rate, g/d	1003	942	970	975	83	**	ns	**	**
Feed conversion ratio, kg/kg	2.81	2.82	2.85	2.78	0.11	ns	–	ns	–
Slaughter									
Age, d	158.7	158.7	159.2	158.2	6.2	ns	ns	ns	*
Empty body weight, kg	115.3	110.1	113.1	112.3	6.0	***	ns	*	ns
Carcass traits									
Hot carcass weight, kg	93.2	89.6	92.1	90.7	4.9	**	ns	*	ns
Dressing, %	80.9	81.3	81.4	80.8	1.4	ns	ns	ns	ns
Mean back fat depth, mm[d]	21.0	20.0	20.7	20.0	2.8	ns	ns	ns	*
Muscle depth, mm	62.6	63.2	63.5	62.4	5.7	ns	ns	ns	ns
Lean meat content (FOM),%[d]	59.1	59.8	59.2	59.7	2.3	ns	ns	ns	**
Lean meat content (cuts), %[d]	53.5	53.7	52.9	54.3	2.7	ns	*	ns	**
Internal fat, kg	1.41	1.48	1.47	1.41	0.33	ns	ns	ns	**
Carcass drip loss, %	2.68	2.74	2.75	2.67	0.22	ns	ns	***	ns
Carcass composition, %									
Ham	24.0	24.1	23.6	24.4	0.6	ns	***	ns	ns
Loin[d]	26.8	26.8	26.7	26.6	1.4	ns	ns	***	**
Shoulder[d]	24.7	24.8	24.6	24.8	0.7	ns	ns	*	*
Belly	13.6	14.4	14.4	13.6	2.8	ns	ns	**	ns
Backfat[d]	7.8	7.5	7.9	7.4	1.0	ns	*	**	***

[a] BO: outdoor area with indoor bedding; SF: conventional on slatted floor. n = 39 per housing system for growth performance and carcass traits. n = 4 per housing system (pens) for average feed intake and feed conversion ratio. Values are least square means.
[b] CD: Duroc sire line pigs, n = 40; CS: synthetic sire line (P76) pigs, n = 38. Values are least square means.
[c] Statistical significance of housing system (H), genotype (G), replicate (R) and sex (S); ***$p<0.001$; **$p<0.01$; *$p<0.05$; ns: $p>0.05$. Rsd: Residual standard deviation.
[d] Interaction between Genotype and Replicate was found ($p<0.05$).

there was no interaction with housing system or genotype on these traits. As usually reported, M grew faster than F (998 *vs.* 947 g/d, $p<0.01$). The lower ambient temperature in the BO than SF housing system, in particular during winter, may explain the higher feed intake and consequently the faster growth rate of the BO pigs. Indeed, the increase in pig voluntary feed intake as a consequence of the decrease in ambient temperature is well established (Le Dividich, Noblet, Herpin, Van Milgen, & Quiniou, 1998). The higher space allowance in the BO compared with the SF housing system, providing easier access of pigs to the feeder in particular at the end of the finishing period, probably contributed also to their higher feed intake and consequently faster growth rate, in agreement with Hamilton, Ellis, Wolter, Schinckel, and Wilson (2003a). These results confirm previous findings (Lebret, Meunier-Salaün, et al., 2006) and are in agreement with other studies reporting improved growth performance of pigs reared in straw-bedded pens or offered an outdoor access, i.e. reared at lower ambient temperature and offered higher pen space, as compared with conventional husbandry conditions (Beattie, O'Connell, & Moss, 2000; Lebret, 2008; Lebret et al., 2002 for review). Since the experiment was designed to evaluate the influence of housing system on plasma and muscle parameters and meat quality, BO and SF pigs were slaughtered at a constant age and not a constant weight. In commercial practices, pigs would be slaughtered at a set market weight (approximately 110 kg). Due to the higher growth rate of the BO compared with the SF pigs in particular during the finishing (70–110 kg) period (1040 *vs.* 925 g/d, $p<0.001$), this would correspond to a difference in slaughter age of 5 days, which is small from a "physiological" point of view.

3.2. Carcass traits

The BO pigs had heavier carcasses than the SF pigs (+3.6 kg, $p<0.01$) as a consequence of their higher empty body weight. All the other carcass traits: dressing, muscle and mean back fat depths, weight of internal fat, lean meat content, drip loss, as well as proportions of wholesale cuts, were not significantly affected by the housing system (Table 1). CS and CD pigs exhibited similar average carcass weight, dressing, muscle and fat depths and commercial lean meat content (LMC FOM) as well as loin, shoulder and belly proportions, whereas CD pigs had significantly lower ham and higher back fat proportions than CS pigs, leading to lower lean meat content determined from weights of wholesale cuts for the CD carcasses (−1.4 point, $p<0.05$). On average, pigs reared during winter exhibited higher carcass weight (+2.8 kg, $p<0.05$) in connection with their higher empty body weight, whereas carcass dressing, muscle and fat depths and lean meat content, were not statistically different between the two seasons. However, lower carcass drip loss (−0.2 point, $p<0.001$), higher average proportions of loin (+1.5 point, $p<0.001$) and backfat (+0.7 point, $p<0.01$) and lower proportions of belly (−2.0 point, $p<0.01$) and shoulder (−0.4 point, $p<0.05$) were noted for pigs reared during the winter compared with those reared during the spring season. Even if the main effects of genotype and replicate (season) on carcass quality did not reach statistical significance for many traits under study, significant interaction effects between genotype and replicate were reported. CS pigs slaughtered during winter had leaner carcasses than CS pigs slaughtered in spring, or CD pigs at both seasons, as measured by their lower mean back fat thickness ($p<0.01$) and higher lean meat content determined from both cuts weights ($p<0.01$) and FOM (60.8 *vs.* 58.6, 59.4 and 58.9% for winter CS, spring CS, winter CD and spring CD respectively, $p<0.05$). The season effect was also more pronounced for CS than CD pigs for loin ($p<0.05$) and shoulder ($p<0.01$) proportions, whereas for backfat, CD pigs slaughtered in winter exhibited higher levels than CD pigs slaughtered in spring (8.6% *vs.* 7.2%, $p<0.001$) than CS pigs at both seasons (7.4% in winter and 7.5% in spring, $p>0.05$). Therefore, the influence of genotype on carcass traits differed according to the season. M exhibited fatter carcasses than F with thicker back fat (+1.8 mm, $p<0.05$), lower LMC (58.4 *vs.* 60.4% FOM, $p<0.01$), higher proportions of backfat (+1.1 point, $p<0.001$) and shoulder (+0.5 point, $p<0.05$), and lower proportion of loin (−1.1 point, $p<0.01$) than F.

The lack of any significant effect of the housing system on carcass fatness and composition is in agreement with the results of Van der Wal et al. (1993), and Lebret et al. (2002) for pigs reared on straw bedding and/or with outdoor access, compared with conventional systems. By contrast, we previously reported fatter carcasses (i.e., higher back fat depth and lower LMC) for synthetic line pigs (as in the present study) reared in the BO compared with the SF housing system (Lebret, Meunier-Salaün, et al., 2006), in agreement with Beattie et al. (2000) and Gentry, McGlone, Blanton, and Miller (2002) for pigs reared on straw bedding compared with slatted floor. These conflicting results indicate that various factors such as climatic conditions (including their variations within the growing–finishing period), pig genotype, influence the deposition of muscle and fat during growth and thereby carcass quality, depending on the housing system. In conclusion, the present results confirm the higher variability generally reported for body composition and carcass quality of pigs produced in alternative compared to conventional housing systems (Lebret, 2008; Millet, Moons, Van Oeckel, & Janssens, 2005, for reviews).

3.3. Urine and plasma parameters assessed during the rearing period and after slaughter

The housing system and the genotype did not influence ($p>0.05$) the urinary concentration of cortisol, cortisone, adrenaline and noradrenaline at 70 kg LW (data analyzed on the basis of Log values and expressed relative to creatinine; Fig. 1). Since hormone levels were measured in urine collected in the morning, they reflected hormone excretion during nighttime. A lack of influence of the housing system (no bedding *vs.* straw bedding + more space) on salivary cortisol level during the night was previously observed (De Jong et al., 2000) whereas higher cortisol levels in the enriched environment (De Jong et al., 2000; Klont et al., 2001) or no effect of housing (Morrison, Johnston, & Hilbrands, 2007) in the daytime period were observed. When considering all animals, there was a positive relationship between cortisol level at 70 kg LW and backfat percentage ($r=0.38$, $p=0.002$) and a negative relationship between cortisol and LMC FOM ($r=-0.46$, $p<0.001$). These results agree with the positive association found between carcass fatness and basal cortisol level, both within and between breeds or in crossbred populations (Foury et al., 2005, 2007).

Just after slaughter, urine levels of cortisol, cortisone, and adrenaline and noradrenaline did not differ ($p>0.05$) between the BO and SF housing systems (Fig. 2). Cortisol, cortisone and noradrenaline levels were similar between CD and CS pigs after slaughter, but CD pigs exhibited higher urine adrenaline level than CS pigs ($p=0.002$). The housing system did not influence the levels of ACTH and cortisol in plasma collected at slaughter (Fig. 3). A significant genotype effect with higher plasma ACTH level in CS than CD pigs ($p<0.001$) was observed, whereas plasma cortisol did not differ between genotypes. The concentrations in plasma glucose and lactate as well as the plasma creatine kinase activity, were not influenced by the housing system (Table 2). Genotype did not influence plasma glucose and lactate levels, but CD pigs exhibited lower CK activity (−27%, $p<0.05$) than CS pigs. There were no significant interactions between genotype and housing system on these parameters.

The lack of any effect of the housing system on urine and plasma hormones and metabolite concentrations at slaughter is in agreement with previous findings comparing similar housing systems (Lebret, Meunier-Salaün, et al., 2006) or comparing pigs reared outdoor on a courtyard with a shed or indoors on slatted floors (Barton-Gade, 2008; Lebret, Foury, et al., 2006). These results are in accordance with the

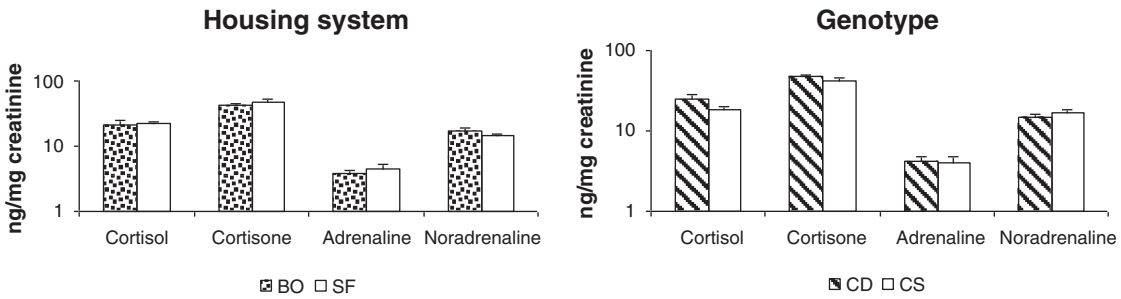

Fig. 1. Urine hormone levels during the rearing period (70 kg LW; least square means + SEM), according to pig housing system (BO: indoor bedding and outdoor area; SF: conventional on slatted floor) or genotype (CD: Duroc sire line; CS: synthetic sire line). None of the comparisons were significantly different.

lack of influence of the housing system on the salivary cortisol responses to various stressors (De Jong et al., 1998). Regarding CK activity, the data show no effect of the housing system, contrary to previous results showing higher plasma CK activity that could be associated with higher numbers of aggressive events between animals during lairage for conventional compared with outdoor reared pigs (Lebret, Foury, et al., 2006), but are in an agreement with Barton-Gade (2008) comparing outdoor and conventional rearing systems. In the present study, BO and SF pigs were handled in the same way and very frequently throughout the study. Therefore they were very familiar with human interaction prior to transport to slaughter. Moreover, they were transported in small groups and not mixed during loading, transport or lairage and, compared to commercial transport and slaughter, the stress experienced by the pigs in the present study during preslaughter handling and slaughtering was probably very low and contributed to the very few differences found in stress indicators between BO and SF pigs.

Apart from the lack of any housing effect, plasma ACTH and CK activities were both higher in CS than in CD pigs and were significantly correlated ($r = 0.29$, $p = 0.009$), suggesting a higher response of the CS pigs to the slaughtering procedure. Indeed, ACTH increases a few minutes after the application of a stressor (Prunier et al., 2005; Warriss, Brown, & Adams, 1994). The higher plasma CK activity and lower urine adrenaline levels in the CS pigs compared with the CD pigs, may be associated with the higher lean meat content (cuts) and lower percentage of backfat of the CS pigs, in agreement with the positive correlation between carcass leanness and serum CK activity, and the negative correlation between carcass leanness and urine adrenaline level reported by Foury et al. (2007).

3.4. Meat quality

The influence of housing on meat quality traits slightly differed according to the muscle considered: LL (Table 3), BF and SM (Table 4). The housing system did not influence ($p > 0.05$) the rate of *p.m.* pH decline (evaluated by pH_1) in LL and BF muscles, whereas the BO pigs had significantly lower pH_1 (−.10 pH unit, $p = 0.047$) in the SM, than SF pigs. However, average pH_1 values remained at acceptable values. In the three muscles, ultimate pH was not affected by the housing system, but BO housing led to higher LL drip losses, 2 and 4 days *p.m.* Meat colour was slightly modified, with BO pigs having higher yellowness (b^*) values in the 3 muscles and higher redness (a^*) values in the SM muscle, compared with SF pigs. This led to higher saturation (or chroma, C^*) values in the ham muscles (BF and SM) and higher hue angle (h°) in the loin (LL) of BO pigs, and would be interpreted as a more "intense" visual colour in the ham, and a less red/more yellow visual colour in the loin, even though differences between BO and SF pigs remained quite low. Free glucose and glucose-6-phosphate concentrations were higher ($p < 0.001$) in the 3 muscles, and lactate concentration was higher in the BF of the BO than SF pigs, whereas glucose from glycogen hydrolysis was not different between BO and SF pigs. This led to higher GP in LL and SM muscles of BO pigs (+8.0 point, $p < 0.05$), whereas the difference did not reach significance in the BF muscle ($p = 0.13$). Finally, intramuscular fat content (IMF) increased in the 3 muscles of BO compared with SF pigs (+0.40 point percentage, $p < 0.01$). When included as a covariate in the model for analysis of variance, slaughter weight had no significant effect on GP ($p > 0.25$) or IMF content ($p > 0.66$) in all three muscles, but the effect of housing system remained significant ($p < 0.05$ for GP in LL and SM, $p < 0.01$ for IMF). This indicates that the higher GP (LL and SM) and IMF contents (LL, SM and BF) observed in the BO compared with the SF pigs, are a consequence of the housing system and do not result from the higher slaughter weight of the BO pigs.

The other main factors under study, i.e. genotype, replicate and sex had some significant effects on meat quality traits even though there were no significant interaction between these factors and the housing system. Regarding genotype, higher ($p < 0.01$) IMF levels were found in the 3 muscles of CD compared with CS pigs. A slightly higher b^* value was found in the BF muscle for CD compared with CS pigs. The replicate (season) significantly influenced meat quality, with higher pH_1 (+0.10 unit, $p < 0.05$) and lower pH_u (−0.25 unit on average, $p < 0.001$) in the three muscles of pigs reared and slaughtered during winter, compared with pigs slaughtered in spring. In the SM and BF muscles, 'winter' pigs also had higher free glucose + G-6-P, and GP

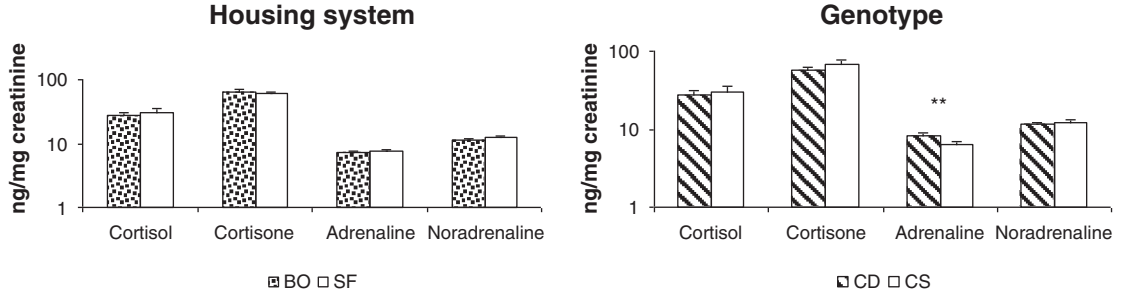

Fig. 2. Urine hormone levels after slaughter (least square means + SEM), according to pig housing system (BO: indoor bedding and outdoor area; SF: conventional on slatted floor) or genotype (CD: Duroc sire line; CS: synthetic sire line). $^{**}p < 0.01$.

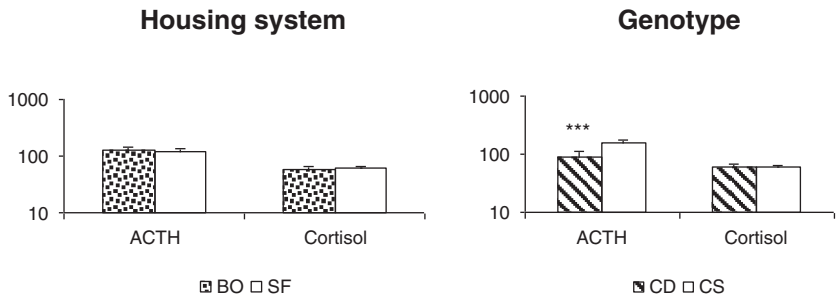

Fig. 3. Plasma ACTH (pg/ml) and cortisol (ng/ml) levels at slaughter (least square means + SEM), according to pig housing system (BO: indoor bedding and outdoor area; SF: conventional on slatted floor) or genotype (CD: Duroc sire line; CS: synthetic sire line). ***$p<0.001$.

levels (+10 μmol eq. lactate/g, $p<0.05$). However, the GP increase in the winter compared with the spring replicate is low and would probably be insufficient to explain the lower pH_u observed in the 'winter' pigs. This suggests that GP is not the only factor determining the extent of muscle *p.m.* pH drop, and that other biochemical mechanisms influence ultimate pH in agreement with the results of Scheffe and Gerrard (2009). Colour of ham muscles was affected, with higher b* and h° values in both BF and SM, and higher C* value in the SM of the 'winter' pigs. Sex influenced only IMF, with higher levels for M than for F (+0.20, +0.30 and +0.50, in the LL, SM and BF muscles, respectively, $p<0.05$).

The lack of any significant effect of the housing system on LL and BF pH_1 values agrees with the similar plasma hormones and CK levels at slaughter in BO and SF pigs, and confirm previous findings (Lebret, Meunier-Salaün, et al., 2006). In the BF muscle, the slightly higher lactate content ($p<0.05$) did not significantly influence pH_1 even though these traits are highly correlated ($r=-0.77$, $p<0.001$). On the other hand, in the SM muscle, the lower pH_1 was not associated with a significantly higher lactate content despite their high correlation ($r=-0.68$, $p<0.001$). Even though the BO system led to generally higher muscle GP, ultimate pH was not modified in the three muscles. By contrast, lower pH_u and higher GP were found in SM and BF muscles of BO compared with SF pigs in our previous study. This indicates that the impact of housing on muscle metabolism and pork quality can vary among studies even when using the same CS genotype, and that other non-controlled factors can affect the muscle metabolic response to the housing system, like the average and variations in ambient temperature and the level of physical activity of animals (Gondret, Combes, Lefaucheur, & Lebret, 2005). In agreement with the present results, most studies have generally reported no significant or only limited impacts of indoor enrichment or outdoor access *vs.* conventional housing on LL, SM or BF pH_1 and pH_u values (Beattie et al., 2000; Geverink, de Jong, Lambooij, Blokhuis, & Wiegant, 1999; Klont et al., 2001; Millet et al., 2005; Van der Wal et al., 1993). Despite similar LL pH_1 and pH_u values, meat drip loss was increased with the BO system, confirming our previous findings. These results agree with those of Hamilton, Ellis, Wolter, McKeith, and Wilson (2003) for pigs reared in a spacious *vs.* crowded environment. The results may be explained by a higher rate of muscle glycolysis and lactate production in the early *p.m.* hours for the BO than SF pigs, as found by Klont et al. (2001) and Schäfer, Rosenvold, Purslow, Andersen, and Henckel (2002) who highlighted the importance of muscle metabolic activity during the 2 to 4 *p.m.* h on subsequent pork drip loss. LL lactate content or pH was not determined at those times, but a high positive correlation between lactate content at 25 min and drip at 2 ($r=0.55$, $p<0.001$) and 4 ($r=0.50$, $p<0.001$) days *p.m.* was found. This indicates that despite limited effects on pH_1 and pH_u as well as muscle lactate content and GP, other important meat quality traits can be affected by the housing conditions. No difference in meat drip loss from pigs raised in "enriched" *vs.* conventional systems were found by Van der Wal et al. (1993), Geverink et al. (1999), and Beattie et al. (2000), but higher drip of pork from free-range (extensive) compared with conventional pigs has been reported (Lebret, 2008 for review).

The influence of housing on pork colour, with higher yellowness, saturation and hue of meat from BO pigs confirms previous results. More yellow and/or darker meat was reported in free range compared

Table 2
Plasma parameters determined at slaughter.

	Housing system[a]		Genotype[b]		Rsd	Sign[c]			
	BO	SF	CD	CS		H	G	R	S
Glucose, mg/ml	1.05	1.10	1.08	1.08	0.14	ns	ns	ns	ns
Lactate, μmol/ml	5.60	4.61	5.12	5.09	3.23	ns	ns	ns	ns
Creatine kinase, U/ml	2.28	2.67	2.09	2.86	1.70	ns	*	ns	ns

[a] BO: outdoor area with indoor bedding, n = 39; SF: conventional on slatted floor, n = 39. Values are least square means.
[b] CD: Duroc sire line pigs, n = 40; CS: synthetic sire line (P76) pigs, n = 38. Values are least square means.
[c] Statistical significance of housing system (H), genotype (G), replicate (R) and sex (S); *$p<0.05$; ns: $p>0.05$. Rsd: Residual standard deviation.

Table 3
Meat quality parameters determined on loin (*Longissimus lumborum*) muscle.

	Housing system[a]		Genotype[b]		Rsd	Sign[c]			
	BO	SF	CD	CS		H	G	R	S
pH_1	6.39	6.42	6.40	6.40	0.17	ns	ns	**	ns
pH_u	5.57	5.56	5.56	5.58	0.11	ns	ns	***	ns
Drip losses, %									
2 d post mortem	3.8	2.3	3.0	3.1	1.7	***	ns	ns	ns
4 d post mortem	6.6	4.7	5.6	5.8	2.1	***	ns	ns	ns
Colour									
L*	55.6	54.5	55.4	54.7	2.9	ns	ns	ns	ns
a*	6.6	6.4	6.4	6.7	1.4	ns	ns	ns	ns
b*	5.5	4.9	5.2	5.1	0.9	**	ns	ns	ns
C*	8.6	8.1	8.3	8.5	1.5	ns	ns	ns	ns
h (hue), °	40.0	37.1	39.1	38.0	5.4	*	ns	ns	ns
Lactate, μmol/g	49.4	48.4	49.1	48.7	12.0	ns	ns	ns	ns
Free glucose + G-6-P, μmol/g[d]	5.07	3.33	3.82	4.58	1.71	***	ns	ns	ns
Glucose (glycogen), μmol/g[e]	42.7	41.3	42.3	41.8	9.57	ns	ns	ns	ns
GP, μmol/g[f]	145.3	137.7	141.4	141.6	13.3	*	ns	ns	ns
Intramuscular fat content, %	2.10	1.73	2.12	1.71	0.38	***	***	ns	*

[a] BO: outdoor area with indoor bedding, n = 39; SF: conventional on slatted floor, n = 39. Values are least square means.
[b] CD: Duroc sire line pigs, n = 40; CS: synthetic sire line (P76) pigs, n = 38. Values are least square means.
[c] Statistical significance of housing system (H), genotype (G), replicate (R) and sex (S); ***$p<0.001$; **$p<0.01$; *$p<0.05$; ns: $p>0.05$. Rsd: Residual standard deviation.
[d] Glucose-6-phosphate.
[e] Glucose issued from glycogen hydrolysis.
[f] Glycolytic potential, micromoles of equivalent lactate per gram of muscle.

Table 4
Meat quality parameters determined on ham (*Biceps femoris* and *Semimembranosus*) muscles.

	Housing system[a]		Genotype[b]		Rsd	Sign[c]			
	BO	SF	CD	CS		H	G	R	S
Biceps femoris									
pH_1	6.39	6.45	6.44	6.40	0.21	ns	ns	*	ns
pH_u	5.58	5.59	5.58	5.59	0.11	ns	ns	***	ns
Colour									
L*	52.2	51.1	51.8	51.5	2.8	ns	ns	ns	ns
a*	11.2	10.5	11.1	10.6	1.7	ns	ns	ns	ns
b*	6.3	5.8	6.4	5.8	1.1	*	*	***	ns
C*	12.9	12.0	12.8	12.1	1.8	*	ns	*	ns
h (hue), °	29.7	29.0	29.9	28.8	4.6	ns	ns	**	ns
Lactate, µmol/g	47.4	39.9	43.9	43.5	14.5	*	ns	ns	ns
Free glucose + G-6-P, µmol/g[d]	4.84	3.22	3.95	4.11	1.79	***	ns	*	ns
Glucose (glycogen), µmol/g[e]	43.2	45.7	45.7	43.2	10.8	ns	ns	ns	ns
GP, µmol/g[f]	143.5	137.8	143.2	138.1	16.5	ns	ns	*	ns
Intramuscular fat content, %	2.55	2.14	2.72	1.97	0.62	**	***	ns	***
Semimembranosus									
pH_1	6.40	6.50	6.45	6.45	0.21	*	ns	**	ns
pH_u	5.60	5.61	5.60	5.61	0.11	ns	ns	***	ns
Colour									
L*	53.1	52.3	52.9	52.5	2.8	ns	ns	ns	ns
a*	10.3	8.9	9.4	9.7	1.5	***	ns	ns	ns
b*	6.5	5.6	6.1	6.0	1.0	***	ns	***	ns
C*	12.2	10.5	11.3	11.4	1.6	***	ns	ns	ns
h (hue), °	32.3	32.0	32.7	31.6	4.2	ns	ns	***	ns
Lactate, µmol/g	46.6	40.8	43.9	43.5	16.7	ns	ns	ns	ns
Free glucose + G-6-P, µmol/g[d]	4.91	3.18	3.74	4.35	42.5	***	ns	*	ns
Glucose (glycogen), µmol/g[e]	46.0	46.4	47.2	45.2	11.3	ns	ns	ns	ns
GP, µmol/g[f]	148.5	139.9	145.9	142.6	15.3	*	ns	**	ns
Intramuscular fat content, %	2.27	1.91	2.25	1.93	0.54	**	**	*	*

[a] BO: outdoor area with indoor bedding, n = 39; SF: conventional on slatted floor, n = 39. Values are least square means.
[b] CD: Duroc sire line pigs, n = 40; CS: synthetic sire line (P76) pigs, n = 38. Values are least square means.
[c] Statistical significance of housing system (H), genotype (G), replicate (R) and sex (S); ***$p<0.001$; **$p<0.01$; *$p<0.05$; ns: $p>0.05$. Rsd: Residual standard deviation.
[d] Glucose-6-phosphate.
[e] Glucose issued from glycogen hydrolysis.
[f] Glycolytic potential, micromoles of equivalent lactate per gram of muscle.

with indoor reared pigs (Bee, Guex, & Herzog, 2004; Warriss, Kestin, & Robinson, 1983). The increased muscle activity and the shift towards a more oxidative muscle metabolism as a consequence of both outdoor access and higher space allowance in the BO (and free range) systems (Gondret et al., 2005) could explain these results. By contrast, Van der Wal et al. (1993), Geverink et al. (1999) and Klont et al. (2001) found no significant effect of outdoor access or indoor enrichment on L*, a* and b* values in the LL and BF muscles.

The higher IMF levels in loin and ham muscles of the BO pigs confirm previous results (Lebret, Meunier-Salaün, et al., 2006). However, it is noteworthy that in the present experiment, IMF increased independently of carcass fatness, despite the positive genetic correlation between these two traits (r = 0.30 on average according to Sellier, 1998), thus demonstrating that the housing system can affect specifically the deposition rate of muscle lipids without negative impact on carcass commercial value. As mentioned above, the higher IMF of BO pigs is not due to their higher slaughter weight but is indeed an effect of the housing system. In accordance with the present study, a higher IMF content in the SM of pigs offered outdoor access has been reported (Lebret et al., 2002), whereas Van der Wal et al. (1993) found similar IMF values for outdoor and indoor pigs. In addition, higher IMF levels were often observed in pigs raised indoor on bedding, but this was usually associated with increased carcass fatness (Beattie et al., 2000; Gentry et al., 2002). The higher muscle lipid content in the CD compared with CS pigs is in agreement with the numerous reports of high IMF contents in pure or cross bred Duroc pigs (Ngapo & Gariépy, 2008; Sellier, 1998), and was expected. However, the response of pigs to housing system on IMF content was similar in both genotypes.

3.5. Meat eating quality

Eating quality of pork was evaluated only on pigs of the winter replicate. Meat from both systems had no abnormal odour or flavour that might have hidden the specific effects of housing system or genotype on sensory traits (Fig. 4). The BO housing system led to higher juiciness scores (+0.4 point, $p<0.05$) whereas meat tenderness and flavour remained unaffected, confirming previous results (Lebret, Meunier-Salaün, et al., 2006). When included as covariate in the statistical analysis, slaughter weight had no significant effect on meat juiciness ($p = 0.92$) but the influence of housing system on this trait remained significant ($p<0.05$). This indicates that the juicier meat from BO than SF pigs is not due to the higher slaughter weight of the BO pigs, but is a consequence of the housing system. Pearson's correlation coefficients calculated between meat juiciness and muscle traits (IMF content, drip loss, pH_1, and pH_u, which are well known to influence pork eating quality) did not reach significance ($p>0.05$). This suggests that the higher juiciness of the BO meat resulted from many factors that interacted with each other, rather than a single one with a strong effect. Indeed, a positive correlation between IMF content and pork juiciness is generally observed above the threshold of 2.5% IMF (Lebret, 2009), whereas the average value was 1.80% in the meat (LL, winter replicate) submitted to sensory analysis.

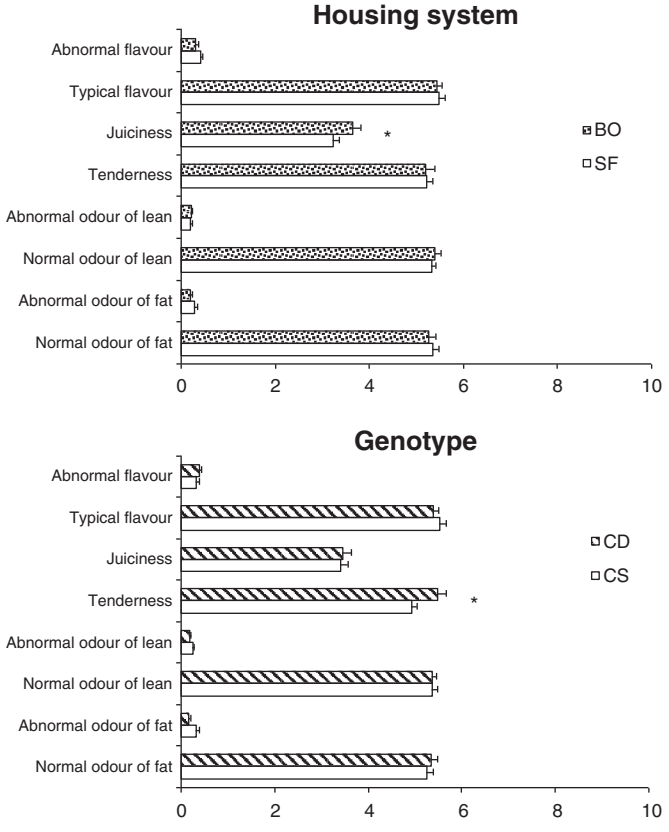

Fig. 4. Sensory quality traits of loin (score 0 to 10, least square means + SEM) according to pig housing system (BO: indoor bedding and outdoor area; SF: conventional on slatted floor) or genotype (CD: Duroc sire line; CS: synthetic sire line). *$p<0.05$.

Moreover, a positive effect of IMF on meat juiciness is generally observed when sensory evaluation is undertaken on loin roasts (Lebret, 2009 for review). Pork was prepared as grilled chops in the present study. This cooking method has probably affected the relationships between muscle properties and eating quality, especially juiciness which is the eating trait the most affected by pork cooking conditions, according to Ngapo and Gariépy (2008). Inconsistent results have been reported on the influence of housing system on pork eating quality. Maw, Fowler, Hamilton, and Petchey (2001) found higher flavour scores for bacon from pigs reared on bedding compared to slatted or concrete floors. On the other hand, Van der Wal et al. (1993) found no difference in meat juiciness and tenderness between "Scharrel" (outdoor access) and conventional pigs.

Pork eating quality was affected by genotype, with the CD pigs exhibiting more tender meat than the CS (+0.6 point, $p<0.05$), but there was no significant interaction between housing system and genotype on any of the other eating quality traits. The higher eating quality of Duroc crossbred pigs is in agreement with reports showing improved tenderness, juiciness, or flavour of pork from pure or cross bred Duroc pigs (Ngapo & Gariépy, 2008 for review). These results are often ascribed to the higher IMF content of Duroc pigs. Using all the samples analyzed for sensory traits it was found that the tenderness score was positively correlated to IMF content ($r=0.38$, $p=0.02$). On these samples, difference in IMF was higher between genotypes (2.06 *vs.* 1.59% for CD and CS pigs, respectively, $p<0.001$) than between housing systems (1.95 *vs.* 1.70% for BO and SF pigs, respectively, $p=0.044$) and the interaction between housing system and genotype was not significant ($p=0.99$). Therefore, the higher tenderness score of the CD compared with CS pigs may be ascribed to their higher IMF content, whereas the higher meat juiciness in the BO pigs would have been determined by other muscle properties in this experiment.

4. Conclusion

The animal response to the housing system (alternative on bedding with outdoor area *vs.* conventional on slatted floor) in terms of growth performance, reactivity to pre-slaughter handling and meat quality, did not differ between genotypes of pigs differing in the sire line, Duroc or synthetic. The results confirm the increase in feed intake and growth rate with the BO housing system. Even though the BO pigs were over 5 kg heavier, they did not differ in carcass composition from pigs raised in the SF system. This highlights the influence of environmental conditions (average and variations in ambient temperature and level of physical activity) on the rates of muscle and fat deposition during growth of pigs. Physiological response of pigs to pre-slaughter handling was not affected by the housing system, leading to similar or only limited differences in the rate and extent of *p.m.* pH decline in the loin (LL) and ham (BF and SM) muscles of BO compared with SF pigs. The BO housing system influenced meat colour through increased yellowness, saturation or hue values depending on the muscle, and led to higher LL drip losses and higher IMF levels in loin and ham muscles. Loin meat (grilled chops) from the heavier BO pigs was judged juicier compared with meat from SF pigs. Regarding pig genotype, CD pigs had higher IMF levels and meat tenderness scores than the CS pigs. Finally, the BO system resulted in higher feed intake, faster growth rate, heavier slaughter weight, increased intramuscular fat, and improved eating quality in both genotypes.

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