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Effects of environment and breed on growth performance and meat quality of fattening pigs

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Abstract

Meat quality is not only influenced by breed but also rearing environment. The aim of this study was to evaluate the influence of different housing environments on growth performance, carcase traits, meat quality, physiological response pre-slaughter and fatty acid composition in two pig breeds. A total of 120 growing pigs at 60–70 days of age were arranged in a 2 × 2 factorial design with the breeds (Duroc × Landrace × Large White [D × L × LW] and Duroc × Landrace × Min pig [D × L × M]) and environmental enrichment (barren concrete floor or enriched with straw bedding) as factors. Each treatment was performed in triplicate with ten pigs per replicate. The pigs housed in the enriched environment exhibited a higher average daily gain, average daily feed intake, saturated fatty acid percentage and backfat depth than the pigs reared in the barren environment. Plasma cortisol levels were lower and growth hormone higher in enriched compared to barren pens. The D × L × M pigs showed lower cooking loss compared with the D × L × LW pigs. Moreover, the D × L × M pigs exhibited poor growth performance but had a better water-holding capacity. Only carcase traits and meat quality interaction effects were observed. We concluded that an enriched environment can reduce pre-slaughter stress and improve the growth performance of pigs and modulate the fatty acid composition of pork products.

Keywords: *animal welfare, environment, growth performance, meat quality, pig breed, pigs*

Introduction

Livestock housing systems can affect many aspects of pork production, such as eating quality of pork products, environmental impact of pig farming, animal welfare and production costs. It has been demonstrated that the different housing systems and pigs' breed may influence meat quality in the fattening pig (Bonneau & Lebret 2010). However, many studies investigating the effect of housing system on both growth performance and meat quality have yielded mixed results (van de Weerd *et al* 2005; Lebret *et al* 2006; Teixeira *et al* 2012; Loponte *et al* 2018). While some studies reported that growth performance and carcase quality differ between barren housing and enriched environment (Beattie *et al* 2000; Lebret *et al* 2006; Loponte *et al* 2018), others found no differences (Klont *et al* 2001; van de Weerd *et al* 2005; Teixeira *et al* 2012). Furthermore, we currently lack knowledge regarding the adaptability of pig breeds to enriched rearing and the choice of breed may also have an impact on meat quality (Terlouw *et al* 2009; Lebret *et al* 2011).

This paper focused on the effects of the housing system (straw bedding vs the conventional barren concrete floor) and breed on various parameters of pork production. The two breeds investigated were D × L × LW (Duroc × Landrace × Large White) and D × L × M (Duroc × Landrace × Min pig) pigs. The Min pig is a local breed in North-eastern China and a source of good meat; it also shows high tolerance towards poor feed quality and cold climate (Wang *et al* 2002; Liu *et al* 2017). D × L × M is a tertiary offspring produced by the binary offspring sows and Duroc boars, with the Min pigs as the female parent and Landrace as the male. Local pork production chains often claim this breed to be of typical or high eating quality; hence, there was a need to study differences in product properties between the local and the conventional breed (D × L × LW) when analysing the effect of rearing systems. Here, we reported the influence of different housing environments on growth performance, carcase traits, meat quality, physiological response to stress, and fatty acid composition in the two different breeds, in order to provide a valuable assessment of the meat quality of the local breed for future swine production.

Materials and methods

Ethics statement

All experimental procedures in this research were reviewed and approved by the Institutional Animal Care and Use Committee of the Northeast Agricultural University (ethical number IACUCNEAU20150616).

Study animals and experimental design

This experiment was conducted with 120 barrows (two breeds of *Sus scrofa domesticus* with 60 pigs per breed) aged 60–70 days. The Duroc × Landrace × Large White (D × L × LW), and Duroc × Landrace × Min pig (D × L × M) pigs were reared in Heilongjiang National Animal Husbandry Park (Acheng, Heilongjiang Province, PR China). The Min pig is a cold-resistant local breed with black hair farmed in North-eastern China, and the D × L × M pig is a high-quality breed selected from crossbreeding and known for having grey, brown and white hair. The experiment was divided into two treatments, each with three replicates comprising ten pigs per pen. Therefore, each breed was reared in two environments (either a conventional barren concrete floor [CF], or with straw bedding [SB]).

Housing and management

All animals were reared in equally sized pens (5.8 × 4.8 × 1.2 m; length × width × height). In the enriched housing system, the concrete floor was covered with straw (2.50 [± 0.25] kg) that was changed weekly, while litter was not provided in the barren environment. Every experimental pen was equipped with Osborne Feed Intake Recording Equipment (FIRE, Osborne Industries Inc, Osborne, KS, USA) for recording feed intake and bodyweight, and the electronic ear-tag identified the individual when the pig entered the equipment. This equipment recorded the information and transferred the data to the computer. All pigs were fed the same diet from the Osborne FIRE (13.02 MJ per kg digestible energy, 17.0% crude protein, 3.40% crude fat, and 1.0% lysine). Ear-tags were applied to the pigs before they entered the pen, and the numbers recorded to distinguish between individuals.

The housing was well-ventilated. A Kestrel 4000 hygrothermograph (Kestrel, Santa Cruz, CA, USA) was used to monitor the temperature and humidity inside the pens, and the temperature and humidity were recorded daily at 0900 and 1500h. The average temperature and humidity inside the pens were 22.5°C and 72.6%, respectively.

Observations

Growth performance

Growth performance indicators, such as feed intake and bodyweight were recorded by the Osborne FIRE, which can provide a daily record of individual food consumption and bodyweight (BW), thereby allowing calculation of the average daily feed intake (ADFI), average daily gain (ADG), and feed conversion ratio (FCR). The initial BW, final BW, slaughter age (age of BW up to 100 kg) were also obtained with the Osborne FIRE.

Physiological indices

One week prior to slaughter, three pigs were randomly selected from each pen to collect blood samples. At 0800h, 6 ml blood was collected from their ear veins, stored in EDTA tubes, and then centrifuged at 2,000 × g for 10 min at 4°C. After centrifugation, the plasma fractions were collected, labelled, and stored in a refrigerator at −20°C. The concentrations of growth hormone (GH) and cortisol were measured using an ELISA kit (Shanghai Xinle Biotechnology Co Ltd, Shanghai, PR China). The quantification limit of the assay was 10 ng ml^{-1} of plasma, and the coefficient of variation of intra- and inter-assay were 7.2 and 10.0%, respectively.

Handling and slaughter

Pigs were slaughtered at the experimental slaughterhouse of Xinhua (Harbin, Heilongjiang, PR China). Four, well-developed animals from each pen with a BW up to 100 kg were randomly selected for slaughter, making a total of 48 pigs. The animals were fasted one day before being transported to the slaughterhouses and kept in lairage in separate pens for each treatment, where access to water was *ad libitum*. The following morning, they were slaughtered by electrical stunning (85 V) for 15 s and exsanguinated, in accordance with the current local regulations applied in Chinese slaughterhouses.

Meat and carcase quality

After slaughter, the *longissimus* muscle on the left side of the carcase at the thoracolumbar junction was immediately sampled for the determination of pH and tenderness. Meat colour was also evaluated using these muscle samples together with a Minolta Chroma Meter colourimeter (Konica Minolta Inc, Osaka, Japan) to determine the L* (lightness), a* (redness), and b* (yellowness) using the average of nine measurements per sample. Samples of *longissimus* muscle were taken from the region between the fourth and fifth lumbar vertebra on the left side of the carcase for the determination of drip loss and cooking loss at two and four days after slaughter, trimmed of external fat, and weighed. Fresh *longissimus* samples were taken from the region between the first and second lumbar vertebra on the left side of the carcase, trimmed of external fat (about 20 g), minced and stored at −20°C until determination of the intramuscular fat (IMF) content as described previously (Lebret *et al* 2014). Then, carcase traits such as dressing percentage, backfat depth, lean meat percentage, loin eye area (which refers to the cross-sectional area of *longissimus* muscle between the first and second last lumbar vertebra) and ham percentage were measured, in accordance with a well-documented technique (Berthiaume *et al* 2006; Faucitano *et al* 2008; Terlouw *et al* 2009).

Fatty acid composition

After slaughter, the fatty acid composition of the subcutaneous adipose tissue (at the last rib) was determined as described previously (Lebret *et al* 2014). Analyses were then performed on a Trace 1310 Gas Chromatograph

Table 1 Mean (± SEM) growth performance of pigs of differing breed and rearing environment (n = 3).

Item	CF[†]		SB[‡]		Effects	
	D × L × W[§]	D × L × M[#]	D × L × W[§]	D × L × M[#]	E	B
Initial BW (kg)	22.53 (± 0.43)	22.11 (± 0.31)	22.5 (± 0.50)	22.07 (± 0.37)	ns; $F_{1,118}$ = 0.01	ns; $F_{1,118}$ = 1.14
Final BW (kg)	100.62 (± 0.33)	100.28 (± 0.28)	100.66 (± 0.38)	100.15 (± 0.27)	ns; $F_{1,118}$ = 0.02	ns; $F_{1,118}$ = 1.85
Slaughter age (days)	166.43 (± 2.55)	193.69 (± 3.22)	165.65 (± 1.64)	185.70 (± 3.83)	***; $F_{1,118}$ = 14.39	***; $F_{1,118}$ = 11.14
ADFI (kg per day)	1.82 (± 0.30)	1.76 (± 0.04)	2.06 (± 0.02)	2.01 (± 0.06)	***; $F_{1,118}$ = 30.05	ns; $F_{1,118}$ = 1.38
ADG (kg)	0.84 (± 0.12)	0.65 (± 0.02)	0.89 (± 0.16)	0.75 (± 0.03)	***; $F_{1,118}$ = 14.39	***; $F_{1,118}$ = 66.87
FCR (kg per kg)	2.21 (± 0.44)	2.75 (± 0.06)	2.31 (± 0.36)	2.71 (± 0.06)	ns; $F_{1,118}$ = 0.27	***; $F_{1,118}$ = 57.11

[†] CF: conventional barren concrete floor;
[‡] SB: floor with straw bedding;
[§] D × L × LW: Duroc × Landrace × Large White;
[#] D × L × M: Duroc × Landrace × Min pig;
* P < 0.05;
*** P < 0.001.

mass spectrometer (Thermo Fisher Scientific, Waltham, MA, USA). Results were expressed as a percentage of the total fatty acids identified and then ratios of saturated fatty acid (SFA), monounsaturated fatty acid (MUFA), polyunsaturated fatty acid (PUFA), n-6 PUFA and n-3 PUFA were calculated according to the previous method (Wood *et al* 2004).

Statistical analysis

All data were submitted to an analysis of variance with SAS 9.2 (SAS Institute Inc, Cary, NC, USA) using the GLM procedure and a model that included the fixed effects of the housing environment (E), breed (B), as well as their interactions (E × B), which found the following effect:

$Y_{ijk} = \mu + E_i + B_j + E_i \times B_j + e_{ijk}$;

where Y_{ijk} = value observed for characteristics analysed; μ indicates the overall average; E_i indicates the effect of the environments on parameters; B_j indicates the effect of pig breeds on parameters; $E_i \times B_j$ indicates the interaction between the breeds and environments; e_{ijk} = random errors associated with observation. However, the interaction effects were only observed on the parameters of carcase traits and meat quality. The model of growth performance, physiological indices and fatty acid composition were reduced to the main effects only. The experimental design was a 2 × 2, with each test conducted in triplicate. Data are shown as the least square means (± SEM). Probability values less than 0.05 were considered significant. Multiple comparison analyses were performed using the GLM procedure for the indices of the interaction effects.

Results

Growth performance

The housing environment significantly influenced the growth performance of the animals. Compared with CF pigs, the SB pigs had an earlier slaughter age (P < 0.001; $F_{1,118}$ = 14.39), as well as a higher ADFI (P < 0.001; $F_{1,118}$ = 30.05) and ADG (P < 0.001; $F_{1,118}$ = 14.39; Table 1). D × L × M pigs exhibited a later slaughter age (P < 0.001; $F_{1,118}$ = 11.14), lower ADG (P < 0.001; $F_{1,118}$ = 66.87) and higher FCR than D × L × LW pigs (P < 0.001; $F_{1,118}$ = 57.11). However, there were no differences in initial and final BW between the different environments and breeds (P > 0.05).

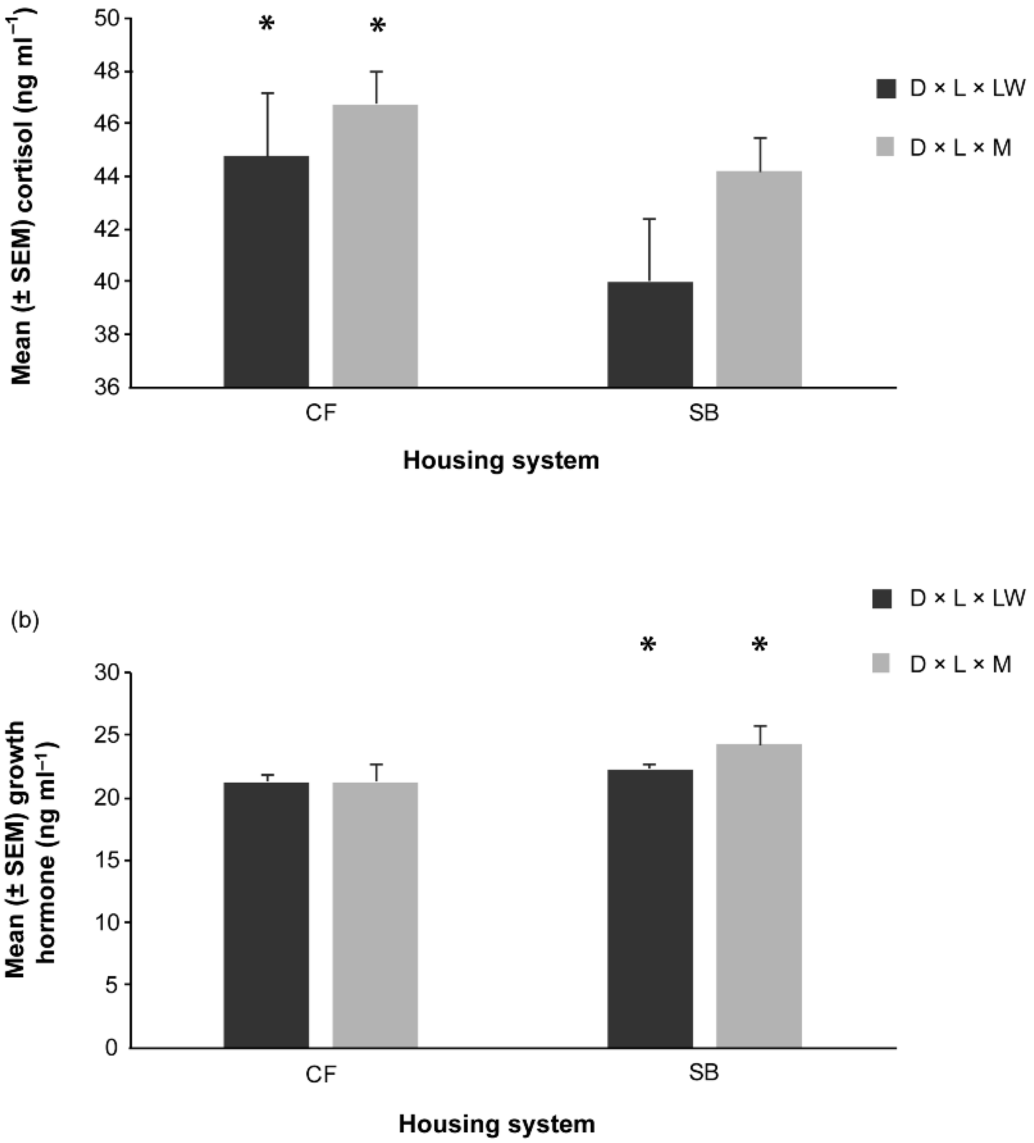
Physiological indices

The housing environment significantly influenced the GH and cortisol concentrations in the plasma pre-slaughter (P < 0.05; Figure 1). However, there were no differences in GH and cortisol concentrations between pig breeds (P > 0.05).

Carcase traits

Only the backfat depth was influenced by the housing environment (P < 0.01; $F_{1,46}$ = 7.63), while all the other carcase traits (dressing and lean meat percentages, loin eye area and ham percentage) showed no differences in environment (see Table 2 in the supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). D × L × LW pigs exhibited a higher lean meat (P < 0.01; $F_{1,46}$ = 8.13) and ham percentage (P < 0.05; $F_{1,46}$ = 5.21) than D × L × M pigs, while D × L × M pigs showed a larger loin eye area

Figure 1



Mean (± SEM) effect of breed and rearing environment on (a) cortisol and (b) growth hormone (GH) levels of fattening pigs. Plasma parameters were determined pre-slaughter according to pig housing system (SB: straw bedding; CF: conventional barren concrete floor) or breed (D × L × LW: Duroc × Landrace × Large White; D × L × M: Duroc × Landrace × Min pig); n = 9. * Significant difference between CF and SB (*P* < 0.05).

compared with D × L × LW pigs ($P < 0.05$; $F_{1,46} = 4.51$). The interaction effects were found in backfat depth ($P < 0.01$; $F_{1,46} = 8.13$), lean meat percentage ($P < 0.01$; $F_{1,46} = 9.61$) and loin eye area ($P < 0.001$; $F_{1,46} = 45.40$). D × L × LW and D × L × M pigs reared in SB housing showed a thicker backfat depth than D × L × LW pigs reared in CF pens (3.15 and 2.85 vs 2.12 cm, respectively; $P < 0.01$). In the CF pens, D × L × LW pigs exhibited a higher lean meat percentage than D × L × M pigs (63.1 vs 49.5%; $P < 0.01$). It is notable that SB-housed D × L × M pigs showed a higher loin eye area than SB-housed D × L × LW pigs (47.11 vs 31.1 cm^2; $P < 0.001$), but in the CF pens, these two breeds showed the opposite trend (35.29 vs 43.62 cm^2; $P < 0.01$).

Meat quality

The housing system did not influence the meat quality parameters, such as ultimate pH (pHu), meat colour, cooking loss, shear force, or IMF content ($P > 0.05$) but did have an effect on drip loss ($P < 0.001$; $F_{1,46} = 12.91$; Table 2; https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Although there were differences in cooking loss between pig breeds ($P < 0.001$; $F_{1,46} = 22.48$), the IMF content of pig breeds showed no difference ($P > 0.05$; $F_{1,46} = 3.36$). D × L × LW pigs exhibited higher L* values than D × L × M pigs ($P < 0.05$; $F_{1,46} = 4.46$). Although the main effects did not have a difference on meat colour or shear force, the interaction effects showed differences on the a* ($P < 0.01$; $F_{1,46} = 9.84$) and b* values ($P < 0.001$; $F_{1,46} = 13.82$) and shear force ($P < 0.001$; $F_{1,46} = 22.61$). SB-housed D × L × M pigs exhibited a lower b* value than SB-housed D × L × LW pigs and CF-housed D × L × M pigs (1.41 vs 2.86 and 2.84, respectively; $P < 0.001$). In addition, SB-housed D × L × M pigs exhibited a higher shear force than D × L × LW pigs (76.38 vs 55.58 N; $P < 0.01$), but in the CF pens, D × L × M pigs produced a lower shear force than D × L × LW pigs (57.82 vs 70.32 N; $P < 0.001$).

Fatty acid composition in the subcutaneous adipose tissue

The enriched environment yielded a higher proportion of SFA ($P < 0.05$; $F_{1,46} = 7.43$), mainly due to a higher C16:0 ratio ($P < 0.01$; $F_{1,46} = 8.57$) in the subcutaneous adipose tissue of the SB-housed pigs compared with the CF-housed pigs (see Table 3 in supplementary material to papers published in *Animal Welfare*: https://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). The higher proportion of C18:3n-3 in the subcutaneous adipose tissue of SB compared to CF ($P < 0.05$; $F_{1,46} = 4.78$), resulted in the higher proportion of n-3 PUFA and lower ratios of n-6 to n-3 PUFA observed in SB pigs. The C20:1 ratio of D × L × M pigs exhibited a significant higher proportion than D × L × LW pigs ($P < 0.01$; $F_{1,46} = 9.13$).

Discussion

Growth performance

The higher ADG exhibited by pigs reared in SB compared to CF housing was in agreement with previous findings (Beattie *et al* 2000; van de Weerd & Day 2009), occurring as a direct consequence of their higher ADFI. Accordingly, this means slaughter occurs at an earlier point in the SB environment. It has been long established that straw is a favourable substrate that stimulates foraging and exploratory behaviour in pigs (van de Weerd *et al* 2003). Therefore, the straw bedding environment increased the amount of physical activity (Bolhuis *et al* 2006; Bulens *et al* 2015), which perhaps contributed to their higher feed intake, and consequently, earlier time to slaughter (van de Weerd & Day 2009). The D × L × M pigs clearly exhibited lower growth performance than the D × L × LW pigs, and local breeds generally exhibited a much lower growth rate than conventional white pig breeds (Labroue *et al* 2000; Lebret *et al* 2014).

Plasma parameters assessed pre-slaughter

Higher blood cortisol levels in domestic animals is generally considered an indicator of chronic stress (Vas *et al* 2013). Here, the cortisol concentration of CF pigs was significantly higher than that of SB pigs, which was consistent with a previous study (Lebret *et al* 2015). If no straw bedding was provided, pigs spent less time exploring compared to those in an enriched environment (Averós *et al* 2010), allowing us to hypothesise that cortisol levels correlate with activity (Rice *et al* 2016). An enriched environment can therefore potentially reduce the stress levels of pigs. We also observed that an enriched housing environment significantly increased the concentration of GH, and the slaughter age of SB pigs was earlier than that of CF pigs. This indicates that an enriched environment has the potential to yield a faster growth rate because the level of activity and feed intake during the rearing period favourably influence growth (Weerd & Day 2009).

Carcase traits

Enriched housing significantly increased the backfat depth, which was in agreement with previous reports showing an enriched environment to significantly improve feed intake, growth rate and improved fat deposition, thereby enhancing backfat depth (Beattie *et al* 2000; Lebret *et al* 2006). The main effects on dressing percentage did not attain statistical significance here but previous work (Lebret *et al* 2014) indicated that an enriched environment would significantly reduce the dressing percentage. In our study, straw was not provided for pigs during the fasting period pre-slaughter, which may have been why no differences in the digestive organs and live weight were observed between both rearing conditions. Unfortunately, the slaughterhouse did not permit collection of organs so we are unable to provide a definitive explanation for this contradictory finding. The interaction effects also indicated that an enriched environment can modulate, to some extent, the loin eye area and lean meat percentage of D × L × M pigs. We speculated that this finding may be associated with the susceptibility of animals towards environmental stressors (Merlot *et al* 2012).

Meat quality

The environment had no effect on the pHu in the *longissimus* muscle, which was consistent with findings elsewhere (Lebret *et al* 2011; Fàbrega *et al* 2019). The pH of meat can be used as an indirect indicator of pre-slaughter handling and animals' stress levels (Kim *et al* 2014). Although cortisol levels suggest an enriched environment could reduce stress, here we saw no major effects on pH values. A higher intramuscular fat content in muscle lowers the water percentage in the meat, resulting in less water available for drip loss post mortem (Klont *et al* 2001). Therefore, we speculated that this low drip loss was caused by high backfat levels in the enriched environment. Decreased cooking losses have been associated with increased water-holding capacity (Terlouw *et al* 2009), therefore, D × L × M has a better water-holding capacity than D × L × LW pigs. Although there was no difference in IMF content between pig breeds, the IMF content of D × L × M has a higher tendency than D × L × LW, which may be explained by the heterosis, while other studies choose pure or binary breeds (Lebret *et al* 2011, 2015).

The environment did not significantly effect meat colour which was in accordance with previously published results (Terlouw *et al* 2009; Fàbrega *et al* 2019), but studies in pigs reared in outdoor housing showed L* values of meat colour to be significantly decreased (Gentry *et al* 2002) while a* (Gentry *et al* 2004) and b* values were higher (Bee *et al* 2004) than in the traditional environment. This may be a result of outdoor housing providing a larger area for activity and, therefore, increasing muscle activity (Gondret *et al* 2005). According to the interaction effect with shear force, D × L × M pigs may be more suitable for rearing in CF pens in order to obtain tender muscle meat.

Fatty acid composition

Breed and housing environment also affected the fatty acid composition of the subcutaneous adipose tissue. The greater proportion of SFA observed in SB-housed pigs, especially that of C16:0, may have been due to the thicker depth of backfat in SB- compared with CF-housed pigs (Aguayo-Ulloa *et al* 2014). The ratio of SFA has an important impact on meat flavour (Wood *et al* 2003). To date, the interest in the fatty acid composition of meat comes mainly from the desire for healthier meat which focuses predominantly on higher PUFA content; a more favourable balance between n-6 and n-3 PUFA (Wood *et al* 2003; Raes *et al* 2004). However, the content of SFA and mono-unsaturated fatty acids (MUFA) increases faster than PUFA as backfat increases, leading to a reduction in the relative proportion of PUFA (Raes *et al* 2004). An enriched environment yielded high levels of C18:3n-3 and n-3 PUFA which may be explained by feeding straw in an enriched environment since certain studies have shown animals reared in a grassland environment to have significantly increased proportions of PUFA in their adipose tissue (Lopez-Bote 1998; Pugliese *et al* 2005; Daza *et al* 2007). The more favourable n-6:n-3 PUFA ration (less than 4) observed in the enriched environment would reduce the risk of cancer and cardiovascular diseases (Enser 2001). Although, in our study, the influence of environment on the SFA was greater than that of PUFA, to some extent it helped modulate the fatty acid composition in a favourable direction.

Minimal differences in fatty acid composition were observed between the two breeds here, a finding also noted previously (Smet *et al* 2004; Wood *et al* 2004, 2008). Although the C20:1 ratio differed between breeds, the MUFA content exhibited no differences; therefore, no differences in total fatty acid composition were found between these two breeds.

Animal welfare implications

Enriched rearing pens are beneficial for pigs from the perspective of welfare; providing an enhanced environment has the further bonus of benefiting production parameters, improving performance, modifying muscle and meat properties and reducing stress. Hence, they are advantageous for producers.

Conclusion

An enriched environment effectively improves growth performance and meat quality and reduces the pre-slaughter stress of fattening pigs. Enriched rearing pens are also beneficial from a welfare point of view. D × L × M pigs are genetically sourced from Min pigs and display the Min pigs' low growth performance, high proportion of carcase fat, but good water-holding capacity. The higher SFA content and lower ratio of n-6: n-3 encountered in the backfat of D × L × M pigs may contribute towards the future production of healthier pork products in local markets. Overall, our results confirm the major effects of breed on growth performance, carcase, meat quality and fatty acid composition and demonstrate that the housing environment of animals, especially the straw bedding system, can modulate the local breed production traits and pork quality in pigs.

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