The relationship within and between production performance and meat quality characteristics in pigs from three different genetic lines

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Abstract

Ninety-six pigs from Large White (LW), Synthetic Genex 3000 (SG) and Meishan-derived dam line (M) genetic lines, each with a mean live body weight (BW) of 20.7±4.2 kg, were used to investigate the relationship that exist between production performance and meat quality parameters for these three genotypes. The animals were assigned to pens in groups of eight and slaughtered at 109.6±3.78 kg BW. At the end of the trial, the LW pigs had the highest (P<0.001) average daily feed intake and average daily gain and protein deposition rates, the M pigs showed (P<0.001) the worst feed conversion, the highest daily backfat gain and the lowest residual energy intake, and the SG pigs had the lowest (P<0.001) daily fat deposition rate. The longissimus muscle of the M pigs had higher a⁎ (P<0.01) and b⁎ (P<0.05) values than the LW pigs, with the SG pigs in between. The M loins also had the highest (P<0.01) shear force value, which may be explained by the lower (P<0.01) soluble collagen content. In spite of their lowest fat deposition rate, the highest (P<0.001) intramuscular fat content was measured in the SG loins, and the highest (P<0.01) protein content was found in the M loins. Eight canonical correlations were obtained between performance and meat quality data, with the first three correlation coefficients of 0.87, 0.66 and 0.64 being significant. Performance and meat quality data were related to a certain extent. Pigs with a higher average daily feed intake also had a higher average daily gain, an average protein deposition rate, residual energy intake and gain-to-feed ratio, and lower meat dry matter, intramuscular fat, a⁎ values and pigment content. Body water content seems to be higher in fast-growing pigs. Furthermore, fast-growing pigs also have lower intramuscular fat, a⁎ values and pigment content. However, there is some indication that the magnitude of these correlations can be breed-dependent. The differences among the studied genotypes are much higher in terms of growth performance than in terms of meat quality traits.

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1. Introduction

For many years, one of the major objectives of the swine industry has been to increase the lean-to-fat
ratio of pig carcasses (Cameron, 1990). As a result, dramatic improvements in the body composition of pigs have been made through genetic selection. Furthermore, because of consumer and industry demands for more uniform and better-quality meats, interest in improving meat quality traits is growing (Dransfield et al., 2005; Ngapo et al., 2007a,b). Knowledge of the relationships between production performance and meat quality characteristics is required to implement selection programs that emphasize product quality.

Correlations between growth rate and meat quality parameters are generally small and negative, but their magnitude may depend on the breed under consideration (de Vries et al., 1994; Bidanel and Ducos, 1995). Similarly, the correlation between feed conversion ratio and meat quality is generally also negative (Ducos et al., 1993; Bidanel and Ducos, 1995).

Information on the relationship between meat eating quality traits and growth and body composition traits is still limited and somewhat contradictory (Lo et al., 1992; de Vries et al., 1994). According to Cameron (1990), eating quality of meat would be reduced by selection for increased carcass leanness as pork flavour and juiciness would become poorer. However, no significant correlation of shear force value with average daily gain and lean percentage was found by de Vries et al. (1994) and low correlations for the score for overall acceptability of meat with growth rate and ultrasonic backfat thickness were reported by Lo et al. (1992). Furthermore, unfavourable genetic correlations between carcass lean meat proportion and tenderness and juiciness and pork flavour intensity and overall acceptability of meat were reported in a number studies reviewed by Sellier (1998).

Although the results of all these trials are fairly consistent, the range of correlation estimates is wide for many traits. This variation can be due to differences between breeds, sample size and the methodology used for the assessment of meat quality traits. On the other hand, Pearson’s correlation and Principal Component’s analyses are commonly used to study the relationship between two or more variables. However, these statistical techniques can not be used to study the relationships between groups of variables. Canonical correlation analysis is novel approach proposed to study the associations between two sets of random variables. The objective of the present study was therefore to investigate with data from three pig genetic lines the existing relationship within production performance parameters, within meat quality characteristics and between these two types of variables.

2. Materials and methods

2.1. Animals and production performance

Ninety-six gilts from three genetic lines [32 Large White (LW) gilts, 32 Synthetic Genex 3000 (SG) gilts and 32 Meishan-derived dam line (M) gilts] were used in this study. The synthetic SG line, which has been selected over the years for larger loin and ham muscle development, is recognized as a purebred type given its consistency and stability in performance. The M line is a F1 synthetic breed derived from a cross between a Meishan female and a hyperprolific LW male (Hypor Inc., Regina, SK, Canada).

The piglets were transported to the Agriculture and Agri-Food Canada (AAFC) Research Centre in Sherbrooke (Quebec, Canada) at 20.7±4.2 kg average live body weight (BW). After their arrival, the animals were distributed by weight and genetic line into 12 pens (4 pens per genotype), each containing 11 pigs. Only 8 pigs per pen were randomly assigned to this study at the beginning of the experiment. The pigs were scanned at the beginning and at 28 d intervals with a dual-energy X-ray absorptiometry (DXA) osteodensitometer (DPX-L model, Lunar Corp., Madison, WI, USA) for the determination of total body fat, lean and minerals. Before each DXA reading, subcutaneous fat thickness and loin muscle thickness were measured ultrasonically in mode B between the third and fourth last ribs at 5 cm from the midline (Ultrascan 50, Alliance Médicale inc., Canada; 120 mm, 3.5 MHz). The pigs were scanned in a lateral position in slow mode according to the manufacturer’s recommendations. The data from the scans were analyzed using the adult program DPX-L (version 3.6z, Lunar Corp., Madison, WI, USA) and placing most of the body in the leg region as previously suggested (Pomar and Rivest, 1996). The pigs from each pen were scanned on the same day on Mondays, Wednesdays and Thursdays. For each pen, the experiment started the day after the first scan at 39.4±3.4 kg and ended once the pigs reached 108.2±5.16 kg BW after the experiment had run 76.9±7.0 d. The pigs weighed 109.6±3.78 kg when slaughtered at the AAFC experimental abattoir. The pigs were cared for in accordance with a recommended code of practice from Agricultural and Agri-Food Canada (1993) and the guidelines of the Canadian Council on Animal Care (1993).

The pigs had ad libitum access to fresh water and pelleted feed throughout the experiment. There was a common three-phase dietary program consisting of 14.3 MJ ME/kg for all phases, with 21% crude protein (CP) and 1.18% lysine for phase 1 (from arrival to 60±2.5 kg BW), 19% CP and 1.05% lysine for phase 2 (until 85±2.5 kg BW), and 17% CP and 0.95% lysine for phase 3 (until slaughter weight). The diets were formulated to meet or exceed NRC (1998) requirements for growing–finishing swine. Initial and final live weight and feed consumption data recorded at the beginning and end of the study were used to calculate the average daily gain (ADG), average daily feed intake (ADFI, on an as-fed basis) and gain-to-feed ratio (G:F).
Residual metabolizable energy intake (REI) was determined over a period of 56 d within the experiment (i.e. between repetition 1 and repetition 3 of the DXA scans) as suggested by Lepron et al. (2007). Briefly, the difference between energy intake and energy used for maintenance and growth is as follows:

$$\text{REI} = \text{MEI} - (\text{MEm} + \text{MEf} + \text{MEp})$$

where MEI is the average metabolizable energy intake (calculated as total feed intake × 14.3/number of days), MEm is the estimated metabolizable energy requirement for maintenance (calculated as 1.02 × BW^{0.6}, where BW is the average body weight for the period as suggested by Noblet et al., 1999), and MEf and MEp are the estimated amounts of energy required for lipid and protein deposition, respectively (calculated as the difference in tissue masses between the last and first DXA scans). All the values are expressed as MJ ME/d. Gross DXA scans values were first adjusted to obtain lipid and protein chemical values (Pomar and Rivest, 1996). These values were then transformed into an energetic cost (MEf and MEp) using the metabolizable energy costs for lipid and protein deposition, which amount to 47.7 MJ ME/d and 37.0 MJ ME/d, respectively (Noblet et al., 1999).

The estimated protein, fat and mineral masses and fat depths at the beginning and end of the study were used to calculate the average daily gains of protein (ADGprot), fat (ADGfat), minerals (ADGmin) and fat depth (ADGp2).

### 2.2. Meat quality

Measurements of pH at 50 min (pH1) and 24 h (pHu) post-mortem were made with a pH/temperature meter (model pH 100 Series, Oakton Instruments, Niles, IL, USA), fitted with a Cole–Parmer spear-type electrode (Cole Palmer Instrument Company, Vernon Hills, IL) and automatic temperature compensation probe, by means of insertion in the right longissimus muscle between the third and fourth last ribs (Canadian carcass grading site). At 24 h post-mortem, pork quality was assessed according to a photographic scale of 1 (devoid) to 10 (abundant) (NPPC, 1999); drip loss. This latter measurement was made using a modified “juice container” described by Correa et al. (2007).

A piece of loin (approximately 15 cm to 20 cm in length) was obtained adjacent to the grading site, vacuum packed, aged for 6 d at 4 °C and frozen (–20 °C) pending the analysis of cooking losses and Warner–Bratzler shear force (TAXT2i Texture Analyzer, Texture Technologies Corp., Scarsdale, NY, USA). The remaining muscle (approximately two thirds of the total muscle) was ground, vacuum-packed and frozen (–20 °C) pending the analyses of dry matter (DM), protein, intramuscular fat (IMF) (AOAC, 2000) and pigment content (Hornsey, 1956). Total collagen was measured as the hydroxyproline concentration in accordance with Mattiske et al. (1992), and a factor of 8 was used to convert the hydroxyproline to collagen. Collagen solubility was determined using the procedure of Hill (1966).

### Table 1

<table>
<thead>
<tr>
<th>Genotype</th>
<th>SG</th>
<th>LW</th>
<th>M</th>
<th>SEM</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth performance</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADFI (kg/d)</td>
<td>2.22&lt;sub&gt;c&lt;/sub&gt;</td>
<td>2.59&lt;sub&gt;c&lt;/sub&gt;</td>
<td>2.25&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.055</td>
<td>***</td>
</tr>
<tr>
<td>ADG (kg/d)</td>
<td>0.84&lt;sub&gt;d&lt;/sub&gt;</td>
<td>1.006&lt;sub&gt;d&lt;/sub&gt;</td>
<td>0.801&lt;sub&gt;d&lt;/sub&gt;</td>
<td>0.0230</td>
<td>***</td>
</tr>
<tr>
<td>G:F (kg/kg)</td>
<td>0.378&lt;sub&gt;b&lt;/sub&gt;</td>
<td>0.389&lt;sub&gt;b&lt;/sub&gt;</td>
<td>0.355&lt;sub&gt;b&lt;/sub&gt;</td>
<td>0.0058</td>
<td>***</td>
</tr>
<tr>
<td>REI (MJ/d)</td>
<td>391.4&lt;sub&gt;c&lt;/sub&gt;</td>
<td>419.6&lt;sub&gt;c&lt;/sub&gt;</td>
<td>304.7&lt;sub&gt;c&lt;/sub&gt;</td>
<td>15.76</td>
<td>***</td>
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<tr>
<td>ADGprot (g/d)</td>
<td>88.9&lt;sub&gt;c&lt;/sub&gt;</td>
<td>106.5&lt;sub&gt;c&lt;/sub&gt;</td>
<td>68.9&lt;sub&gt;c&lt;/sub&gt;</td>
<td>2.82</td>
<td>***</td>
</tr>
<tr>
<td>ADGp2 (mm/d)</td>
<td>0.128&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.171&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.271&lt;sub&gt;c&lt;/sub&gt;</td>
<td>0.0103</td>
<td>***</td>
</tr>
<tr>
<td>ADGfat (g/d)</td>
<td>149.7&lt;sub&gt;c&lt;/sub&gt;</td>
<td>192.4&lt;sub&gt;c&lt;/sub&gt;</td>
<td>212.7&lt;sub&gt;c&lt;/sub&gt;</td>
<td>7.46</td>
<td>***</td>
</tr>
<tr>
<td>ADGmin (g/d)</td>
<td>17.9</td>
<td>17.9</td>
<td>17.5</td>
<td>0.53</td>
<td>NS</td>
</tr>
</tbody>
</table>

| **Meat quality traits**<sup>c</sup> | | | | | |
| pH<sub>1</sub> | 6.59<sup>3</sup> | 6.48<sup>3</sup> | 6.66<sup>3</sup> | 0.051 | * |
| pH<sub>u</sub> | 5.36<sup>a</sup> | 5.32<sup>a</sup> | 5.22<sup>a</sup> | 0.028 | ** |
| EC (µS) | 4.05<sup>a</sup> | 5.67<sup>a</sup> | 4.49<sup>a</sup> | 0.405 | NS |
| Marbling score | 2.24<sup>a</sup> | 1.48<sup>a</sup> | 1.63<sup>a</sup> | 0.07 | *** |
| L*<sup>a</sup> | 44.16<sup>b</sup> | 45.33<sup>b</sup> | 45.81<sup>b</sup> | 0.494 | † |
| a*<sup>b</sup> | 6.42<sup>b</sup> | 5.88<sup>b</sup> | 7.28<sup>b</sup> | 0.279 | ** |
| b*<sup>a</sup> | 3.89<sup>a</sup> | 3.57<sup>a</sup> | 4.08<sup>a</sup> | 0.142 | * |
| Drip loss (%) | 4.57 | 5.37 | 4.87 | 0.458 | NS |
| DM (%) | 25.97<sup>c</sup> | 25.08<sup>c</sup> | 25.83<sup>c</sup> | 0.084 | *** |
| IMF (%) | 1.93<sup>d</sup> | 1.15<sup>d</sup> | 1.51<sup>d</sup> | 0.088 | *** |
| Protein | 23.59<sup>c</sup> | 23.50<sup>c</sup> | 23.84<sup>c</sup> | 0.069 | ** |

| (% fresh meat) | Total collagen (mg/100 g) | 436.5 | 427.9 | 411.3 | 10.67 | NS |
| Soluble collagen (%) | 9.82<sup>c</sup> | 10.95<sup>c</sup> | 8.20<sup>c</sup> | 0.546 | ** |
| Pigment content (µg/g) | 39.0<sup>c</sup> | 33.4<sup>c</sup> | 36.5<sup>c</sup> | 0.772 | *** |
| Warner–Bratzler force (kg) | 1.89<sub>b</sub> | 1.82<sub>b</sub> | 2.11<sub>b</sub> | 0.067 | ** |

NS: non-significant; †P<0.10, *P<0.05, **P<0.01, ***P<0.001. x,y,z LSmeans were compared pairwise by a t-test with a Tukey correction. Within a line, LSmeans without a common superscript differ (P<0.05).

<sup>c</sup> Data are LSmeans of 30 pigs per genetic line. LW: Large White; SG: Synthetic Genex 3000; M: Meishan-derived dam line.

<sup>b</sup> Average initial and final body weights were 39.4±3.43 kg and 108.2±5.16 kg, respectively. ADFI: average daily feed intake (on an as-fed basis); ADG: average daily gain; G:F: gain-to-feed ratio (on an as-fed basis); REI: residual energy intake; ADGprot: average daily gain in protein; ADGp2: average daily gain in backfat; ADGfat: average daily gain in fat; ADGmin: average daily gain in bone mineral.

<sup>a</sup> pH<sub>1</sub>: pH at 50 min post-mortem; pH<sub>u</sub>: pH at 24 h post-mortem; EC: electric conductivity at 24 h post-mortem; Marbling score according to a photographic scale of 1 (devoid) to 10 (abundant) (NPPC, 1999); L*: a*: b*: reflectance coordinates; DM: Dry matter; IMF: chemical intramuscular fat.
2.3. Statistical analysis

Each individual pig was considered to be an experimental unit. The data were analyzed according to a completely randomized design using the GLM procedure of SAS (SAS, 2000). The model included genotype as the main effect. Adjusted means were computed and compared pairwise using a t-test with a Tukey correction for multiple comparisons.

The standard correlation and canonical correlation analyses were performed using the CORR and CANCORR procedures of SAS (SAS, 2000). The latter is a multivariate statistical method for analyzing the relationship between two sets of independent variables (Thompson, 1991). It calculates canonical variables, which are linear combinations of the measured variables in each data set (i.e. growth performance and meat quality traits). These linear combinations are derived such that the correlation between any two sets of canonical variables is maximized.

Data from only 90 pigs (30 pigs per genotype) were used in the statistical analyses (GLM, CORR and CANCORR) performed in this study, as the CANCORR procedure of SAS does not allow the utilization of experimental units with missing data on any measured variable. As the sample size did not match the recommended criteria for canonical analysis (the number of observations was not at least 10 times the number of variables), a Wherry correction was carried out in the CANCORR analysis (Wherry, 1931; Cliff, 1987). For the same reason, comparisons between genotypes were avoided.

3. Results and discussion

3.1. Production performance

At the end of the finishing phase, the LW pigs showed a higher ($P<0.001$) ADG and ADFI than the SG or M pigs did (Table 1). The worst G:F and the lowest REI ($P<0.001$) were recorded in the M pigs. Weiler et al. (1998) and Sutherland et al. (2005) also found higher ADG and ADFI and better feed conversion in LW pure- and crossbred pigs as compared to M pigs, in both the growing and the finishing phases. Furthermore, Tibau et al. (1997) reported better production performance in LW pigs than in leaner lines, such as Landrace and Pietrain.

The LW pigs showed the highest ADGprot, and the M pigs showed the lowest, with the SG pigs in between ($P<0.001$). These results are in agreement with those of Marcoux et al. (2005), who found higher lean contents in LW carcasses than in the other two genotypes. In agreement with other studies (Suzuki et al., 1991; Bidanel et al., 1993), the M pigs showed higher ($P<0.001$) ADGp₂ than the LW and SG pigs, a finding that reflects their higher ADGfat. A higher fat deposition and carcass fatness in M pigs have been already reported by a number of studies (Suzuki et al., 1991; Bidanel et al., 1993; Faucitano et al., 2005a,b). The higher body fatness of M pigs may result from the early achievement of maturity in this line (White et al., 1995; Fisher et al., 2003).

Although genotype influenced protein and fat deposition, no effect was found on ADGmin despite the fact that the SG pigs had a slightly higher carcass bone mineral content than the remaining genetic lines. These results suggest that, independent of the initial and final bone masses, the amount of minerals retained in a given weight interval is related to time rather than to body growth rate.

3.2. Meat quality

A higher ($P<0.05$) pH₄ value was found in the muscle from the M pigs compared to the muscle from the LW pigs. Overall, the pHu values obtained in this study are rather low, possibly because of the still high glycogen reserves in the muscle at slaughter allowing an extended pH fall over time. As already observed by Faucitano et al. (2006), in small scale studies conducted under experimental conditions it is difficult to observe a significant depletion in muscle glycogen levels as the stress level is generally very low. Differences in pHu values between genotypes could be observed in this study. The LM from M showed the lowest ($P<0.01$) pHu value compared to LW and SG pigs. These results are in contrast to those of Faucitano et al. (2005a,b), who did not report any difference in pH values between the M and LW lines. Furthermore, the lack of difference in loin pH values between the LW pigs and the leaner SG pigs is not in agreement with the results of other studies (Tibau et al., 1997; Candek-Potokar et al., 1998) that reported lower pH values in loins from LW pigs than in loins from Pietrain genetic lines.

The loins from the M pigs tended to be paler (highest $L^*$ value; $P=0.06$) than those from the SG pigs. Furthermore, M pigs had redder (higher $a^*$ value; $P<0.01$) and more yellow (higher $b^*$ value; $P<0.05$) loins than LW. In agreement with the results of Lan et al. (1993), the LW pigs had the lowest ($P<0.001$) pigment content in the meat, which explains the lower redness score ($a^*$ value) recorded.

The loins from the LW pigs had lower ($P<0.001$) DM and IMF contents compared to those from the SG pigs. The loins from the M pigs had higher protein content than those from the SG or LW pigs ($P<0.01$). Contrary to the findings of other studies on M genetics (Touraille et al., 1989; Lan et al., 1993), the higher carcass fatness found in the M line was not reflected in a
higher IMF deposition at the muscle level. Surprisingly, the marbling score and IMF content were in fact higher \((P<0.001)\) in the SG loins \((P<0.001)\) than in the M loins. These results are in contrast to those of Ellis et al. (1996) and Brewer et al. (2002), who reported a lower apparent percentage of fat in loins from leaner lines (Pietrain and synthetic line) compared to Duroc crosses and Berkshire pigs. This result was also unexpected in the light of the higher backfat daily gain and fat deposition recorded in the M pigs during the growing period. It confirms the weak relationship that seems to exist between carcass fatness and IMF (Lundstrom et al., 1989; Faucitano et al., 2004). Wood et al. (2004) reported that the relationship between backfat and IMF is breed-dependent: it is high in Duroc and in traditional breeds (Berkshire and Tamworth) and low in pigs of LW genetics.

Contrary to the findings of Lan et al. (1993), Faucitano et al. (2005a,b), the loins from the M pigs showed higher shear force values than those from the SG or LW pigs \((P<0.01)\). This higher toughness in the M loins may be related to the lower IMF and heat-soluble collagen contents in the muscle \((P<0.01)\). Indeed, the direct relationship between these two muscle components and tenderness shear force values have been reported in pork by a number of studies (Devol et al., 1988; Ramsey et al., 1989; Ellis et al., 1996; Correa et al., 2006).

### 3.3. Correlations within the growth performance variables

A strong correlation among growth performance variables was found in this study, with ADG being highly and positively correlated with ADFI \((r=0.82)\) and ADGprot \((r=0.88)\) and moderately correlated with G:F \((r=0.61)\). These results are consistent with those of Nguyen and McPhee (2005) and Suzuki et al. (2005a). They also confirm the relationships that exist between growth rate, feed intake, feed efficiency and daily protein deposition, as previously reported by Woltman et al. (1992) and Hermesch et al. (2000). On the other hand, ADGprot is positively correlated with ADFI \((r=0.60)\) and G:F \((r=0.71)\), indicating that pigs with a high lean growth rate also have higher feed consumption and better feed efficiency, as also found by Chiba et al. (2002). However, a high ADFI is also associated with a high ADGfat \((r=0.80)\) and a moderate REI \((r=0.66)\). Such a result might support the hypothesis that pigs with high ADFI grow fast but retain more fat than lean in their growth. These results are consistent with those of Hermesch et al. (2000), who concluded that in pigs the extra energy intake, especially the intake recorded at the end of the growing period, is mainly converted into fat tissue. von Felde et al. (1996) also reported a good correlation between feed intake and lean deposition over the growing period. Lastly, ADGfat and ADGp2 were highly correlated \((r=0.80)\), confirming that backfat is the targeted anatomical location for fat deposition during the growing period.

### 3.4. Correlations within the meat quality variables

Meat DM content is highly and positively correlated with IMF \((r=0.81)\) but moderately correlated with marbling score \((r=0.60)\). A positive relationship between DM and IMF content was also reported by Weatherup et al. (1998), Latorre et al. (2003a,b). In fact, water is an important constituent of lean tissues, while only small amounts of water are found in fat tissues. Furthermore, a correlation of \(r=0.66\) was found between marbling score and IMF, which is close to the magnitude of the correlation reported by Huff-Lonergan et al. (2002) but lower than the correlation of 0.86 reported by Faucitano et al. (2004). This relationship is not surprising, as marbling is the visible portion of IMF that increases at higher IMF levels (Faucitano et al., 2005a).

Moderate positive correlations were found between meat colour coordinates. Thus, correlations of \(r=0.64\) between L* and b* values and \(r=0.76\) between b* and a* values were observed. The positive relationship between L* and b* has to do with the lightening effect higher b* values have on increasing the Hue angle. The positive relationship between yellowness and redness is surprising and hard to explain as these colour coordinates are usually inversely correlated (Sonesson et al., 1998).

### 3.5. Correlations between growth performance and meat quality variables

In this study, growth performance and meat quality variables were negatively correlated. For instance, ADG was negatively correlated with the DM \((r=-0.63)\) and IMF \((r=-0.45)\) contents, showing that pork from fast-growing pigs has higher moisture and lower IMF contents. Sonesson et al. (1998) and Hermesch et al. (2000) also reported a negative correlation between growth rate and IMF content in pork from LW and Landrace genotypes, respectively. However, some authors have reported contradictory effects. Lo et al. (1992) and Suzuki et al. (2005b) found a positive correlation between growth rate and IMF levels in both Duroc and Landrace
crossbred pigs, while Correa et al. (2006) did not find differences in the IMF content of pork between Duroc crossbred pigs selected for high and low growth rates.

As well, the ADGprot showed a negative relationship with the DM \( (r = -0.61) \) and IMF \( (r = -0.42) \) contents, suggesting that pigs with high daily protein deposition can produce pork with lower moisture and IMF contents. Such a relationship has been reported by a number of other studies (Cameron, 1990; de Vries et al., 1994; Lonergan et al., 2001).

All of the above and the relationship described among the performance traits suggest that pigs with a high feed intake grow faster and deposit mainly fat, whereas pigs with a high growth rate have a higher intake capacity and deposit mostly protein (and in consequence have lower fat deposition in carcasses and a lower IMF proportion in meat). Whittemore (1998) reported that, in the chemical composition of a finishing pig whose ADG is constant or even decreased, the percentage of body lipids is higher than in growing pigs, which are characterized by relatively higher protein content.

However, these correlations (between ADG or ADGprot and DM or IMF) can thus be considered as not systematic but genotype-dependent. Knapp et al. (1997) found these correlations to be higher and negative in LW pigs and smaller and positive in leaner genotypes such as those from Pietrain.

Soluble collagen proportion was positively correlated to ADG \( (r = 0.40) \) and to ADGprot \( (r = 0.47) \). McCormick (1994) reported that rapid growth is generally though to produce meat with collagen characteristics that are conducive to tenderness, because newly synthesized collagen dilutes the older, existing muscle collagen.

Higher ADG and ADFI have been associated with a lower \( a^* \) value in meat \( (r = -0.40 \) and \( r = -0.49 \), respectively). After birth, muscles are known to grow through the increase of the size of individual muscle fibres. A rapid increase in cell size might dilute mitochondria causing a shift to a more glycolytic system, hence decreasing proportion of myoglobin although from a fibre type point of view, the relationship between fibre composition and growth performance is still unclear (Lefaucheur and Gerrard, 1998). According to the negative correlation between ADFI and pigment content \( (r = -0.45) \), the lower redness score of the loin can be explained by the lower pigment concentration in the muscle of higher-feed-intake pigs that achieved the slaughter weight at a younger age. The ADFI is also negatively correlated with DM content \( (r = -0.55) \). The age effect on the moisture (or DM) content and the \( a^* \) value variation have also been reported in other studies (Garcia-Macias et al., 1996; Latorre et al., 2004).

### 3.6. Canonical correlation analysis

Eight canonical correlations were obtained in the analysis of the growth performance and meat quality data. The values of the first, second and third (significant) canonical correlations were 0.87, 0.66 and 0.64, respectively. The Wherry correction yielded adjusted canonical correlations of 0.66, 0.23, and 0.21, respectively. Thus, the relationship between the two sets of variables may be reduced to a three-dimensional space, with the first dimension accounting for the most important part of the observed variation \( (r = 0.44) \) and the other two dimensions being less important. These results suggest that meat quality attributes are correlated with performance measurements to a limited extent.

The correlation between the first canonical variable of performance data and the first canonical variable of meat quality data is illustrated in Fig. 1 for all observations and in Fig. 2 for each genotype taken separately. The relationship between the first canonical variable of each set of variables is strong within the whole dataset, suggesting that it may be possible to relate meat quality attributes to performance measures. However, the correlation seems to be breed-dependent, since the magnitude of correlation between the two sets of variables is much weaker for the LW pigs than for the other two breeds (Fig. 2). Indeed, the range of variation for the computed scores of the LW pigs on the first canonical variable for both sets of variables is much lower than for the other two genotypes. Nonetheless, these differences between breeds are in relation to the canonical variables and do not occur in the relationships between the measured variables.

The standardized canonical coefficients of each original variable for the first three canonical variables are presented in Table 2. The first canonical variable for

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![Fig. 1. Relationship between the first two canonical variables calculated from the growth performance (Performance1) and meat quality (Meat1) data sets (canonical correlation coefficient= 0.87).](image-url)
the performance measures, which is mainly characterized by ADFI, ADG and ADGprot, explains 35% of the total observed variability. The first canonical variable for the meat quality traits, which is mostly represented by DM content, explains only 17% of the total observed variability.

Measured variables can be represented in a common space defined by the first two canonical variables from each performance set of pooled data from the three genetic lines of pigs (Fig. 3). The common space is found by averaging the normalized vectors for each space on each variable (Pélissier et al., 2001). The new vector in the common space is then the bisector of the angle formed by the two canonical variables. The coordinates of each variable are the average correlations between the original variable and both canonical variables. The proximity of one variable to another and their position in the graph (distance from the origin) are the basis for determining the influence of each variable in the whole dataset. A variable lying far from the origin, or at least outside the central circle representing a correlation of 0.5 in any direction, has more influence in the relationship between performance and quality traits. Such a variable maximizes the correlation between the canonical variables from both sets of data. However, other variables within or between datasets can be highly correlated, but they are not well represented in this common space, because they are not contributing to the relationship between the two sets of variables.

In this study, the majority of the performance variables are far from the origin, whereas most of the meat quality variables are inside the $r=0.5$ circle, close to the origin. Variables that seem to be most important along the first dimension are ADFI, ADG, ADGprot, REI and G:F for

![Fig. 2. Regression data and lines by genotype (Large White: ⬤ and −−; Synthetic Genex 3000: ■ and – –; Meishan-derived dam line: ▲ and ⬤ respectively) between the first canonical variables calculated from the growth performance (Performance1) and meat quality (Meat1) data sets.](image)

the growth performance dataset and DM, IMF, $a^*$, pigment content and soluble collagen for the meat quality dataset. In the common space of the canonical correlations, ADFI, ADG, ADGprot, REI and G:F are close; this indicates that pigs with higher ADFI also have higher ADG, ADGprot, REI and G:F. Similarly, the pigs showing higher values for these growth performance variables also have lower DM, IMF, $a^*$ and pigment content values. The lower DM content in the fast-growing pigs is associated with the pigs’ faster ADGprot. Body water content seems to be higher in the fast-growing pigs, which in general have faster protein deposition rates. Fast-growing pigs also seem to have lower IMF, $a^*$ values and pigment content, that is, they are leaner and paler.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Canonical coefficients of the first three canonical variables for growth performance and meat quality traits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Canonical variate 1</td>
</tr>
<tr>
<td><strong>Growth performance</strong>$^a$</td>
<td></td>
</tr>
<tr>
<td>ADFI</td>
<td>$-1.6198$</td>
</tr>
<tr>
<td>ADG</td>
<td>$2.1028$</td>
</tr>
<tr>
<td>G:F</td>
<td>$-0.6817$</td>
</tr>
<tr>
<td>REI</td>
<td>$0.2675$</td>
</tr>
<tr>
<td>ADGprot</td>
<td>$-1.5346$</td>
</tr>
<tr>
<td>ADGp2</td>
<td>$0.0223$</td>
</tr>
<tr>
<td>ADGfat</td>
<td>$-0.2655$</td>
</tr>
<tr>
<td>ADGmin</td>
<td>$0.1673$</td>
</tr>
<tr>
<td><strong>Meat quality traits</strong>$^b$</td>
<td></td>
</tr>
<tr>
<td>pH$_1$</td>
<td>$0.1719$</td>
</tr>
<tr>
<td>pH$_{24}$</td>
<td>$-0.2429$</td>
</tr>
<tr>
<td>EC</td>
<td>$-0.1552$</td>
</tr>
<tr>
<td>Marbling score</td>
<td>$-0.1971$</td>
</tr>
<tr>
<td>L$^*$</td>
<td>$0.1878$</td>
</tr>
<tr>
<td>a$^*$</td>
<td>$0.2920$</td>
</tr>
<tr>
<td>b$^*$</td>
<td>$-0.2171$</td>
</tr>
<tr>
<td>Drip loss</td>
<td>$0.1612$</td>
</tr>
<tr>
<td>DM (%)</td>
<td>$0.7772$</td>
</tr>
<tr>
<td>IMF (%)</td>
<td>$-0.1095$</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>$-0.0450$</td>
</tr>
<tr>
<td>Total collagen (%)</td>
<td>$-0.0233$</td>
</tr>
<tr>
<td>Soluble collagen (%)</td>
<td>$-0.1966$</td>
</tr>
<tr>
<td>Pigment content (mg/g)</td>
<td>$0.2513$</td>
</tr>
<tr>
<td>Warner–Bratzler force (kg)</td>
<td>$0.0832$</td>
</tr>
</tbody>
</table>

$^a$ Average initial and final body weights were 39.4±3.43 and 108.2±5.16 kg, respectively. ADFI: average daily feed intake (on an as-fed basis); ADG: average daily gain; G:F: gain-to-feed ratio (on an as-fed basis); REI: residual energy intake; ADGprot: average daily gain in protein; ADGp2: average daily gain in backfat; ADGfat: average daily gain in fat; ADGmin: average daily gain in bone mineral.

$^b$ pH$_1$: pH at 50 min post-mortem; pH$_{24}$=pH at 24 h post-mortem; EC: electric conductivity at 24 h post-mortem; L$^*$: a$^*$: b$^*$: reflectance coordinates; Marbling score according to a photographic scale of 1 (devoid) to 10 (abundant) (NPPC, 1999); DM: dry matter; IMF: chemical intramuscular fat.
3.7. Discrimination of genotypes

The graphical representation of the first two canonical variables of performance and meat quality are shown in Fig. 4A and B, respectively. These graphics show that the first canonical variable suggests discrimination of the LW genotype from the SG and M genotypes. The second canonical variable seems to segregate the M pigs from the SG pigs, at least according to the performance variables. In the graph of canonical variables for meat quality, the three genotypes are more overlapped. This overlapping may be related to the lower percentage of variability, which is explained by the first two canonical variables (25% and 49% for meat quality and performance variables, respectively). This result also suggests that these three genotypes differ more in performance than in meat quality traits.

4. Conclusion

Pig performance is mainly explained by ADFI, ADG and ADGprot, and pig meat quality is mainly explained by DM content. Pigs with higher ADFI also have meat with higher ADG, ADGprot, REI, and G:F and lower DM, IMF, a* values and pigment content. Body water content seems to be higher in fast-growing pigs. Furthermore, fast-growing pigs also have lower IMF, a* values and pigment content. However, there is some indication that the magnitude of correlation could be breed-dependent. The differences among the studied genotypes are much higher in terms of performance than in terms of meat quality traits.

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