Comparison of muscle fibre characteristics and production traits among offspring from Meishan dams mated to different sires

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ABSTRACT

This study evaluated how various porcine sires affected muscle fibre characteristics, with respect to production traits. Sires from Berkshire, Duroc, Meishan, and Yorkshire pigs were mated to Meishan dams (BM, DM, MM, and YM offspring, respectively). A total of 96 pigs were evaluated for muscle fibre characteristics and production traits. The progeny from Duroc and Yorkshire sires had the greatest number of total fibres (P<0.05) and exhibited less backfat thickness (P<0.001) and larger loin muscle areas (P<0.05) than BM pigs. The DM and BM crossbreds showed higher marbling (P<0.01), and colour scores (P<0.05), as well as lower shear force scores (P<0.001). The MM pigs had greater proportional area of type IIb muscle fibres (P<0.05), and also displayed higher drip loss (P<0.01), higher lightness (P<0.001), and a greater incidence of PSE pork (pale, soft, and exudative; 25%) than DM, BM, and YM. These results showed that a greater number of total muscle fibres without increasing the cross sectional area of fibres improved lean meat production, and that a lower proportion of type IIb fibres was associated with better meat quality. For these reasons, the Duroc sire × Meishan dam crossbreed emerged as the most appropriate mating type examined herein to simultaneously enhance both lean meat production and meat quality.

Key words: Pig, Terminal sire effects, Muscle fibre characteristics, Lean meat production, Meat quality.

RIASSUNTO

COMPARAZIONE TRA LE CARATTERISTICHE DELLE FIBRE MUSCOLARI E I CARATTERI PRODUTTIVI DI SUINI OTTENUTI DA SCROFE MEISHAN CON VERRI DI RAZZE DIVERSE

Questo studio ha valutato l’utilizzo di verri di diverse razze sulle caratteristiche delle fibre muscolari e sulle attitudini produttive. Verri di razza Berkshire, Duroc, Meishan e Yorkshire sono stati impiegati nell’incrocio...
con scrofe di razza Meishan (BM, DM, MM, e YM, rispettivamente, i suini ottenuti). Un totale di 96 suini sono stati utilizzati e valutati per quanto concerne le caratteristiche sopracitate. I suini ottenuti dai verri di razza Duroc e Yorkshire hanno evidenziato, rispetto ai suini BM, un maggior numero di fibre musculari totali (P<0,05), accompagnato da un minore spessore del grasso dorsale (P<0,001), inoltre è stata registrata una superiore area del lombo (P<0,05). Gli ibridi DM e BM hanno presentato un più elevato grado di marezzatura (P<0,01) e valori maggiori nella scala colourimetrica (P<0,05), rivelando inoltre punteggi inferiori per quanto concerne la resistenza al taglio (P<0,001). I suini MM hanno mostrato una superficie proporzionalmente maggiore di fibre musculari di tipo IIb (P<0,05) e carni con più elevata perdita di sgocciolamento (P<0,01) e più chiare (P<0,001), con un’incidenza maggiore di PSE (pale, soft, exudative; 25%) rispetto ai suini DM, BM e YM. Questi risultati dimostrano che un numero maggiore di fibre musculari, a parità di sezione trasversale, migliora la produzione di carne magra, inoltre che una minore proporzione di fibre IIb è associata ad una migliore qualità della carne. Per queste ragioni l’incrocio tra i verri Duroc e le scrofe Meishan è risultato il più appropriato, tra quelli esaminati, al fine di migliorare sia la produzione di carne magra sia la qualità della carne.

Parole chiave: Suini, Effetti del verro terminale, Caratteristiche delle fibre musculari, Produzione di carne magra, Qualità della carne.

Introduction

Selecting higher quality animals as parents within breeds can genetically improve a herd. The crossbreeding process expands and capitalises on individual heterosis for reproduction and growth traits, and for breed complementarity. In addition, various breeds or lines might be maintained for various breeding purposes, in order to utilize their heterosis. For example, specialised sire and dam lines are selected for lean meat production and reproductive ability, respectively (Visscher et al., 2000). Korean commercial pigs are commonly three-way crosses of Yorkshire, Landrace, and Duroc pigs: Yorkshire pigs have thinner backfat and good milk production; Landrace pigs have greater carcass length and good lean meat production ability; Duroc pigs possess a superior marbling score and desirable growth traits.

Meishan pigs are an excellent dam line choice because of their reproductive ability: Meishan sows reach puberty within only 60 days, much earlier than other pigs, they ovulate more eggs per cycle, and they have a larger uterine capacity. All of these traits result in more live piglets. In fact, on average, Meishan pigs produce three to four more pigs per litter than American or European breeds (Haley et al., 1990; Haley and Lee, 1993).

Both high meat quality and lean meat production are especially important goals in pig crossbreeding (Plastow et al., 2005). However, breed differences in meat quality traits are large (Lawrie, 1985), and lean meat production tends to negatively correlate to meat quality (Cameron, 1990). To counteract this relation, muscle fibre characteristics are considered as a good indicator for simultaneously improving both traits (Lengerken et al., 1994). In pigs, the total number of muscle fibres positively correlates to muscle growth potential (Stickland and Goldspink., 1973; Stickland and Goldspink., 1978; Dwyer et al., 1993). Fibre type composition influences post mortem metabolic changes and subsequently meat quality (Ryu et al., 2005). Therefore, muscle fibre characteristics such as these could be considered new traits by which to compare the efficacy of crossbreeding combinations.

The aim of this study was to compare muscle fibre characteristics and production traits among offspring from Meishan dams mated to four different sires, defining which crossbreeding combination was the most...
suitable to enhance both lean meat production and meat quality.

**Material and methods**

**Animals and production ability**

This study utilised a total of 96 pigs, the offspring of Meishan sows mated with four different sire breeds: Berkshire, Duroc, Meishan, and Yorkshire (Table 1). Pigs from different pens of the same farm were fed the same commercial diet (17.0 % crude protein, 1.20% lysine, 0.80% Ca, 0.65% P, 0.2% Na). The pigs were designed by two experimental blocks. The number of pigs from each block was 48 (24 female and 24 male). There were 12 pigs (6 males and gilts) of each sire line. Pigs of each block were slaughtered at 161 days and 160 days old, respectively (body weight 111.8±7.5 kg). Pigs were slaughtered in a commercial abattoir by standard procedures under the supervision of the Korean grading service for animal products.

Backfat thickness was expressed as mean of two values measured at the 11th and last thoracic vertebrae. The loin muscle area was measured at the last rib. These traits were measured in all pigs, but muscle fibre characteristics and meat quality were measured in the 48 pigs of second block.

**Analysis of muscle fibre characteristics**

Within 45 min post mortem, muscle samples were taken from the middle of *longissimus dorsi* muscle at the 8th thoracic vertebrae. Muscle samples were cut into 0.5x0.5x1.0 cm³ pieces, promptly frozen in isopentane cooled by liquid nitrogen, and stored at -80° until subsequent analysis. The histochemical analyses of muscle fibre characteristics were conducted as follows: transverse serial sections (10µm) were prepared using a cryostat microtome (CM1850; Leica, Germany) at -20°C and stained for myofibrillar ATPase after acid preincubation (pH 4.35) to identify type I, IIa, and IIb fibres, as previously described (Brooke and Kaiser, 1970). Muscle fibre samples were examined using an image analysis system consisting of an optical microscope equipped with a charge-coupled device colour camera (IK-642K; Toshiba, Japan) and a standard workstation computer that controlled the image analysis system (Image-Pro Plus; Media Cybernetics, USA). Approximately, 300 fibres per sample were evaluated. The fibre density was calculated from the mean number of fibres per mm². Total fibre number was estimated as the product of fibre density and last rib loin muscle area. Fibre cross sectional area (CSA) was the ratio of total fibre area to total fibre number. Fibre area composition was estimated from proportion of total CSA of each fibre type to total fibre area, and fibre number composition was estimated in the same way.

**Meat quality measurements**

The pH value was measured from the 13th/14th thoracic vertebrae using a spear-

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**Table 1.** Cross-breeding models of four sire breeds with Meishan dam pigs.

| Mating type                  | Abbreviation | Male (n) | Female (n) | Total (n) |
|------------------------------|--------------|----------|------------|-----------|
| Berkshire sire x Meishan dam | BM           | 12       | 12         | 24        |
| Duroc sire x Meishan dam     | DM           | 12       | 12         | 24        |
| Meishan sire x Meishan dam   | MM           | 12       | 12         | 24        |
| Yorkshire sire x Meishan dam | YM           | 12       | 12         | 24        |

*n=number of pigs.*
type electrode (Model 290A; Orion Research Inc.; USA) at 45 min post mortem (pH\textsubscript{45min}). The carcasses were chilled at 4°C for 24 h, and the *longissimus dorsi* muscle was taken to evaluate the other meat quality traits. To measure drip loss, muscle samples with a standardised surface area were suspended in an inflated plastic bag for 48 h at 4°C, and the ratio of loss weight to initial weight was estimated (Honikel, 1987). The lightness of the meat was determined at 24 h post mortem by exposing the surface to air for 30 min at 4°C and measuring with a chromameter (CR-300; Minolta Camera Co.; Japan) at the 8th/9th thoracic vertebrae. The average of triplicate measurements was recorded and expressed as the C.I.E. (Commission International de l’Eclairage) Lightness (L*), redness (a*) and yellowness (b*), but only lightness (L*) was shown in this study. Meat colour and marbling scores were determined based on NPPC (National Pork Producers Council) pork quality standards (1991). Warner-Bratzler shear force (WBS) was measured using an Instron Universal Testing Machine (Model 1011; Instron Corp.; USA) equipped with a Warner-Bratzler shearing device, as follows: six cores (1.27 cm diameter) were removed from each steak parallel to the longitudinal orientation of muscle fibres, and samples were sheared perpendicular to the long axis of the core.

**Statistical analysis**

The variance was analysed by a general linear model to evaluate associations between sire breeds and traits, using the SAS 9.13 (SAS Institute Inc., 2001) statistical software package. The model was as follows: $y_{ijkl} = \mu + B_i + S_j + E_k + e_{ijkl}$, where $y_{ijkl}$ is the observation, $\mu$ is the general mean, $B_i$ is the fixed effect of breed $i$, $S_j$ is the fixed effect of sex $j$, $E_k$ is the fixed effect of experimental block of slaughter $k$, and $e_{ijkl}$ is the random error. When significant effects were detected, the mean values were separated by the probability difference (PDIF) option at a predetermined probability rate of 5%. Results are presented as least square means with standard errors. The chi-square test was used to analyse the frequency of PSE (pale, soft, exudative) pork between crossbreds.

**Results**

**Muscle fibre characteristics**

The muscle fibre characteristics of the different mating combinations are shown in Table 2. The fibre traits were total fibre number, fibre number per mm$^2$, cross-sectional areas, and fibre-type compositions. The combinations of the DM and YM pigs had the highest total number of muscle fibres, followed by MM and BM (P<0.05). The progeny from Meishan sires (MM) had a lower proportion of type IIa fibres (P<0.05), and a higher proportion of type IIb fibres than the other mating types (P<0.05) in fibre area composition. And the area proportion of type I fibre was not significantly different among crosses. Other muscle fibre characteristics, including the fibre number per mm$^2$ and the cross-sectional area, were not significantly different between crossbred types. The effects of sex were not significant in the total number and in the composition of muscle fibres.

**Carcass traits**

The results from carcass traits were presented in Table 3. The progeny from Duroc and Yorkshire (DM and YM) displayed superior abilities for producing lean meat, as indicated by significantly thinner backfat thickness (P<0.001) and larger loin muscle areas (P<0.05) than BM. MM pigs were shown as intermediate performance among crossbred. And DM pigs had greater average daily gain than MM (P<0.05). The combination of BM exhibited the greatest backfat thickness and the lowest loin muscle area.
Comparision of porcine sire effects

Least square means for meat quality traits, including pH45min, drip loss, lightness (L*), meat colour, marbling scores, and shear force, are reported in Table 4. Among these traits, the muscle pH45min was not significantly different between crosses, but the other meat quality traits varied remarkably. The combination of MM showed the highest drip loss (P<0.01) and lightness (L*) (P<0.001) at 24 h post mortem among crosses. The drip loss and lightness were indicators for determining meat quality classification (Joo et al., 1999). Significant differences between crossbreds could be found using chi-square test. Although all of the least square means

Table 2. Muscle fibre characteristics of porcine longissimus dorsi in pigs of different mating types (Least Square Means ±SE).

| Trait                  | Mating type | Significance |
|------------------------|-------------|--------------|
| Total fibres n10^3    | BM          | 1269 ± 84.9^a | 1457 ± 84.9^ab | 1547 ± 84.9^a | *          |
|                       | DM          | 1643 ± 84.9^a |               |               |            |
|                       | MM          | 1457 ± 84.9^ab|               |               |            |
|                       | YM          | 1547 ± 84.9^a |               |               |            |
| Fibre n/mm^2          | BM          | 256.1 ± 8.21  |               |               |            |
|                       | DM          | 261.5 ± 8.21  |               |               |            |
|                       | MM          | 256.4 ± 8.21  |               |               |            |
|                       | YM          | 257.0 ± 8.21  |               |               |            |
| Mean CSA of fibre µm^2| BM          | 3938 ± 128.9  |               |               |            |
|                       | DM          | 3847 ± 128.9  |               |               |            |
|                       | MM          | 3951 ± 128.9  |               |               |            |
|                       | YM          | 3999 ± 128.9  |               |               |            |
| Fibre area composition (%)|
| Type I                | BM          | 8.21 ± 1.04   |               |               |            |
|                       | DM          | 6.56 ± 1.11   |               |               |            |
|                       | MM          | 5.58 ± 0.98   |               |               |            |
|                       | YM          | 6.55 ± 0.98   |               |               |            |
| Type IIa              | BM          | 9.65 ± 0.88^a |               |               | *          |
|                       | DM          | 9.89 ± 0.94^a |               |               |            |
|                       | MM          | 6.91 ± 0.83^b |               |               |            |
|                       | YM          | 9.83 ± 0.83^a |               |               |            |
| Type IIb              | BM          | 82.1 ± 1.20^a |               |               | *          |
|                       | DM          | 83.5 ± 1.28^a |               |               |            |
|                       | MM          | 87.5 ± 1.13^b |               |               |            |
|                       | YM          | 83.6 ± 1.13^a |               |               |            |
| Fibre number composition (%)|
| Type I                | BM          | 9.90 ± 1.67   |               |               |            |
|                       | DM          | 10.76 ± 1.77  |               |               |            |
|                       | MM          | 9.89 ± 1.56   |               |               |            |
|                       | YM          | 10.08 ± 1.56  |               |               |            |
| Type IIa              | BM          | 15.78 ± 1.49  |               |               |            |
|                       | DM          | 15.10 ± 1.58  |               |               |            |
|                       | MM          | 11.49 ± 1.39  |               |               |            |
|                       | YM          | 14.98 ± 1.39  |               |               |            |
| Type IIb              | BM          | 74.32 ± 1.71  |               |               |            |
|                       | DM          | 74.14 ± 1.82  |               |               |            |
|                       | MM          | 78.61 ± 1.60  |               |               |            |
|                       | YM          | 74.94 ± 1.60  |               |               |            |

a,bMeans with different superscripts within a row are significantly different.
*P<0.05, ns=not significant.
CSA=Cross sectional area.

Table 3. Production and carcass traits in pigs of different mating types (Least Square Means ±SE).

| Trait                  | Mating type | Significance |
|------------------------|-------------|--------------|
| Average daily gain g   | BM          | 691.6 ± 9.60^ab | 679.7 ± 9.60^ab | 698.8 ± 9.60^ab | *          |
|                       | DM          | 717.3 ± 9.60^a |               |               |            |
|                       | MM          | 679.7 ± 9.60^b |               |               |            |
|                       | YM          | 698.8 ± 9.60^ab|               |               |            |
| Back fat thickness mm  | BM          | 23.75 ± 0.95  |               |               |            |
|                       | DM          | 18.21 ± 0.95  |               |               |            |
|                       | MM          | 21.42 ± 0.95  |               |               |            |
|                       | YM          | 19.96 ± 0.95  |               |               |            |
| Loin eye area cm²      | BM          | 51.32 ± 1.70^b | 56.71 ± 1.70^a | 53.03 ± 1.70^ab| *          |
|                       | DM          | 56.71 ± 1.70^a |               |               |            |
|                       | MM          | 56.86 ± 1.70^a |               |               |            |
|                       | YM          | 56.86 ± 1.70^a |               |               |            |

a,b,cMeans with different superscripts within a row are significantly different.
*P<0.05, **P<0.001.

Meat quality traits
Least square means for meat quality traits, including pH45min, drip loss, lightness (L*), meat colour, marbling scores, and shear force, are reported in Table 4. Among these traits, the muscle pH45min was not significantly different between crosses, but the other meat quality traits varied remarkably. The combination of MM showed the highest drip loss (P<0.01) and lightness (L*) (P<0.001) at 24 h post mortem among crosses. The drip loss and lightness were indicators for determining meat quality classification (Joo et al., 1999). Significant differences between crossbreds could be found using chi-square test. Although all of the least square means
of those traits were within the normal range, MM more frequently yielded PSE (pale, soft, and exudative) pork (25%, P<0.05). Notably, however, PSE pork was not observed in YM pigs. The marbling scores were greater in BM and DM and lesser in MM (P<0.01). The meat colour scores in MM pigs were also lesser than in BM and DM pigs but the majority of the pork of this study was within the normal range of reddish dark colour. Shear force was lowest in BM and DM (P<0.001). The results indicated that meat from BM and DM animals was more tender.

Discussion

Muscle fibre number and size

Rehfeldt et al. (2000) found that the fibre number and size critically affected muscle mass among the muscle fibre characteristics, because muscle tissue is primarily comprised of muscle fibres. Meishan pigs used by the dam line in this study had an inborn upper limit for muscle growth (McLaren, 1989), due to lower muscle fibres overall (Bonneau et al., 1990; Lefaucheur and Patrick, 2005). The results showed a similar tendency. In this study, DM and YM pigs had greater numbers of total muscle fibres, and also showed thinner backfat and greater loin muscle area than BM pigs. The progeny sired by Meishan pigs was intermediate among those that were crossbred. However, cross sectional areas of the fibres were not significantly different among the mating types. Therefore, it was suggested that the total number of muscle fibres was associated with muscle growth potential in pigs, as was also suggested in several previous studies (Stickland and Goldspink, 1973, 1978; Dwyer et al., 1993). Moreover, the total number and size of muscle fibres also affects meat quality. Low muscle fibre numbers correlate to fibres that show larger hypertrophy, which may relate to stress susceptibility and poor meat quality in pig breeds (Cassens et al., 1975; Fiedler, 1993; Lengerken et al., 1997; Fiedler et al., 1999). Although notable correlations were not observed between total numbers of fibres and meat quality, the DM and YM crossbreds showed superior abilities for lean meat production and showed the lowest incidence of poor meat quality in this study. Therefore, it

Table 4. Meat quality traits of longissimus dorsi muscle in pigs of different mating types (Least Square Means ±SE).

| Trait                  | BM          | DM          | MM          | YM          | Significance |
|------------------------|-------------|-------------|-------------|-------------|--------------|
| pH<sub>45min</sub><sup>1</sup> | 5.86 ± 0.06 | 5.78 ± 0.06 | 5.81 ± 0.06 | 5.86 ± 0.06 | ns           |
| Drip loss %            | 4.20 ± 0.44<sup>a</sup> | 3.62 ± 0.44<sup>a</sup> | 5.84 ± 0.44<sup>b</sup> | 4.17 ± 0.44<sup>a</sup> | **           |
| Lightness L<sup>*</sup> | 47.20 ± 0.48<sup>b</sup> | 45.97 ± 0.48<sup>a</sup> | 49.05 ± 0.48<sup>b</sup> | 46.47 ± 0.48<sup>a</sup> | ***          |
| Colour<sup>1</sup>     | 2.58 ± 0.13<sup>a</sup> | 2.71 ± 0.13<sup>a</sup> | 2.23 ± 0.13<sup>b</sup> | 2.37 ± 0.13<sup>ab</sup> | *            |
| Marbling score<sup>1</sup> | 1.83 ± 0.10<sup>a</sup> | 1.73 ± 0.10<sup>ab</sup> | 1.28 ± 0.10<sup>c</sup> | 1.57 ± 0.10<sup>b</sup> | **           |
| Shear force (N)<sup>1</sup> | 36.16 ±1.36<sup>a</sup> | 36.18 ±1.36<sup>a</sup> | 42.15 ±1.36<sup>b</sup> | 43.81 ±1.36<sup>b</sup> | ***          |
| PSE<sup>2</sup> n (%) | 2 (8.3)     | 1 (4.2)     | 6 (25.0)    | 0 (0.0)     | *            |

<sup>a, b, c</sup>Means with different superscripts within a row are significantly different.

*P<0.05, **P<0.01 and ***P<0.001; ns=not significant.

<sup>1</sup>Evaluated in 48 pigs.

<sup>2</sup>The number and percentage of PSE (pale, soft, and exudative) : drip loss >6.0%, lightness >50. Chi-square analysis.
also suggested that the simultaneous presence of a large fibre number without a large fibre size would exert a favourable influence on lean meat production and meat quality.

Muscle fibre composition

Muscle fibre type composition was more associated with the meat quality than was the total number of fibres. Types I and IIb fibres are involved in slow-oxidative and fast-glycolytic energy metabolism, respectively, and type IIa fibres are an intermediate between them. Composition of muscle fibre is associated with post mortem metabolic changes that subsequently influence meat quality. A greater proportion of type IIb fibres, and concomitantly smaller proportions of types I and IIa fibres, increase drip loss and lightness and deteriorate the overall meat quality (Ryu and Kim, 2005). For these reasons, fibre type composition in pork is related to the occurrence of PSE (Candek-Potokar et al., 1999). The results obtained showed similar tendencies. The progeny from Meishan sires had a lower percentage of type IIa and a higher percentage of type IIb fibre area than the other mating types, though their type I fibre area was not different. MM also displayed a higher drip loss and lightness, and showed the highest PSE pork frequency.

Conclusions

The objective of this study was to compare sire effects based on muscle fibre characteristics related to production traits to be considered the most suitable combination of crossbreeding. The progeny from DM and YM exhibited the greatest total fibre numbers and possessed superior abilities for lean meat production. In addition, the meat quality of DM and BM was better than that from MM and YM. Taken together, therefore, the results suggested that the Duroc breed had greater merit as a sire line than the other breeds tested, with respect to both lean meat production and meat quality.

The first two authors have contributed equally to this study.

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