Comparison of muscle amino acid and fatty acid composition of castrated and uncastrated male pigs at different slaughter ages

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Abstract

The purpose of this study was to investigate the effects of castration and slaughter age on amino acid and fatty acid compositions in Longissimus dorsi (LD) muscle of pigs, as well as growth rates and meat quality. The total amino acid, essential amino acid and nonessential amino acid contents of barrows were significantly higher (P<0.01, < 0.001, < 0.001, respectively) than the ones of boars. Additionally, the content of several saturated fatty acids and total mono-unsaturated fatty acids was significantly higher (P<0.001), and total polyunsaturated fatty acids was significantly lower (P<0.001) in the LD muscle of barrows than in boars. Compared with barrows, barrows had lower (P<0.05) growth rates after 147 days, higher (P<0.05) intramuscular fat content at 147 days, and higher (P<0.01) average back fat thicknesses at 147 and 210 days. These results suggest that the amino acid and fatty acid compositions of LD muscle from male pigs, as well as growth rates and meat quality, were influenced by castration, and, to a lesser degree, by slaughter age.

Introduction

Castration of male farm animals is an ancient custom dating back almost as far as human domestication of animals, first recorded in the Chinese Shang Dynasty (Xue et al., 1997). It is widely noted that castrating males prevents the appearance of boar taint in meat (Font i Furnols and Oliver, 1999; Banon et al., 2003). The benefits of castration are however debatable, because it may influence animal growth and lead to more fat in the carcass (Bonneau, 1998). Most castration studies in pigs focus on growth performance and carcass traits (Latorre et al., 2004; Bender et al., 2006; Pauly et al., 2009). However, little research has been conducted on the effects of castration on the nutritive and flavour characteristics of meat, such as amino acid and fatty acid compositions of pork meat.

Amino acids are the fundamental units of protein, and amino acid content plays an important role in meat quality by providing nutritive value and flavour characteristics. Amino acids are divided into essential amino acids (EAA) and non-essential amino acids (NEAA), depending on whether the body can or not synthesize them. The ten essential amino acids must be obtained from food for good health in humans (Okrohla et al., 2006); meat is one of the main protein sources for human nutrition (Higgs, 2000). From the nutritional point of view, it is very important to know not only the protein content but the amino acid composition as well. Factors such as species, age and muscle type have been reported to influence the amino acid composition of meat (Lawrie, 1985), yet little data exists on how castration affects the amino acid composition of meat in male pigs.

The total lipid content (intramuscular fat, IMF) and fatty acid composition of muscle has an important role in the tenderness, juiciness, and flavour of meat (Wood et al., 2008). Early works on meat fatty acid composition concentrated on adipose tissue, since it includes many fatty acids. Recently, there has been more emphasis on studying muscle fatty acid composition because animal protein originates from muscle, and it has an impact on human health.

The effect of castration on pork muscle fatty acid composition has been previously described (Hogberga et al., 2004; Razmaite et al., 2008). However, little is known about the effect of castration on the chemical composition comprising amino acid and fatty acid composition of male pigs at different slaughter ages. The objectives of the present study were to investigate i) the Longissimus dorsi (LD) muscle amino acid and fatty acid compositions in castrated and uncastrated male pigs; and ii) whether slaughter age affects those compositions.
calculated. After slaughter, the carcasses were eviscerated according to standard commercial procedures. The head, feet and internal organs were removed and individual carcass weight were obtained and used to calculate carcass yield. At 45 min post-mortem, body length was recorded, and back fat thickness was measured using a ruler on the left side of each carcass, at five locations (shoulder, thorax-waist, buttock, between the third and fourth rib, and between the sixth and seventh rib). Muscle pH and temperature were taken on the LD muscle using a Thermo Orion pH meter (Model 230, USA) and an Ama-digit meter (Germany). Meat colour parameters (CIE system: lightness, L*; redness, a*; yellowness, b*; chromic, c*; and hue angle, h*) were determined using an X-rite apparatus (sp60, USA).

Chemical composition analysis
A sample of LD muscle at the thirteenth rib was immediately taken from the carcass at the time of slaughter and frozen at -70°C, until chemical analyses were done. Moisture, intramuscular fat (IMF) and Crude protein content of LD muscle were analyzed by an Antaris meat analyzer (Thermo Electron, USA), in the wavelength range of 780-2,500 nm by the near infrared transmission (NIT) principle (Lanza, 1983). Meat samples were minced and distributed in cylindrical sample cell (130 mm diameter and 10 mm deep), with a clear plastic bottom and an open top surface. Intramuscular fat percentage data were expressed as g of fat / 100 g of muscle.

Amino acid analysis
About 0.2 g of minced muscle samples of meat used for amino acid analysis were freeze-dried at 55°C for 48 h, and then hydrolyzed with 6 M HCl at 110°C for 22 h in sealed evacuated tubes (Finley, 1985). Amino acid composition of the muscle powder was analyzed using ion-exchange chromatography with an automatic amino acid analyzer (L-8900 Hitachi Automatic Amino Acid Analyzer, Japan). Tryptophan content was determined after alkaline hydrolysis with 4 M LiOH for 20 h at 110°C. The content of each individual amino acid was calculated on g/100 g of wet matter basis for each body component.

Fatty acid analysis
The total lipids were extracted from 1 g of minced muscle samples with chloroform by the method described by Folch et al. (1957). Fatty acid methyl esters (FAMEs) were identified and quantified using gas chromatography (HP6890/5973). The temperature program was as follows: the carrier gas (helium) flow rate was 0.81 mL/min, the column was equilibrated at 150°C for 3.5 min, then it was increased to 200°C at 20°C/min, furtherly it was increased to 280°C at 5°C/min, and finally it was kept at 280°C for 37 min. The identification of fatty acids was accomplished by comparison with external standards. The area of the peak of each FA was expressed as a percentage of the total peak area for all FA. The percentage of total of saturated FA (SFA), monounsaturated FA (MUFA) and polyunsaturated FA (PUFA) were calculated from individual FA percentages.

Results and discussion
Growth performance and meat quality
Until 147 days of age, barrows had slightly higher growth rates than boars, although it was not significant (P>0.05); thereafter, barrows grew faster than barrows and at 210 days they had a significant higher live body weight (P<0.05) and average daily gain (P<0.01) than barrows (Figure 1). This result was similar to that reported by Knudson et al. (1985), who reported that the ADG of barrows was slightly greater than that of boars until the pigs reached a live body weight of 76.3 kg (17.2 wk). The carcass traits and meat quality data are shown in Table 2. At a slaughter age of 147 days, barrows had significantly higher (P<0.01) average back fat (ABF) thicknesses than those of boars, but no significant differences (P>0.05) were found in carcass weight, body length, dressing percentage, pH45 value (45 min after slaughter), temperature, and meat colour (L*, a*, b*, c*, and h*) between barrows and boars. At a slaughter age of 210...
days, boars had a higher (P<0.05) carcass weight and a lower (P<0.01) ABF compared with barrows. However, castration did not have a significant effect on body length, dressing percentage, pH45 value, temperature or meat colour (L*, a*, b*, c*, and h*). The ABF thicknesses were significantly higher (P<0.01) for barrows than for boars, as reported by others (Newell and Bowland, 1972; Knudson et al., 1985). Similar to previous studies, castration did not have a significant effect on pH value or meat colour (Bender et al., 2006; Pauly et al., 2009). The chemical (protein, fat and moisture) composition of the LD muscle of male pigs is presented in Table 3. Others have shown that castration affects the chemical composition of muscle, since it can increase fat content and decrease water content (Knudson et al., 1985; Latorre et al., 2004). Significant effects of castration were found on the muscle IMF content of male pigs at 147 days of age (P<0.05), the IMF content in the LD muscle of barrows were 0.5% higher than that of boars.

### Amino acid composition

Table 4 shows the amino acid composition in LD muscle of barrows and boars. Purchas et al. (2009) reported that porcine Longissimus lumborum and semimembranosus muscles had high contents of Glu, Lys, Leu and Arg, which is very similar to our results, as we found a large amount of Glu, Lys, Leu and Arg in the LD muscle of male pigs. In regard to the essential amino acids, Lys was present at the highest levels, followed by Leu. A similar trend had been observed by Nielsen (1973), with Lys and Leu being the two essential amino acids present at the highest levels.

Castration greatly influenced the amino acid composition of LD muscle. Barrows had higher levels of EAA, including Ile, Lys, Met, Phe, Thr, Trp (P<0.001), Leu (P<0.01), and Arg, Val (P<0.05). Barrows also had a higher content of NEAA, including Ala, Glu (P<0.001), Ser (P<0.01), and Asp (P<0.05). The total amino acid, total EAA, and total NEAA of barrow LD muscle were higher by 1.57%, 0.93% (P<0.001) and 0.63% (P<0.01) compared with those of the boar, respectively. Grandhi et al. (2002) reported that the requirements of dietary amino acid are higher for boars as they have a higher lean growth potential than barrows. Maybe, the lower deposition of muscle amino acids observed for boars indicated that the maximum lean growth potential may not have been reached in boars.

To our knowledge, there are few studies regarding the effects of castration on muscle amino acid composition of male pigs at different slaughter ages. Based on our results, we concluded that castration may influence the deposition of amino acids in the muscle of male pigs, and the amino acid composition differ between castrated and uncastrated male pigs.

For both castrated and uncastrated pigs, age did not significantly affect the amino acid composition in LD muscle. Slaughter age only affected the levels of Ile and Val in LD muscle. At 210 days, Ile was higher than that in pigs slaughtered at 147 days (P<0.01). However, Val was higher (P<0.05) in pigs at 147 days. An interaction between castration and slaughter age was not observed. Similarly, Sun and Lu (2002) noted that the profile of muscle amino acid in young (60 d) and old (180 d) Chinese Wuzhishan mini-pig showed no significant changes in relation to the growing slaughter age.

### Fatty acid composition

The influence of castration and slaughter age on the fatty acid composition of LD muscle is presented in Table 5. Castration was found to significantly affect the fatty acid composition of LD muscle. Barrows had more (P<0.001) C16:0, C13:0, C15:0, C16:0, C17:0 fatty acids. Barrows also had a higher (P<0.01) content of monounsaturated fatty acids (MUFA), including C16:1, C18:1, C20:1, and total MUFA. Compared with barrows, boars had higher amounts of SFA in the LD muscle, including C12:0, C18:0 (P<0.001), and PUFA, such as C18:2, C18:3, C20:4, C20:5, C22:5 (P<0.001), C20:2 (P<0.05). Total PUFA and the n-6/n-3 ratio were also higher (P<0.001) in boars than in barrows. These results were similar to those reported by Razmaite et al. (2008), who found that higher percentages of C14:0, 16:0, C16:1, C18:1, and total MUFA, but lower amounts of C18:2, C18:3, C20:4, C22:5, total PUFA, PUFASFA, and n-6/n-3 were present in the LD muscle of barrows compared with boars.

Slaughter age did not significantly affect the LD muscle fatty acid composition, with the exception of C15:0. An interaction between castration and slaughter age was observed for C15:0 (P<0.05), C22:1 (P<0.01), C22:3 and SFA (P<0.05).

Saturated (except for C18:0) and MUFA positively correlated with meat quality, since they can improve the characteristics of meat tenderness, juiciness and flavour. However, extremely high amounts of SFA (primarily fatty acids C12:0, C14:0, and C16:0), may contribute to heart disease by raising plasma low-density lipoprotein cholesterol (Fernandez and West, 2005; Cutrignelli et al., 2008). No significant differences were found for total SFA and C14:0 in the LD muscle between barrows and boars at the two slaughter ages.

### Table 2. Carcass traits and meat quality.

| Age (days) | 147 | 210 |
|------------|-----|-----|
| Male type  |  |  |
| Barrows (n=9) | Boars (n=9) | P | Barrows (n=9) | Boars (n=9) | P |
| Carcass weight, kg | 60.39±2.49 | 58.21±3.82 | 0.79 | 85.02±3.97 | 95.27±5.50 | 0.05* |
| Body length, cm | 82.52±1.56 | 82.32±2.03 | 0.17 | 94.69±1.51 | 97.50±1.57 | 0.53 |
| Dressing percentage, % | 67.19±0.78 | 66.05±0.66 | 0.14 | 70.36±0.67 | 69.32±0.60 | 0.19 |
| ABF, cm | 2.62±0.21 | 1.62±0.10 | 0.01** | 2.78±0.22 | 2.14±0.28 | 0.01** |
| pH45 | 6.55±0.06 | 6.45±0.07 | 0.19 | 6.24±0.03 | 6.21±0.10 | 0.72 |
| Temperature, °C | 38.77±0.41 | 38.66±0.58 | 0.79 | 39.97±0.53 | 39.72±0.50 | 0.80 |
| L* | 46.29±1.70 | 45.49±2.72 | 0.57 | 43.34±0.46 | 43.95±0.99 | 0.71 |
| a* | 6.85±0.78 | 6.60±0.40 | 0.78 | 7.84±0.47 | 7.53±0.51 | 0.68 |
| b* | 6.37±0.96 | 6.94±0.36 | 0.67 | 6.50±0.25 | 6.51±0.39 | 0.98 |
| c* | 9.42±1.22 | 8.99±0.44 | 0.71 | 10.20±0.47 | 9.92±0.62 | 0.75 |
| h* | 42.15±1.02 | 42.62±1.87 | 0.70 | 39.90±1.50 | 40.46±0.77 | 0.73 |

Values are presented as mean ± standard error. Average back fat (ABF), * P<0.05, ** P<0.01.

### Table 3. Characteristics of Longissimus dorsi muscle.

| Age (days) | 147 | 210 |
|------------|-----|-----|
| Male type  |  |  |
| Barrows (n=9) | Boars (n=9) | P | Barrows (n=9) | Boars (n=9) | P |
| IMF, % | 2.32±0.25 | 1.82±0.16 | 0.04* | 2.46±0.36 | 1.93±0.13 | 0.28 |
| CP, % | 23.97±0.40 | 23.37±0.60 | 0.34 | 24.33±0.12 | 24.13±0.32 | 0.66 |
| Moisture, % | 73.71±0.59 | 74.81±0.70 | 0.27 | 73.21±0.35 | 73.94±0.36 | 0.30 |

Values are presented as mean ± standard error. Intramuscular fat (IMF), Crude protein (CP), * = P<0.05.
Table 4. Amino acid composition in *Longissimus dorsi* muscle.

| Male type | 147 | 210 | Significance |
|-----------|-----|-----|--------------|
| Barrows (n=9) | Boars (n=9) | Barrows (n=9) | Boars (n=9) | Castration | Age | Interaction |
| Essential, % of total protein | | | | | | |
| Arg | 4.94±0.08 | 4.60±0.12 | 4.81±0.12 | 4.60±0.12 | * | ns | ns |
| His | 3.65±0.09 | 3.63±0.07 | 3.63±0.08 | 3.46±0.07 | ns | ns | ns |
| Ile | 3.88±0.09 | 3.52±0.08 | 4.12±0.03 | 3.69±0.06 | *** | ** | ns |
| Leu | 7.02±0.10 | 6.78±0.22 | 7.01±0.04 | 6.50±0.15 | ** | ns | ns |
| Lys | 8.56±0.16 | 7.92±0.18 | 8.78±0.17 | 7.80±0.09 | *** | ns | ns |
| Met | 3.13±0.06 | 2.85±0.05 | 3.09±0.07 | 2.83±0.09 | *** | ns | ns |
| Phe | 3.17±0.08 | 3.45±0.12 | 3.61±0.05 | 3.37±0.05 | *** | ns | ns |
| Thr | 3.77±0.08 | 3.61±0.11 | 3.62±0.06 | 3.36±0.05 | * | ns | ns |
| Val | 1.02±0.04 | 0.82±0.03 | 0.94±0.04 | 0.82±0.04 | *** | ns | ns |
| Non-essential, % of total protein | | | | | | |
| Asp | 8.23±0.22 | 7.79±0.23 | 8.09±0.25 | 7.26±0.24 | * | ns | ns |
| Ala | 4.27±0.10 | 3.95±0.11 | 4.21±0.09 | 3.93±0.06 | *** | ns | ns |
| Glu | 13.63±0.18 | 12.91±0.36 | 13.34±0.15 | 12.91±0.16 | *** | ns | ns |
| Gly | 3.20±0.07 | 3.18±0.09 | 3.14±0.09 | 2.99±0.06 | ns | ns | ns |
| Pro | 3.11±0.06 | 3.14±0.12 | 3.14±0.08 | 2.99±0.05 | ns | ns | ns |
| Ser | 3.38±0.10 | 3.15±0.08 | 3.30±0.02 | 3.11±0.08 | ** | ns | ns |
| Tyr | 1.86±0.03 | 1.87±0.05 | 1.91±0.04 | 1.80±0.04 | ns | ns | ns |
| Sum, % of wet matter | | | | | | |
| EAA | 10.13±0.07 | 9.20±0.04 | 10.14±0.10 | 9.40±0.07 | *** | ns | ns |
| NEAA | 9.03±0.08 | 8.40±0.03 | 9.04±0.08 | 8.32±0.04 | *** | ns | ns |
| Total AA | 19.16±0.14 | 17.63±0.03 | 19.17±0.18 | 17.73±0.09 | ** | ns | ns |
| EAA/NEAA | 1.12±0.01 | 1.10±0.01 | 1.12±0.01 | 1.13±0.01 | ns | ns | ns |
| EAA/Total AA | 0.53±0.01 | 0.53±0.01 | 0.53±0.01 | 0.53±0.01 | ns | ns | ns |

Values are presented as mean±standard error. EAA (essential amino acid), NEAA (nonessential amino acid), AA (amino acid).  ns = not significant (P>0.05), * = P<0.05, ** = P<0.01, *** = P<0.001.

Table 5. Fatty acid composition (% of total FAMEs detected) in *Longissimus dorsi* muscle.

| Male type | 147 | 210 | Significance |
|-----------|-----|-----|--------------|
| Barrows (n=9) | Boars (n=9) | Barrows (n=9) | Boars (n=9) | Castration | Age | Interaction |
| C8:0 | 0.19±0.01 | 0.17±0.02 | 0.18±0.03 | 0.17±0.02 | ns | ns | ns |
| C10:0 | 0.21±0.03 | 0.15±0.02 | 0.22±0.02 | 0.16±0.01 | *** | ns | ns |
| C12:0 | 0.12±0.01 | 0.15±0.01 | 0.12±0.02 | 0.14±0.01 | *** | ns | ns |
| C13:0 | 1.25±0.06 | 1.14±0.05 | 1.27±0.02 | 1.18±0.02 | *** | ns | ns |
| C14:0 | 0.31±0.05 | 0.33±0.01 | 0.36±0.04 | 0.35±0.02 | ns | ns | ns |
| C15:0 | 4.32±0.26 | 4.65±0.08 | 4.69±0.41 | 4.07±0.07 | *** | ** | * |
| C16:0 | 27.22±0.15 | 25.16±0.12 | 27.29±0.26 | 25.02±0.21 | *** | ns | ns |
| C17:0 | 0.33±0.02 | 0.21±0.01 | 0.32±0.02 | 0.22±0.01 | *** | ns | ns |
| C18:0 | 13.20±0.36 | 16.2±0.17 | 13.17±0.27 | 16.08±0.27 | *** | ns | ns |
| C20:0 | 0.16±0.03 | 0.15±0.01 | 0.17±0.02 | 0.16±0.01 | ns | ns | ns |
| C21:0 | 2.42±0.07 | 2.12±0.08 | 2.43±0.12 | 2.07±0.05 | *** | ns | ns |
| C22:1 | 0.06±0.01 | 0.05±0.01 | 0.05±0.01 | 0.06±0.01 | ns | ns | ** |
| C18:2 | 3.12±0.06 | 3.09±0.01 | 3.09±0.01 | 3.09±0.01 | ns | ns | ns |
| C22:2 | 0.14±0.01 | 0.15±0.01 | 0.15±0.01 | 0.15±0.01 | ns | ns | ns |
| C20:4 | 0.06±0.01 | 0.06±0.01 | 0.06±0.01 | 0.06±0.01 | ns | ns | ns |
| SUM SFA | 47.37±0.13 | 47.70±0.07 | 47.85±0.19 | 47.59±0.08 | ns | ns | ns |
| SUM MUFA | 46.91±0.22 | 41.95±0.11 | 46.20±0.37 | 41.92±0.21 | *** | ns | ns |
| SUM PUFA | 6.02±0.16 | 10.36±0.14 | 6.09±0.14 | 10.49±0.21 | *** | ns | ns |
| n-6/n-3 | 10.44±0.38 | 12.72±0.27 | 11.30±0.65 | 12.38±0.23 | *** | ns | ns |

Values are presented as mean±standard error. FAMEs (fatty acid methyl esters), SFA (saturated fatty acids), MUFA (monounsaturated fatty acids), PUFA (polyunsaturated fatty acids). SUM SFA = C8:0 + C10:0 + C12:0 + C13:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0; SUM MUFA = C16:1 + C18:1 + C20:1 + C22:1; SUM PUFA = C18:2 + C18:3 + C20:2 + C20:4 + C20:5 + C22:3 + C22:5 + C22:6; ns = not significant (P>0.05), * = P<0.05, ** = P<0.01, *** = P<0.001.
ied, and C12:0 in the LD muscle from barrows was lower than in boars by 0.03% (P<0.001) at 147 days and 0.2% (P<0.001) at 210 days. The largest component of the MUFA was C18:1 and it has been reported to reduce the risk of cardiovascular diseases (Hoffman et al., 2007), and C18:1 in the LD muscle from barrows was higher than in boars by 4.23% and 4.03% at the two slaughter ages.

High levels of polyunsaturated fatty acids (PUFA) are undesirable, especially in pork, because they adversely affect consistency, storage stability and texture of the processed pork products. Fat from heavy boars is softer and contains more oleic acid than fat from the corresponding barrows (Field, 1971). Malmfors and Nilsson (1978) demonstrated that fat from uncastrated male pigs became rancid faster than the one from gilts and castrated pigs. Boars had higher amounts of total PUFA in LD muscle than barrows by 4.34% and 4.40% (P<0.001) at 147 and 210 days, respectively.

Pork normally has a high C18:2 content, with an unfavourable n-6/n-3 ratio. The recommended n-6/n-3 ratio should be less than 4 (Wood et al., 2003). Moreover, nutritionists have recently focused on the balance between n-6 PUFA and n-3 PUFA in the diet, since the n-6/n-3 ratio of PUFA is also a risk factor for cancers and coronary heart disease, especially the formation of blood clots leading to heart attacks (Williams, 2000; Monteiro et al., 2006). This study showed that barrows had lower n-6/n-3 ratios of PUFA in LD muscle by 1.83% and 1.08% (P<0.001) than boars at a slaughter age of 147 and 210 days, respectively.

Conclusions

The study investigated the effects of castration and slaughter age on the amino acid and fatty acid compositions of the Longissimus dorsi (LD) muscle of male pigs. Although only one muscle was analysed, the results gave a good indication of the effect that castration and slaughter age may have on the amino acid and fatty acid compositions of the meat.

Barrows had higher levels of total amino acid, essential amino acid, and non-essential amino acid in the LD muscle than boars. Higher contents of IMF and MUFA, lower C12:0 and n-6/n-3 ratios of PUFA were found in the LD muscle of barrows compared with boars. Considering the nutritive value of proteins and profile of fatty acids, meat from barrows appeared therefore to be more favourable from the human health point of view. Castration exhibited a significant effect on the muscle amino acid and fatty acid composition of male pigs, whereas the effects of slaughter age were found to be minor.

References

Banon, S., Gil, M.D., Garrido, M.D., 2003. The effects of castration on the eating quality of dry-cured ham. Meat Sci. 65:1031-1037.
Bender, J.M., See, M.T., Hanson, D.J., Lawrence, T.E., Cassady, J.P., 2006. Correlated responses in growth, carcass and meat quality traits to divergent selection for testosterone production in pigs. J. Anim. Sci. 84:1331-1337.
Bonneau, M., 1998. Use of entire males for pig meat in the European Union. Meat Sci. 49(Suppl 1):257-272.
Cutriggelli, M.I., Calabro, S., Bovera, F., Tudisco, R., D’Ursio, S., Marchiello, M., Piccolo, V., Infascelli, F., 2008. Effects of two protein sources and energy level of diet on the performance of young Marchigiana bulls. 2. Meat quality. Ital. J. Anim. Sci. 7:271-285.
Fernandez, M.L., West, K.L., 2005. Mechanisms by which Fatty Acids Modulate Plasma Lipids. J. Nutr. 135: 2075-2078.
Field, R.A., 1971. Effect of Castration on Meat Quality and Quantity. J. Anim. Sci. 32:849-858.
Finley, J.W., 1985. Reducing variability in amino acid analysis. In: J.W. Finley and D.T. Hopkins (eds.) Digestibility and amino acid availability in cereals and oilseeds. ACC Inc Publ, Saint Paul, MN, USA, pp 15-30.
Folch, J., Less, M., Stanley, G.H.S., 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497-509.
Font i Furnols, M., Oliver, M.A., 1999. Review: production and consumption of pork meat with different levels of boar taint. Food. Sci. Technol. Int. 5:367-375.
Grandhi, R.R., Nyachoti, C.M., 2002. Effect of true ileal digestible dietary methionine to lysine ratios on growth performance and carcass merit of boars, gilts and barrows selected for low backfat. Can. J. Anim. Sci. 82:399-407.
Higgs, J.D., 2000. The changing nature of red meat: 20 Years of Improving nutritional quality. Trends. Food. Sci. Technol. 11:85-95.
Hoffman, L.C., Kruckcamp, M., Manley, M., 2007. Meat quality characteristics of springbok (Antidorcas marsupialis).3: Fatty acid composition as influenced by age, gender and production region. Meat Sci. 76:768-773.
Hogberg, A., Pickova, J., Sternb, S., Lundstrom, K., Bylund, A.C., 2004. Fatty acid composition and tocopherol concentrations in muscle of entire male, castrated male and female pigs, reared in an indoor or outdoor housing system. Meat Sci. 68:659-665.
Knudson, B.K., Hogberg, M.G., Merkel, R.A., Allen, R.E., Magee, W.T., 1985. Developmental comparisons of boars and barrows: I. Growth rate, carcass and muscle characteristics. J. Anim. Sci. 61:789-796.
Lanza, E., 1983. Determination of moisture, protein, fat, and calories in raw pork and beef by near infrared spectroscopy. J. Food. Sci. 48:471-474.
Latorre, M.A., Lazaro, R., Valencia, D.G., Medel, P., Mateos, G.G., 2004. The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs. J. Anim. Sci. 82:526-533.
Lawrie, R.A., 1985. The conversion of muscle to meat, Meat Science. 4th ed. Pergamon Press, Oxford, UK.
Malmfors, B., Nilsson, R., 1978. Meat quality traits of boars in comparison with castrates and gilts. Swed. J. Agr. Res. 8:209-217.
Monteiro, A.C.G., Santos-Silva, J., Bessa, R.J.B., Navas, D.R., Lemos, P.C., 2006. Fatty acid composition of intramuscular fat of bulls and steers. Livest. Sci. 99:13-19.
Newell, J.A., Bowland, J.P., 1972. Performance, carcass composition and fat composition of boars, gilts and barrows fed two levels of protein. Can. J. Anim. Sci. 52:543-551.
Nielsen, A.J., 1973. Anatomical and chemical composition of Danish Landrace pigs slaughtered at 90 kilograms live weight in relation to litter, sex and feed composition. J. Anim. Sci. 36:476-483.
Okrouhla, M., Stupka, R., Citek, J., Sypsl, M., Kluzakowa, E., Trnka, M., Stolc, L, 2006. Amino acid composition of pig meat in relation to live weight and sex. Czech. J. Anim. Sci. 51:529-534.
Pauly, C., Spring, P., O’Doherty, J.V., Ampuero, K.S., Bee, G., 2009. Growth performance, carcass characteristics and meat quality of group-penned surgically castrated, immunocastrated (Improvac®) and entire male pigs and individually penned entire male pigs. Animal 3:1057-1066.
Purchas, R.W., Morel, P.C.H., Janz, J.A.M., Wilkinson, B.H.P., 2009. Chemical composition characteristics of the longissimus
and semimembranosus muscles for pigs from New Zealand and Singapore. Meat Sci. 81:540-548.

Razmaite, V., Kerziene, S., Siukscius, A., 2008. Pork Fat Composition of Male Hybrids from Lithuanian Indigenous Wattle Pigs and Wild Boar Intercross. Food. Sci. Technol. Int. 14:251-257.

SPSS, 2006. Base System User’s Guide. Statistics 13.0. SPSS Inc., Chicago, IL, USA.

Sun, J.S., Lu, F, 2002. Study on pork characteristics of Chinese Wuzhishan Mini-Pig. Pak. J. Nutr. 1:169-173.

Williams, C.M., 2000. Dietary fatty acids and human health. Ann. Zootech. 49:165-180.

Wood, J.D., Enser, M., Fisher, A.V., Nute, G.R., Sheard, P.R., Richardson, R.I., Hughes, S.I., Whittington, E.M., 2008. Fat deposition, Fatty acid composition and meat quality: A review. Meat Sci. 78:343-358.

Wood, J.D., Richardson, R.I., Nute, G.R., Fisher, A.V., Campo, M.M., Kasapidou, E., Sheard, P.R., Enser, M., 2003. Effects of fatty acids on meat quality: A review. Meat Sci. 66:21-32.

Xue, J.L., Dial, G.D., Pettigrew, J.E., 1997. Performance, carcass, and meat quality advantages of boars over barrows: A literature review. Swine Health Prod. 5:21-28.