



Association analysis between carcass weight and meat quality of Bamei pigs

J.P. Zhou¹, G.F. Wu^{1*}, A.Q. Xiang², L. Wang¹, S.D. Sun², C. Yang¹ and F.F. Xu³

¹Stake Key Laboratory of Plateau Ecology and Agriculture, Qinghai Academy of Animal Science and Veterinary Medicine, Qinghai University, Xining, Qinghai, China

²College of Animal Science and Technology, Northwest A& F University, Yangling, Shaanxi, China

³Qinghai Province Huzhu County Bamei Pig Seed Breeding Farm, Huzhu, Qinghai, China

Corresponding author: G.F. Wu
E-mail: letitbe521@163.com

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ABSTRACT. A total of 48 crossbred Bamei pig carcasses were divided into three groups (A, 60-69 kg; B, 70-79 kg; and C, 80-90 kg) to investigate the influence of carcass weight on meat quality. The intramuscular fat content of the three groups increased from 2.20% (Group A) to 4.14% (Group C). Group B had higher drip loss (6.83%, $P < 0.05$) than the other two groups. Warner-Bratzler shear force decreased with increasing weight (61.16 > 51.63 > 43.64 N, $P < 0.05$). No significant differences were observed in meat color, cooking percentage, and water holding capacity among the three groups. The polyunsaturated fatty acids/saturated fatty acids ratio in group B (0.23) was significantly higher than that in the other two groups. In conclusion,

our results suggested that a carcass weight of 70-79 kg is suitable for the production of Bamei pigs.

Key words: Carcass weight; Fatty acid composition; Bamei pig; Meat quality; Free amino acid composition

INTRODUCTION

Bamei pigs are a local variety of QingHai Province, which is a plateau that has permitted a long period of natural and artificial selection, leading to this pig variety having strong adaptability, fat deposition ability, and good meat quality characteristics (Jin, 2006; Yang and Gun, 2007). Results of hybridization experiments have shown that Bamei pigs are an excellent maternal, binary and trispecific hybrid pig showing better combining ability and heterosis. Binary and trispecific hybrid pigs are leaner, have larger hindquarters, and demonstrate better breeding performance than purebred Bamei pigs (Yang et al., 2010; Yang et al., 2011; Guo et al., 2012). However, few scientific studies have examined the meat quality of Bamei pigs, particularly with respect to the relationships between carcass, intramuscular fat (IMF) content, and fatty acid composition. Previous research has found that the adipose growth rate of Bamei pigs significantly increased after they reached 35 kg, the muscle growth rate significantly decreased after the animals reached 55 kg (Yang and Song, 1991), and prolonged feeding wasted feed. It is important to determine a suitable carcass weight in order to obtain the best pork from Bamei pigs.

Muscle microstructure is an important determinate of meat quality, which affects muscle physicochemical traits. Postmortem changes affect fiber type composition in the conversion of muscle to meat, and thus affect meat quality (Ryu and Kim, 2006). In pigs, a larger muscle fiber cross-sectional area is thought to be detrimental to meat quality, owing to its poor water-holding capacity and tenderness (Rehfeldt et al., 2000). However, IMF content and fatty acid composition also affect the nutritional quality of muscle, and have been widely studied in meat science because of their importance to human health (Pfeuffer, 2001; Raes et al., 2004). Therefore, we investigated suitable carcass weights and assessed the relationship between this trait and meat quality from Bamei pigs.

MATERIAL AND METHODS

All experimental procedures were performed according to the Guide for Animal Care and Use of Laboratory Animals in the Institutional Animal Care and Use Committee of QingHai University. The experimental protocol was approved by the Department of Animal Ethics Committee of QingHai University.

Animals and management

A total of 48 Bamei Pigs, ranging from 60 to 90 kg in carcass weight, were selected and divided into three weight groups containing 16 carcasses each: A, 60-69 kg (8 months old); B, 70-79 kg (10 months old); and C, 80-90 kg (12 months old). All pigs were fed *ad libitum* with a commercial diet ([Table S1](#)) suited to their nutritive needs. The pigs were fasted and given free access to water for 16 h, and were then electrically stunned, exsanguinated, scalded, and rinsed.

Carcass and meat quality measurements

At 45 min after slaughter, pH was measured using a portable pH meter, and meat color was estimated by a colorimeter; Warner-Bratzler shear force was measured using a C-LM3 Digital Display tenderness instrument equipped with a shearing device (XIELI Sci. Co., Ltd.; Harbin, China) (Qin et al., 2014). After the carcass was aged for 24 h, the longissimus lumborum muscles were isolated to evaluate drip loss using the method described by Honikel (1998) with modifications: muscle samples standardized for surface area (5 x 3 x 2.5 cm³) were suspended in an inflated plastic bag for 24 h at 4°C.

Determination of muscle fiber diameter and type

The composition of muscle fiber type was determined by qRT-PCR. RNA was extracted from the longissimus dorsi muscle with TRIzol reagent (TaKaRa, China) using standard techniques. Total RNA (1 µg) was reverse transcribed to synthesize cDNA using the Prime Script RT-Reagent Kit for RT-PCR. Real-time PCR amplifications were carried out on a Bio-Rad iQ5 by SYBR Premix Ex TaqTM II (TaKaRa) chemistry detection system under amplification conditions. mRNA data were quantified using the comparative threshold cycle (40 CT) method with slight modifications. The relative efficiency of each primer was included in the calculations. The specificity of the PCR amplification was verified by melting curve analysis. Details of the gene primers are presented in [Table S1](#).

Muscle fiber diameter was determined by hematoxylin-eosin staining (Kim et al., 2013). Images were visualized and captured using a Nikon TE 2000 microscope (Nikon; Tokyo, Japan), and approximately 600 fibers per sample were counted.

IMF content and fatty acid composition

Muscle samples were obtained from the fourth-to-fifth intercostal space. IMF content was determined using the Weibull-Stoldt method (AOAC, 1997). Fatty acids from the longissimus lumborum muscle were detected based on their methyl ester content according to the method described by Park and Goins (1994). Separation of fatty acid methyl esters was performed by gas chromatography using a Tracege Ultra system (Thermo Scientific; Waltham, MA, USA), and fatty acid composition was calculated using response factors derived from chromatographic standards (GLC-91, NU-CHEK; Elysian, MN, USA) of known composition. The results are reported as a percentage of the total fatty acid content.

Free amino acid analysis

The composition of free amino acids was detected by spectrophotometric analysis with ninhydrin reagent. Each amino acid sample was subjected to an automatic amino acid analyzer (model L-8900; Hitachi, Tokyo, Japan) for cation-exchange chromatography separation. Accuracy and repeatability of this analysis was ensured by the inclusion of a control sample of known amino acid composition with the samples prior to hydrolysis.

Statistical analyses

Statistical analyses were performed using SAS version 8.0 (SAS Inst. Inc.; Cary, NC, USA). Differences were considered significant when $P < 0.05$.

RESULTS AND DISCUSSION

Meat quality traits

IMF significantly increased with increasing carcass weight ($P < 0.05$), from 2.2 to 4.14% (Table 1). The overall pH was not significantly different among the three groups, and all values were within the normal range. The meat color value did not differ significantly among the three groups ($P < 0.05$) (Table 1), which was inconsistent with the results of previous studies (Correa et al., 2006; Galián et al., 2009). Bamei pig is a plateau species, and its meat contains more redness, so the color value was almost the same in the three groups. The muscle fiber diameters in the three groups were 40.83, 48.96, and 58.33 μm , respectively (Figure 1). Group A contained the highest levels of MyHC I, IIA, and MyHC IIX mRNA among the three groups. Group C contained more oxidized muscle fibers than the other two groups, and showed the highest level of MyHC IIB mRNA expression (Figure 1). Ryu and Kim (2005) reported that fiber number and area percentage were not affected by carcass weight and loin-eye area. Other studies have showed that pigs with greater weights have the highest proportion of type IIB fibers, and thus, the proportion of type I and IIA fibers decreased (Bee, 2004). Our results are consistent with the observation that lower carcass weights are associated with higher percentages of oxidative muscle fiber.

Table 1. Meat quality traits of Bamei pigs.

| Item | A (60-69 kg) | B (70-79 kg) | C (80-90 kg) |
|------------------------|-------------------------------|-------------------------------|-------------------------------|
| Carcass weight (kg) | 63.50 \pm 1.45 ^a | 75.50 \pm 1.88 ^b | 89.00 \pm 1.18 ^c |
| Ultimate pH | 5.55 \pm 0.21 ^a | 5.72 \pm 0.19 ^{ab} | 6.01 \pm 0.08 ^b |
| <i>L*</i> Value | 51.84 \pm 0.31 ^a | 51.03 \pm 0.51 ^b | 49.82 \pm 0.08 ^a |
| <i>A*</i> Value | 19.22 \pm 0.44 ^a | 18.52 \pm 0.72 ^b | 20.13 \pm 0.26 ^c |
| <i>B*</i> Value | 7.80 \pm 0.87 ^a | 8.39 \pm 0.23 ^b | 7.19 \pm 0.28 ^a |
| IMF content (%) | 2.20 \pm 0.81 ^a | 3.91 \pm 1.77 ^b | 4.14 \pm 0.37 ^b |
| WBSF (N) | 61.16 \pm 3.48 ^a | 51.63 \pm 7.10 ^b | 43.64 \pm 5.76 ^c |
| WHC (%) | 92.24 \pm 1.61 | 89.97 \pm 3.92 | 90.56 \pm 3.41 |
| Drip loss (%) | 3.85 \pm 0.71 ^a | 6.83 \pm 0.57 ^b | 3.76 \pm 0.32 ^a |
| Cooking percentage (%) | 66.28 \pm 3.19 | 65.26 \pm 2.11 | 67.29 \pm 1.84 |

^{a,b,c}Means within the same row with different superscript letters are significantly different ($P < 0.05$). WBSF: Warner-Bratzler shear force; WHC: water holding capacity.

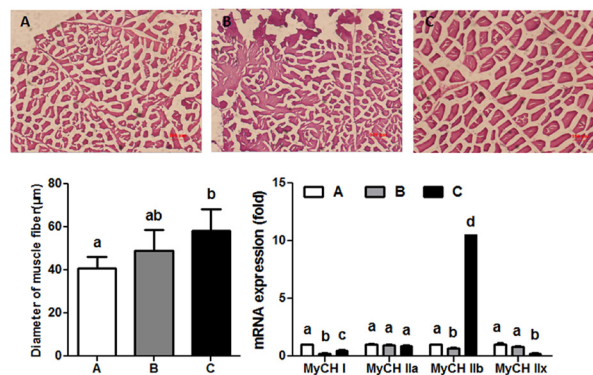


Figure 1. Determination of the diameter and percentage of muscle fiber in three groups of pigs. **A.** H&E staining of muscle; **B.** diameter of muscle fiber; **C.** quantification of muscle fiber types. Data are reported as means \pm standard error of the mean; different letters (a-e) indicate significantly different results ($P < 0.05$).

Fatty acid composition of IMF in the longissimus lumborum muscle

A summary of the fatty acid profile and selected ratios are shown in Table 2. The fatty acid composition of the longissimus lumborum muscle showed that the level of saturated fatty acids (SFA) in group B (37.24%) was significantly lower than that in the other two groups, while the percentage of monounsaturated fatty acids was the highest (54.12%), and mainly included oleic acid. Group B showed the highest polyunsaturated fatty acid/SFA (P:S) ratio ($P < 0.05$). The content of the two major monounsaturated fatty acids (oleic and palmitoleic acids) in both group B and C was higher than in group A. Kouba et al. (2003) and Furman et al. (2010) found that the C16:1n-7 and C18:1n-9 in the longissimus muscle were higher according to increasing age and fattiness of pigs. Our results are not consistent with those previously reported, which may be due to the different range of body weights.

Table 2. Fatty acid content of the longissimus lumborum muscle from different pig carcasses.

| Item | A (60-69 kg) | B (70-79 kg) | C (80-90 kg) |
|-----------------------------|---------------------------|---------------------------|----------------------------|
| SFA (%) | 41.70 ± 0.74 ^a | 37.24 ± 3.21 ^b | 42.96 ± 0.39 ^a |
| C14:0 (myristic acid) | 1.50 ± 0.16 ^a | 1.26 ± 0.12 ^b | 1.41 ± 0.01 ^{ab} |
| C16:0 (palmitic acid) | 27.34 ± 0.30 | 24.68 ± 1.47 | 26.84 ± 0.53 |
| C18:0 (stearic acid) | 14.12 ± 0.08 ^a | 11.30 ± 1.63 ^b | 13.45 ± 1.27 ^a |
| MUFA (%) | 50.76 ± 1.14 ^a | 54.12 ± 3.31 ^b | 48.75 ± 1.89 ^a |
| C16:1n-7 (palmitoleic acid) | 3.29 ± 0.33 | 3.51 ± 0.11 | 3.32 ± 0.54 |
| C18:1n-9 (oleic acid) | 45.46 ± 1.56 ^a | 50.61 ± 3.20 ^b | 47.44 ± 0.60 ^{ab} |
| PUFA (%) | 8.29 ± 0.85 ^a | 8.64 ± 0.54 ^a | 7.54 ± 0.40 ^b |
| C18:2n-6 (linoleic acid) | 8.29 ± 0.85 ^a | 8.64 ± 0.54 ^a | 7.54 ± 0.40 ^b |
| PUFA/SFA (P:S) ratio | 0.19 ± 0.07 ^a | 0.23 ± 0.05 ^b | 0.18 ± 0.03 ^a |

^{a,b}Means within the same line with different superscript letters are significantly different ($P < 0.05$). SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

The fatty acid composition of food stuffs is of great importance to healthy human nutrition (Parunović et al., 2012). The P:S ratio is more beneficial to human health (Mapiye et al., 2011) than SFA and trans fatty acids, which are associated with an increased risk of cardiovascular disease and some cancers (Burlingame et al., 2009; Brouwer et al., 2010; USDA and HHS, 2010; Mapiye et al., 2011). While all the P:S ratios were acceptable (≥ 0.4) (WHO, 2003), a higher P:S ratio was observed with lower IMF content in commercial pigs. Enser et al. (1996) showed that the pork with the highest proportion of C18:2n-6 (14.2% of the total fatty acids) also had the highest P: S ratio (0.58), which is consistent with our results. A comparison of the P:S ratio for the three groups, suggested that group B had the best proportions of fatty acids.

Free amino acids composition

The profile of free amino acids contributes to the taste of meat (Nishimura, 2009), and is known to be related to the development of particular tastes, flavors, or aromas, including saltiness, acid taste, and bitter taste (Guàrdia et al., 2008). Free amino acids can be classified into four categories: saccharinity (threonine, serine, glycine, and alanine), amino acids with sulfide (methionine and cysteine), fragrant amino acids (phenylalanine and tyrosine), and essential amino acids (threonine, valine, methionine, isoleucine, leucine, phenylalanine, histidine, lysine, and arginine) (Bailey and Ayling, 2007). The levels of all amino acid decreased as the pig weight increased; EAA, NEAA, DAA, AAA, BCAA followed the same trend. TAA, EAA,

NEAA, and AAA were significantly higher in groups A and B than in group C, but there were no significant differences between groups A and B. Group A contained the highest level of aspartic and glutamic acids, which are known for the umami taste of loin. Arginine is known for its bitter taste and showed a small increasing trend, but no significant difference was found between the three groups (Table 3).

Table 3. Free Amino acid content in Bamei pigs muscle.

| Item | A (60-69 kg) | B (70-79 kg) | C (80-90 kg) |
|-----------------------------------|---------------------------|---------------------------|---------------------------|
| Threonine (Thr) ^Δ | 0.78 ± 0.02 | 0.76 ± 0.05 | 0.72 ± 0.02 |
| Valine (Val) ^{Δ†} | 0.85 ± 0.02 | 0.84 ± 0.05 | 0.80 ± 0.01 |
| Methionine (Met) ^Δ | 0.50 ± 0.02 | 0.44 ± 0.05 | 0.45 ± 0.01 |
| Isoleucine (Ile) ^{Δ†} | 0.75 ± 0.01 | 0.73 ± 0.05 | 0.69 ± 0.02 |
| Leucine (Leu) ^{ΔΔ} | 1.34 ± 0.03 | 1.33 ± 0.08 | 1.24 ± 0.03 |
| Phenylalanine (Phe) ^{Δ*} | 0.82 ± 0.02 | 0.82 ± 0.07 | 0.75 ± 0.02 |
| Lysine (Lys) ^Δ | 1.53 ± 0.05 | 1.48 ± 0.10 | 1.39 ± 0.04 |
| Aspartic Acid (Asp) ^{‡§} | 1.60 ± 0.05 | 1.56 ± 0.09 | 1.49 ± 0.03 |
| Glutamic acid (Glu) ^{‡§} | 2.83 ± 0.01 ^a | 2.53 ± 0.18 ^b | 2.71 ± 0.08 ^a |
| Glycine (Gly) ^{‡§} | 0.72 ± 0.05 | 0.75 ± 0.04 ^a | 0.67 ± 0.01 |
| Alanine (Ala) ^{‡§} | 0.94 ± 0.03 | 0.93 ± 0.05 | 0.87 ± 0.01 |
| Arginine (Arg) [‡] | 1.08 ± 0.04 | 1.06 ± 0.07 | 0.98 ± 0.03 |
| Serine (Ser) [‡] | 0.67 ± 0.02 | 0.65 ± 0.04 | 0.62 ± 0.01 |
| Proline (Pro) [‡] | 1.19 ± 0.07 | 1.24 ± 0.05 | 1.17 ± 0.01 |
| Cystine (Cys) [‡] | 0.18 ± 0.02 | 0.20 ± 0.01 | 0.20 ± 0.01 |
| Tyrosine (Tyr) ^{‡*} | 0.57 ± 0.01 | 0.56 ± 0.03 | 0.53 ± 0.02 |
| Histidine (His) [‡] | 0.67 ± 0.02 | 0.64 ± 0.10 | 0.56 ± 0.01 |
| TAA | 16.92 ± 0.49 ^a | 16.62 ± 1.11 ^a | 15.58 ± 0.37 ^b |
| EAA | 6.57 ± 0.17 ^a | 6.40 ± 0.45 ^a | 6.04 ± 0.15 ^b |
| NEAA | 10.35 ± 0.32 ^a | 10.22 ± 0.66 ^a | 9.54 ± 0.22 ^b |
| DAA | 6.09 ± 0.14 | 5.77 ± 0.36 | 5.74 ± 0.13 |
| AAA | 1.39 ± 0.03 ^a | 1.38 ± 0.10 ^a | 1.28 ± 0.04 ^b |
| BCAA | 2.94 ± 0.06 | 2.90 ± 0.18 | 2.73 ± 0.06 |
| DAA/TAA (%) | 35.99 ± 0.48 ^c | 34.72 ± 0.27 ^a | 36.84 ± 0.34 ^b |
| EAA/TAA (%) | 38.83 ± 0.45 | 38.51 ± 0.73 | 38.77 ± 0.20 |

^{a,b,c}Means within the same row with different superscript letters are significantly different ($P < 0.05$). TAA: total amino acids; ^ΔEAA: essential amino acids; [‡]NEAA: nonessential amino acids; [§]DAA: delicious amino acids; [†]BCAA: branched chain amino acids; ^{*}AAA: aromatic amino acids.

In conclusion, the carcass weight of Bamei pigs is related to muscle fiber characteristics, and has an influence on meat quality. In Bamei pigs, the longissimus lumborum in animals with a heavier carcass weight showed bigger muscle fiber diameters and lower levels of oxidized muscle fibers. The IMF also increased with increasing carcass weight, and group B contained the highest proportion of fatty acids. Total amino acid content decreased according to the increase or decrease of carcass weight. In conclusion, a suitable carcass weight was found to be important for meat quality. A comprehensive consideration of meat quality and economic benefits found the suitable slaughter weight of Bamei pigs to be 70-79 kg.

Conflicts of interest

The authors declare no conflict of interest.

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Supplementary material

[Table S1](#). Primers used for real-time PCR analysis.