Breed Characteristics of Indigenous Pigs in Okinawa:
Growth Performance, Carcass Traits and Meat Quality

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Abstract: Agu, a relatively small-bodied pig with a black coat, is indigenous to Okinawa, the southernmost island in Japan. The objective of this study was to evaluate growth, carcass and meat quality traits of Agu pigs and to elucidate breed characteristics. A total of 16 Agu pigs and 18 LWD three-way cross pigs (Duroc sires × F1 dams; Landrace × Large White) were fed a commercial diet ad libitum at 70 kg and slaughtered at 110 kg. Daily gain, dressing percentage and the area of the Longissimus dorsi muscle (LM) were significantly lower in Agu than in LWD pigs at the same body weight. Agu pigs had much thicker backfat than the LWD pigs at the same finishing body weight. The content of intramuscular fat (IMF) was significantly higher in Agu than in LWD pigs. Though raw Agu meat had lower water holding capacity, cooked meat had lower cooking loss and higher pressed juice percentage than LWD meat. Moreover, the inner layer of Agu backfat contained a higher proportion of monounsaturated fatty acids (MUFA), a lower proportion of polyunsaturated fatty acids (PUFA) and had a lower melting point. The results revealed that Agu pigs had meat characteristics different from those of LWD pigs that are a common crossbred in commercial production.

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Key words: Agu, carcass trait, growth performance, Okinawan indigenous pig, meat quality

Introduction

The Agu pig, an indigenous breed maintained since the era of the Ryukyu kingdom in Okinawa prefecture (Japan), is recognized as the only native pig in Japan. The first Agu pigs are assumed to have been introduced from China during the Ming dynasty in the latter half of the 14th century. The body size of the Agu pig is similar to that of medium-sized Chinese breeds such as Jinhua pigs (TOUMA and OIKAWA, 2017). Previous studies have revealed that Agu pigs are characterized by poor fertility in terms of litter size (TOUMA and OIKAWA, 2017), and poor male reproductive ability attributed to sperm quality and concentration (YAMAUCHI et al., 2009).

Meat of this breed is a source of valuable protein for inhabitants of Okinawa and has contributed to the unique food culture of the region for many years. In the early 1900s Euro-American breeds were introduced into Okinawa; Agu pigs were gradually replaced by foreign breeds, decreasing to about 30 pigs, the smallest population size in history. Be-
cause of organized promotion of conservation and propagation by the local government, the population of Agu pigs has recovered and reached around 700 animals. Recently the Agu has been officially recognized as a new breed by the Okinawa Agu pig Promotion Council based on genetic tests using microsatellite DNA markers and mitochondrial genome. Moreover, the pork quality has been praised by daily consumers, holidaymakers, gourmet tourists and locals. Recently, Agu production has grown considerably in response to the strong demand for Agu pork both within and outside Okinawa.

Thus, Agu pigs are a very important genetic resource for the pig industry in Okinawa. Nonetheless, little scientific data have been presented on not only meat quality but also growth and carcass traits of this breed. The objective of this study was to evaluate the traits of growth, carcass and meat quality of Agu pigs as compared with common three-way crosses from LWD (Duroc sires × F1 dams; Landrace × Large White) on the basis of the same finishing body weight.

Material and methods

Animals and management

Sixteen Agu pigs (6 gilts, 10 barrows) and 18 LWD pigs (9 gilts, 9 barrows) were group-housed (5–6 pigs per 3.5×2.7 m pigpen) at the Okinawa Prefectural Livestock and Grassland Research Center in Japan. The pigs were reared in accordance with the code of Standards of Rearing Hygiene Management of Okinawa Prefecture. The pigs had free access to water and feed, and at a weight of 70 kg were given a commercial diet containing 12.5% CP, 1.5% crude fat, 6.5% CF, 9.0% crude ash, and 73.5% TDN for fattening. At the normal slaughtered weight of 110 kg, the animals were slaughtered at a commercial slaughterhouse.

Meat samples and carcass measurements

The heads and organs of the slaughtered pigs were removed, the carcasses were scalded, split longitudinally and chilled at 0°C for 24 h. Hot carcass weight, dressing percentage, backfat thickness and the area of the Longissimus dorsi muscle (LM) were measured. Backfat thickness was measured at the thinnest portion of the 9th and 13th ribs. The LM at the last rib was photographed with a digital camera, and the area measured with Image J 1.46 software (Rasband and Ferreira, 2012). A sample of the LM with subcutaneous backfat from the lumbar vertebra to the last rib was vacuum-packaged, frozen, and held at −30°C for subsequent physical and chemical analyses.

Physicochemical analyses

The moisture content was measured by using a drying oven (135°C for 2 h), the intramuscular fat (IMF) analyzed with the Soxhlet method, the water holding capacity of raw meat measured with the filter-paper press method (Suzuki et al., 1991), and the difference in weight between cooked and raw samples taken as cooking loss. A cube of loin was weighed and packaged in a polyethylene bag, heated in a warm bath at 70°C for 30 min, cooled at room temperature, the moisture on the meat blotted up and the meat weighed again. After determining cooking loss, the cooked sample was divided into two masses: one was cut into 1×1×5 cm portions placed on filter paper and assessed for juiciness as described by Nii et al. (2005). After weighing the meat and pressing at 35 kg/cm² for 1 min with a pressurizer, the released liquid was deduced as the percentage (%) of pressed juice; the other cooked sample was cut into 1×1×5 cm portions in the direction of the muscle fiber, then tenderness and toughness, were assessed with a Tensipresser (Model TTP-50BXII, Taketomo-Electric Company, Tokyo, Japan). The machine was developed to evaluate meat texture attributes by an up-and-down motion to simulate mastication (Nakai et al., 1992). Tenderness was assessed by the severing threshold: a high value indicates tough meat and a low one shows tender meat. Toughness denotes the amount of work required to sever cooked meat: a high value indicates meat that is hard to bite off.

Analysis of fatty acid composition and measurement of melting point

The composition of fatty acid in the inner layer of backfat was determined after its extraction with chloroform / methanol (2 : 1) and methylation with Fatty Acids Methylation kits (Nacalai Tesque Co.
Kyoto, Japan). The methyl esters were analyzed on an Agilent 7890 gas chromatograph (Agilent Technologies Co., California, USA) equipped with a capillary column (DB-23, 60 m × 0.25 mm internal diameter, Agilent Technologies Co., California, USA). Seven fatty acids were identified by comparison with retention times of known standards and quantified by external standard calibration: myristic (C14 : 0), palmitic (C16 : 0), palmitoleic (C16 : 1), stearic (C18 : 0), oleic (C18 : 1), linoleic (C18 : 2) and linolenic (C18 : 3). The content of the seven ingredients was expressed as a percentage. The melting point of the inner layer of backfat on the LM was measured with the capillary tube. To extract lipids, a 20 g sample of minced fat was heated at 105°C for 4 h while filtering. The lipids were drawn to a height of 1 cm into capillary tubes. Seven tubes were prepared for each sample, held at −30°C overnight and placed into a water bath. The temperature of the water was raised gradually at the rate of 1°C/2 min. The temperature at which the lipid rose 1 cm in the tube was regarded as the melting point.

Statistical analyses

Accumulated records were analyzed by using the GLM procedure of JMP software (SAS Institute, Inc., Cary, NC North Carolina, USA). Analysis of variance was used to evaluate the effects of breed, sex and their interactions as follows:

\[ Y_{ijk} = \mu + B_i + S_j + (BS)_{ij} + e_{ijk}, \]

where \( Y_{ijk} \) is the \( k \)th observation within the \( i \)th breed and \( j \)th sex, \( \mu \) the overall mean, \( B_i \) the effect of \( i \)th breed, \( S_j \) the effect of \( j \)th sex, \( (BS)_{ij} \) the effect of interaction between breed and sex and \( e_{ijk} \) the random error. Least squares means were compared with the use of Tukey’s test.

Results

Growth and carcass traits

Least squares means of growth and carcass traits showed that only breed had a statistically significant effect, with growth performance being lower in Agu than in LWD pigs. It took approximately 170 days for LWD pigs and 227 days for Agu pigs (\( P < 0.001 \)) to reach the target slaughter weight of 110 kg. Thus, at the same finishing weight, daily gain was significantly lower in Agu. Carcass weight tended to be lower in Agu pigs. Dressing percentage was lower in Agu pigs. The effect of breed and sex was significant on backfat thickness: barrows had thicker backfat than did gilts; Agu pigs had much thicker backfat than did LWD pigs. The LM area, however, was much smaller in Agu than in LWD pigs (Table 1).

Table 1. Least squares means and standard errors for production traits of breed and sex

<table>
<thead>
<tr>
<th>Breed</th>
<th>Sex</th>
<th>Significance</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Agu</td>
</tr>
<tr>
<td>Number of animals</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Initial body weight (kg)</td>
<td>67.7±1.2</td>
<td>69.5±1.1</td>
</tr>
<tr>
<td>Final body weight (kg)</td>
<td>109.8±1.1</td>
<td>107.6±1.0</td>
</tr>
<tr>
<td>Age at initial (days)</td>
<td>148.2±2.5a</td>
<td>113.3±2.3b</td>
</tr>
<tr>
<td>Age at final (days)</td>
<td>226.8±4.9c</td>
<td>170.2±4.5c</td>
</tr>
<tr>
<td>Daily gain (g/day)</td>
<td>565.2±32.1c</td>
<td>680.5±29.3d</td>
</tr>
<tr>
<td>Carcass weight (kg)</td>
<td>77.4±0.8</td>
<td>79.6±0.8</td>
</tr>
<tr>
<td>Dressing percentage (%)</td>
<td>70.5±0.4a</td>
<td>74.2±0.4a</td>
</tr>
<tr>
<td>Backfat thickness (cm)</td>
<td>4.9±0.1a</td>
<td>2.3±0.1c</td>
</tr>
<tr>
<td>Longissimus muscle area (cm²)</td>
<td>24.2±1.4b</td>
<td>45.8±1.3a</td>
</tr>
</tbody>
</table>

* Means within the same row with different superscripts differ significantly at \( P < 0.05 \) for breed and sex. 
** \( P < 0.05 \), *** \( P < 0.001 \).
Meat quality traits

Breed had a significant effect on most of the meat quality traits: the content of IMF, a trait often targeted as a selection objective, was significantly higher in Agu than in LWD pigs (5.9 vs. 2.4%; \( P < 0.001 \)). Moisture content and water holding capacity of raw meat were lower in Agu. On the other hand, cooking loss was lower and pressed juice percentage in cooked meat was higher in Agu pigs. No significant difference was found in meat tenderness and toughness (Table 2).

**Fatty acid composition and melting point**

Breed had a significant effect on fatty acid composition and the melting point of the inner layer of backfat, except on the proportion of C18:0. Agu pigs had higher proportions of C14:0, C16:0, C16:1, C18:1 and of monounsaturated fatty acid (MUFA), whereas LWD had higher proportions of C18:2, C18:3 and of polyunsaturated fatty acid (PUFA) (Table 3).
The effect of the interaction between sex and breed was significant on the proportion of PUFA (Table 3): in LWD pigs the proportion was higher in gilts than in barrows; in Agu pigs, on the other hand, barrows had a higher proportion, although no significant difference was observed between the sexes (Fig. 1). The melting point of the inner layer of backfat was lower in Agu than in LWD pigs.

**Discussion**

**Growth and carcass traits**

The body size of mature Agu pigs is smaller than that of Euro-American breeds. Our study confirmed that Agu have a lower growth rate than LWD pigs and, as a result, Agu pigs have lower meat production efficiency at the finishing stage. As shown in Table 1, the daily gain and the LM area in Agu pigs were 83% and 53% of those in LWD pigs, respectively; whereas backfat deposition in Agu was 2.1 times as thick as in LWD pigs. Moreover, on the same finishing weight basis, Agu pigs had a lighter carcass and a smaller dressing percentage than did LWD pigs. Our results indicated that Agu pigs had carcass characteristics of low lean meat productivity and high fat deposition which is consistent with previous studies on other indigenous breeds such as Iberian pigs (MORALES et al., 2003), Meishan (LAN et al., 1993), Jinhua (MIAO et al., 2009), Basque pigs (ALFONSO et al., 2005) and Creole pigs (RENAudeau and MOUROT, 2007). MIAO et al. (2009) has reported that backfat thickness in Jinhua pigs increases with age. Thus, the higher backfat thickness in Agu pigs can be attributed to their longer fattening periods required than for LWD pigs, in addition to their propensity for high fat deposition.

Sex had a significant effect only on backfat thickness: barrows had thicker backfat than did gilts, as described by PIAO et al. (2004) and RENAUDEAU et al. (2006).

**Meat quality traits**

Meat quality of Agu pigs showed breed-specific characteristics (Table 2). The content of IMF in Agu pork (5.9%) was significantly higher than that in LWD meat (2.4%), which is within ordinary values (2%–3%) often observed in the commercial pig population in Japan (MAEDA et al., 2014). A positive relation between IMF and palatability of pork has been confirmed in many studies (DEVol et al., 1988;
For Japanese consumers, IMF is the key factor in appraising meat quality. An international comparison of consumer preferences for pork has shown that Japanese consumers tend to prefer significantly more marbled pork (Ngapo et al., 2007). Our results suggested that Agu pigs have a propensity for accumulating high IMF content. Although the IMF profile of Agu pigs in relation to age is not known, in Jinhua pigs IMF content increases with age (Miao et al., 2009). Thus, one of the factors for the high IMF content in Agu pigs may be attributed to the longer fattening periods required than for LWD pigs.

In contrast to the content of IMF, that of moisture was lesser in Agu meat than in LWD meat; this negative correlation is consistent with previous studies (Devol et al., 1988; Hodgson et al., 1991). Cooked Agu meat showed smaller cooking loss and larger pressed juice percentage than did LWD meat (Table 2). These values may be associated with higher IMF content in Agu meat; in this regard, a favorable relation between IMF and cooking loss was reported by Hodgson et al. (1991). Furthermore, smaller cooking loss is coincident with a high score of sensory juiciness and overall palatability (Devol et al., 1988; Hodgson et al., 1991; Huff-Lonergan et al., 2002).

Water holding capacity of raw Agu meat was smaller than that of LWD meat, indicating that raw Agu meat releases more water in storage than LWD meat, although water loss in cooking was smaller in Agu meat than in LWD meat. The mechanisms of water loss from raw meat and in cooking are different (Hughes et al., 2014), as supported by findings by Huff-Lonergan et al. (2002) and Cannata et al. (2010), who reported low correlations between drip loss and cooking loss (0.016 by the former and 0.07 by the latter advocate).

Some studies have demonstrated a favorable relation between IMF content and instrumental assessment of tenderness measured by Warner-Bratzler shear force (Devol et al., 1988; Hodgson et al., 1991). On the other hand, Hovenier et al. (1993) reported little correlation between IMF and tenderness, also assessed by Warner-Bratzler shear force. In this study, although the content of IMF in Agu pigs was significantly higher than in LWD pigs, the tenderness of Agu meat was not significantly different from that of LWD meat. This result is consistent with a study by Suzuki et al. (2003) indicating that there is no significant difference in the tenderness of the meat measured by a tensiopresser, although the IMF of Duroc and LDD (Duroc sires × F1 dams; Landrace × Duroc) is thicker than that of Berkshire and LDB (Berkshire sires × F1 dams; Landrace × Duroc). In general, meat tenderness is affected by not only IMF content but also other factors such as the amount and solubility of connective tissue, the composition and contractility of muscle fibers (Joo et al., 2013), the length of proteolysis sarcomere and the content of collagen (Wheeler et al., 2000). Our results suggested that factors other than IMF content mostly influenced the tenderness of Agu meat.

**Fatty acid composition and melting point**

Breed had a significant effect on most components of fatty acids in the inner layer of backfat (Table 3), with the exception of C18:0. In particular, Agu pigs exhibited a higher concentration of C16:0 and MUFA, but a much lower concentration of PUFA than did LWD pigs. This result is consistent with previous studies on the composition of fatty acids in indigenous pigs such as Iberian and Creole pigs (Serra et al., 1998; Renaudeau and Mourot, 2007). It is known that breed has a large effect on fatty acid composition (Morales et al., 2003). Genetically fat-type pigs have a higher proportion of saturated fatty acid (SFA) and MUFA but a lower proportion of PUFA than do lean pigs (Scott et al., 1981). It seems that the synthesis of C16:0 and MUFA is higher in Agu than in LWD pigs.

In our study, a significant interaction was observed between breed and sex in terms of C18:2, C18:3 and PUFA. Higher PUFA in gilts than in barrows has frequently been reported (Warnants et al., 1996; Desmet et al., 2004). In the present study, gilts had higher PUFA than did barrows of LWD pigs, which is consistent with those previous reports. Agu pigs, however, did not exhibit a signifi-
cant difference between sexes (Fig. 1): the small difference attributed to sex in terms of the concentration of PUFA is assumably one of the characteristics of fatty acid composition in Agu pigs.

A higher concentration of C18 : 2 in inner backfat lowers the melting point (Wood et al., 1978). Our result is not consistent with that study. The melting point of Agu fat was lower than that of LWD fat (35.2 vs. 39.9℃; Table 3), although C18 : 2 was significantly lower in Agu than in LWD pigs. Katsumata et al. (2015) have reported that the relationship between melting point and fatty acid composition is complicated. The melting point of fat determines its hardness (Pitchford et al., 2002) and influences its texture. Our result demonstrated that the melting point of Agu fat was as high as the temperature of the human body. Agu pork seems to have a smoother sentient texture than LWD pork.

In conclusion, this study revealed that despite their low lean meat productivity, Agu pigs demonstrated characteristics distinctly different from those of LWD pigs that are a common crossbred in commercial production: high IMF content, low cooking loss, high juiciness, high MUFA and low PUFA concentration.

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発育、枝肉形質および肉質からみたアグーの品種特性について

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要 約 沖縄県の在来豚であるアグーは, 西洋系品種の普及により一時期, 絶滅の危機に瀕していたものの, 肉質に優れていることが評価され, ブランド豚として注目を集めている。しかしながら, その肉質についての知見は少ない。そこで, 本研究では, アグーの品種特性を明らかにするため, アグー16頭(雌6頭, 去勢10頭)と国内で広く用いられている三元交雑種(LWD)(デュロック種雄×F1交雑種雌; ランドレース×大ヨークシャー)18頭(雌9頭, 去勢9頭)を110kgまで肥育し, 発育, 枝肉形質および肉質について調査を行った。発育と枝肉形質に関連する項目については, 一日増体量, 枝肉歩留りおよびロース面積は, アグーがLWDよりも有意に低かったのに対し, 背脂肪厚はアグーが有意に厚かった。肉質に関連する項目については, 加熱前の保水性は, アグーがLWDよりも有意に劣ったのに対し, 加熱時の保水性を示す加熱損失率は, アグーが有意に優れていた。さらに, 筋肉内脂肪含量と圧搾肉汁率もアグーがLWDよりも有意に高かった。背脂肪内層の脂肪酸組成において, アグーはLWDと比べて, 一価不飽和脂肪酸含量が有意に高く, 多価不飽和脂肪酸は有意に低かった。さらにアグーの脂肪融点は, LWDよりも有意に低かった。これらの結果から, アグーは国内で広く用いられているLWDと比べて発育や産肉量は劣るもの, 特徴的な肉質を持つことが明らかとなった。

キーワード: アグー, 枝肉形質, 発育成績, 沖縄在来豚, 肉質