Genetic parameter estimates of meat quality traits in Duroc pigs selected for average daily gain, longissimus muscle area, backfat thickness, and intramuscular fat content

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ABSTRACT: Using a multitrait animal model BLUP, selection was conducted over seven generations for growth rate (ADG), real-time ultrasound LM area (LMA), backfat thickness (BF), and intramuscular fat content (IMF) to develop a new line of purebred Duroc pigs with enhanced meat production and meat quality. This selection experiment examined 543 slaughtered pigs (394 barrows and 153 gilts) from the first to the seventh generation for meat quality traits. Further, electric impedance and collagen content of loin meat were measured from the fourth to sixth generation. The present study was intended to estimate genetic parameters of the correlated traits of tenderness (TEND), meat color (pork color standard: PCS; lightness = L*), drip loss (DL), cooking loss (CL), pH (PH), electric impedance (IMP), and collagen (COL) of the LM, and the genetic trends of these traits. Respective heritability estimates for IMF, TEND, DL, CL, PCS, L*, PH, IMP, and COL were 0.39, 0.45, 0.14, 0.09, 0.18, 0.16, 0.07, 0.22, and 0.23. Genetic correlations of IMF with ADG and BF were low and positive, but low and negative with LMA. Tenderness was correlated negatively with ADG (–0.44) and BF (–0.59), but positively correlated with LMA (0.32). The genetic correlation between LMA and DL was positive and high (0.64). The genetic correlations of TEND with IMF and COL were low (–0.09 and 0.26, respectively), but a moderate genetic correlation (0.43) between COL and IMF was estimated, suggesting related increases of IMF and connective tissue. Genetic correlations among meat quality traits suggested that when IMF increases, the water holding capacity improves. Genetic trends of meat quality traits showed increased IMF and lighter meat color.

Key Words: Collagen, Duroc Pigs, Genetic Parameters, Impedance, Meat Quality Traits

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Introduction

Fresh pork has a large market share among meats in Japan. Tenderness and water-holding capacity of sliced meat affect eating quality and are important indices of meat quality. In addition, i.m. fat is an important trait that is related to meat taste and intraoral smoothness. Japanese people have a strong preference for marbled pork, almost equal to their preference for marbled beef. In 1995, a seven-generation selection experiment began at the Miyagi Prefecture Animal Industry Experiment Station (Suzuki et al., 2005). That selection experiment examined some meat quality traits, such as meat color, pH, water-holding capacity, and tenderness at each generation of selection. Moreover, the collagen content and electric resistance (impedance; **IMP**) of pork meat were measured in the fourth to sixth generations. Although genetic and phenotypic correlations among meat quality traits have been reported (Hovenier et al., 1993a; NPPC, 1995; Sellier, 1998), genetic correlations between collagen and other meat quality traits have not. Furthermore, electrical impedance has been used to predict the fat content of pork carcasses nondestructively because carcasses with a higher fat content have greater electrical impedance (Swantek et al., 1992). Impedance measurement can be made quickly, and the instrument is easily handled. For those reasons, the impedance method is useful in areas of animal breeding requiring numerous measurements. We examined whether IMP is effective as a technology for evaluating pork quality. Selection for lean meat growth efficiency adversely affects meat quality (Cameron et al., 1999; Lonergan et al., 2001). Therefore, it is of interest to examine the influence of selection for

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ADG, LM area, backfat thickness, and i.m. fat content (**IMF**) of the loin on other meat quality traits. The present study was intended to estimate the genetic parameters and assess correlated genetic trends of meat quality traits with selection.

Materials and Methods

Animals and Performance Testing Procedures

Duroc pigs used in this experiment were from a line selected through seven generations at the Miyagi Prefecture Animal Industry Experiment Station from 1995 to 2001. Selection criteria traits were daily gain from 30 kg to 105 kg BW (ADG), LM area (**LMA**), and backfat thickness (**BF**) at 105 kg BW measured by ultrasound technology, and IMF measured in slaughtered sib pigs. The average population size of each generation was 15.6 boars and 44.5 gilts. Gilts farrowed only once and boars were retained for use for one 4- to 6-wk breeding period. Thereby, a new generation was obtained each year. Pigs were weaned at 4 wk. At 8 wk, one or two male piglets (total of 50 piglets) and two to four female piglets (total of 100 piglets) from each litter were selected as candidates for boars and gilts mainly based on the BW at 8 wk. At the same time, approximately 80 piglets comprising mainly boars and some gilts from each litter were selected for full-sib testing in each generation. This first stage of selection was conducted within litters. Boars for full-sib tests were subsequently castrated. Performance tests began when BW reached 30 kg and ended at 105 kg; therefore, ADG was from 30 to 105 kg of BW. Backfat thickness and LMA were measured on 105-kg animals on the left side at the position of half body length using an ultrasound (B-mode) color-scanning scope (SR-100; Kaijo Corp., Tokyo, Japan). Computer software determined LMA. Pigs were provided ad libitum access to a commercial diet (15% CP protein, 78% TDN, 0.76% lysine content; DM basis) during the testing periods from 30 to 105 kg of live weight. Pigs had free access to water. Boars were reared individually in performance-testing pens. Gilts and barrows were reared in growing pens and group fed in a concrete-floored building with eight pigs per pen, which allowed 1.2 m^2 floor space for each pig.

Selection Method

Objectives of this selection were to produce a Duroc line to be used as terminal sires to improve meat production and meat quality traits. Subsequently, these Duroc boars will be supplied to pork producers as commercial terminal sires. Because of the limited accommodation ability of facilities, selection was conducted without a control line. First and second generations of selection were performed using an index selection method based on relative desired gains (Yamada et al., 1975). Traits that we selected for were ADG, LMA, BF, and IMF. Genetic and phenotypic parameters used to derive selection criteria were obtained, respectively, from performance test data of the first and second generations. Respective means of ADG, LMA, BF, and IMF at the first generation were 865 g, 36.1 cm^2, 2.34 cm, and 4.3%, respectively. Relative desired gains were established as 135 g, 3.9 cm^2, –0.54 cm, and 0.7% for ADG, LMA, BF, and IMF, respectively. Consequently, the selection index equation was I = 0.038DG + 1.38EM – 15.10BF + 12.63IMF – 56.68. Selection was made within sire families for boars and within litters for gilts at the first generation to avoid rapid loss of genetic diversity from the population. Breeding values of ADG, LMA, BF, and IMF were estimated from the third generation onward by multiple-trait, animal model BLUP. Breeding values were calculated using the PEST3.1 program (Groeneveld, 1990) after estimating genetic parameters using the VCE4.25 program (Neumaier and Groeneveld, 1998), with models including generation and sex as fixed effects and random effects of individual additive genetic effect and error. Relative economic weights of selection traits were calculated from the relative desired gains, which were established for ADG, LMA, BF, and IMF from performance test data of the first generation, as described previously. Aggregate breeding values were calculated by multiplying the relative economic weights by the EBV of each trait, after which the selection was executed. Relative economic weights of selection traits were calculated from the relative desired gain as follows. The selection index where the breeding goal is predetermined as intended genetic gains was proposed by Yamada et al. (1975) as:

$$\mathbf{Q} = \mathbf{G'Rb}$$

$$\mathbf{b} = (\mathbf{G'R})^{-1}\mathbf{Q} \quad [1]$$

$$\mathbf{Pb} = \mathbf{RGa}$$

$$\mathbf{a} = (\mathbf{RG})^{-1}\mathbf{Pb} \quad [2]$$

From Eq. [1] and [2], the economic weight can be found assuming the desired gains index as:

$$\mathbf{a} = (\mathbf{RG})^{-1}\mathbf{Pb} = (\mathbf{RG})^{-1}\mathbf{P}(\mathbf{G'R})^{-1}\mathbf{Q}$$

where **a** is the economic weight, **P** represents the phenotypic variance, covariance matrix, **G** is the genetic variance, covariance matrix, **R** is the numerator relationship matrix, **b** is the weighting coefficient vector, and **Q** is the desired gain vector.

The relative desired gains of ADG, LMA, BF, and IMF were established from performance test data of the first generation, as described before; however, the breeding goals changed to 1,000 g, 40 cm^2, 2.0 cm, and 5.0% respectively for ADG, LMA, BF, and IMF. The reason for the change in breeding goals is that improvement of the i.m. fat cannot be expected when the backfat thickness is thinned too much. When the IMF breeding goal is assumed as 6%, the weight to IMF becomes too

high. Therefore, the respective economic weights were assumed to be 0.076, –0.391, –10.850, and 3.753 for ADG, LMA, BF, and IMF; however, the genetic parameters estimated at the third generation differed from those of the fifth and seventh generations. The relative economic weights obtained using these parameters also were different. The relative economic weights obtained at the third generation were used for the third and fourth generations and those at the fifth generation were used for the fifth generation and thereafter. The aggregate breeding values were calculated by multiplying the relative economic weights by the EBV of each trait, and then selection was executed. Approximately 15 boars and 50 gilts were selected at each generation. Inbreeding coefficients for individual pigs were computed for each generation. Based on inbreeding information, all mating was planned to minimize the rate of increase in inbreeding.

Carcass Dissection and Meat Quality Measurement

Pigs for full-sib tests (barrows and gilts) were slaughtered by manual low-voltage (200 V) electrical stunning 24 h after feed removal with free access to water. Processed dressed carcasses were placed in a refrigerator as soon as possible. Carcasses were placed in a conventional chiller at 4°C for 24 h. Subsequently, for measuring meat quality in the LM, a 7- to 10-cm-long piece of the loin (two thoracic vertebrae sections above the last rib) was taken from the left half of each pig carcass. At that time, pork color was measured using the pork color standard (**PCS;** 1 = light, to 6 = dark; Nakai et al., 1975). Chops were then moved to a laboratory to measure meat quality traits. External loin adipose tissue was removed. The meat was cut vertically along the length of loin. The sliced meat (approximately 50 g) was hung by wire in the specimen case. Drip loss (**DL**) was determined by weighing sliced meat stored at 4°C in the refrigerator after 24 h and calculated as a percentage of the sliced meat original weight; L* was measured using a spectrophotometer (CM-2002, Minolta Co., Ltd., Tokyo, Japan) after cutting and blooming for more than 15 min. A four-terminal bioelectrical impedance analyzer (model BIA-101, RJL Systems Inc., Detroit, MI) was used to measure resistance (**Rs,** Ω). After weighing (approximately 170 g) the loin meat, it was put on a plastic board. Two 20-gauge needles were inserted carefully at 10-cm intervals. In addition, two other needles were inserted in the vertical direction of each needle at 2-cm intervals. The lead line of the detector and transmitter were connected with two (left and right) needles. Resistance was measured on the meat at 800 μA and 50 kHz. Resistance readings were obtained twice. Impedance (**IMP;** Z) was calculated from reactance (Xc) and Rs as $Z = (Rs^2 + Xc^2)^{.5}$; because reactance was negligible, only resistance was measured. The remaining loin meat section was cut into two along the muscle fiber and was used to analyze cooking loss, tenderness, and pliability. Two 2 × 2 × 5 cm pieces of cut meat from each were weighed and packaged in polyethylene bags. They were vacuum-packaged and heated in a warm bath at 70°C for 30 min. Then, after cooling at room temperature, moisture on the meat was wiped off and the meat weight was measured again. Cooking loss (**CL**) was determined by measuring drippings as a percentage of the original meat weight. Furthermore, two cooked pieces per animal were cut to 1 × 1 × 5 cm. We measured the tenderness (**TEND,** kg of force/cm^2) using a Tensipresser (TTP-50BXII; Taketomo Electric Corp., Tokyo, Japan) developed by Nakai et al. (1992). This machine was developed to evaluate meat tenderness accurately using an up and down motion to imitate chewing action. Two minced loin meat samples of approximately 20 g were analyzed using the Soxhlet method to determine IMF.

Collagen Content

Loin meat sampled at the third thoracic vertebra above the last rib was used. Soluble and insoluble collagen were drawn using the method of Hill (1966). Approximately 5 g of minced meat samples were freeze-dried (–50°C, overnight). The sample was crushed and added to 12 mL of solution containing 147 mM NaCl, 4 mM KCl, and 0.22 mM $CaCl_2$. It was heated for 63 min at 77°C and then centrifuged for 10 min at 1,500 × g. The supernatant solution was decanted, and the pellet was suspended in the same solution and recentrifuged. The supernatant solutions were combined, after which the hydroxyproline content was determined using the procedure of Bergman and Loxley (1963). Each sample was hydrolyzed in 6 N HCl under high temperature (110°C) for 20 h. The hydrolyzed sample was filtered, and a 1.0-mL portion of the sample solution was mixed with 2.0 mL of isopropanol, followed by mixing with 1.0 mL of oxidant solution (75 wt/vol chloramines T, 1 volume and acetate/citrate buffer [pH 6.0], 3 volumes); it was kept for 4 min at room temperature (17 to 20°C). After adding 13 mL of Ehrlich's reagent solution, the sample was incubated at 60°C for 25 min, cooled in running water for 2 to 3 min, and diluted with 50 mL of isopropanol. Spectrophotometric determination of hydroxyplorine was carried out. Insoluble and soluble collagen contents were calculated by multiplication of the hydroxyproline content by 7.52 and 7.25, respectively. The sum of insoluble and soluble collagen was designated as total collagen (**COL**).

Statistical Analyses

Performance data for ADG, LMA, BF, and meat quality data for IMF, TEND, PCS, L*, DL, CL, PH, IMP, and COL were used for final estimation of genetic parameters. Table 1 shows the number of pigs for each measurement.

The following multiple trait-animal model was used for analysis to estimate genetic parameters:

Table 1. Number of animals, mean, standard deviation, and estimates of heritability (h^2), common environmental effects (c^2), and genetic SD (σ_G)

Trait[a]	No.	Mean	SD	$h^2 \pm$ se	$c^2 \pm$ se	σ_G
ADG, g	1,642	873.6	109.3	0.47 ± 0.02	0.04 ± 0.01	55.3
LMA, cm^2	1,639	37.0	4.0	0.45 ± 0.02	0.02 ± 0.01	2.5
BF, cm	1,642	2.37	0.43	0.72 ± 0.02	0.02 ± 0.01	0.33
IMF, %	544	4.25	1.46	0.39 ± 0.02	0.10 ± 0.02	0.87
TEND, kg force/cm^2	545	72.52	12.71	0.45 ± 0.02	0.07 ± 0.01	8.26
DL, %	543	2.21	1.31	0.14 ± 0.01	0.17 ± 0.02	0.49
CL, %	545	24.7	3.33	0.09 ± 0.02	0.16 ± 0.02	0.97
PCS	541	3.42	0.46	0.18 ± 0.02	0.08 ± 0.01	0.19
L*	543	48.44	3.16	0.16 ± 0.02	0.15 ± 0.02	1.13
PH	515	5.97	0.43	0.07 ± 0.02	0.22 ± 0.02	0.07
IMP, Ω	232	486.3	163.9	0.22 ± 0.03	0.18 ± 0.02	76.2
COL, %	225	0.51	0.14	0.23 ± 0.05	0.15 ± 0.02	0.06

[a]LMA = LM area; BF = backfat thickness; IMF = intramuscular fat; TEND = tenderness; DL = drip loss; CL = cooking loss; PCS = pork color standard (1 to 5, light to dark); L* = lightness; PH = pH; IMP = electric impedance; and COL = total collagen.

$$Y_{ijklm} = \mu_i + G_{ij} + S_{ik} + c_{il} + a_{im} + e_{ijklm}$$

where Y_{ijklm} = observation for traits *i;* μ_i = common constant for trait *i;* and G_{ij} = fixed effect of selection generation *j* for trait *i.*

This selection generation effect included the genetic effect of selection and the environmental effect at each generation: S_{ik} = fixed effect of sex *k* for trait *i;* c_{il} = random effect of common environment *l* of littermates for trait *i;* a_{im} = random additive genetic effect of animal *m* for trait *i;* e_{ijklm} = random residual effect for trait *i.*

Seven generations of pedigree information from 1,642 animals, with data from 152 ancestors born before the fourth generation (total of 1,794 animals), were included in this analysis. The number of pigs is given in Table 1. For each generation, approximately 50 boars and 100 gilts were performance-tested. In all, 547 pigs (394 barrows and 153 gilts) were slaughtered to measure meat quality. The VCE4.25 program (Neumaier and Groeneveld, 1998) was used to estimate (co)variance components and their respective SE. Standard errors of heritability and genetic correlations estimates were estimated using the VCE4.25 program.

Results and Discussion

Selection for ADG and real-time ultrasound measurement of LMA, BF, and IMF was conducted using multiple-trait animal model BLUP in Duroc pigs over seven generations (Suzuki et al., 2005). The desired gains for ADG, LMA, and BF were not achieved, but the average breeding value of IMF at the seventh generation (1.20%) exceeded the first desired gain (0.7%). The mean of the IMF level reached about 5.0%.

Heritability Estimates of Meat Quality Traits

Table 1 shows means, SD, heritabilities and common environmental effects of IMF, TENDER, DL, CL, meat color (PCS and L*), PH, IMP, and COL. The heritability of IMF was moderate (0.39). Hovenier et al. (1993b), NPPC (1995) and Sellier (1998) presented mean heritability estimates of approximately 0.50 for i.m. fat. Recent estimates were 0.38 for Large White, 0.67 for Landrace, and 0.42 for Pietrain by Knapp et al. (1997), 0.44 for Large White by Larzul et al. (1997), 0.35 for Large White and Landrace by Hermesch et al. (2000a), and 0.25 for Iberian pigs by Fernandez et al. (2003). Knapp et al. (1997) reported high common environmental effects for IMF (0.14 for Large White and 0.16 for Pietrain). In the present experiment, the common environmental effect for IMF was 0.10. The common environmental effect is litter-specific, effects such as nongenetic components of uterine nutrition, uterus capacity, and nutrition during the suckling period. A highly common environmental effect for IMF implies that such an effect influences the i.m. fat accumulation during the subsequent fattening period. The heritability estimate for TEND of 0.45 was higher than estimates presented by Lo et al. (1992), de Vries et al. (1994), and NPPC (1995) of 0.17, 0.20, and 0.20, respectively. These heritabilities for tenderness were assessed by shear force measurements using a Warner-Bratzler or Universal Testing machine. Further, Hovenier et al. (1993a) reported that heritabilities for tenderness assessed by shear force measurement and by taste panels vary from 0.21 to 0.37. In addition, Sellier (1998) reported a 0.26 average heritability for tenderness by instrumental determination, and 0.29 for that of sensory panel scores. The high heritability in the present study suggests that the Tensipresser is an appropriate device to evaluate meat tenderness. Low heritabilities for water-holding capacities of DL and CL (0.14 and 0.09, respectively) also were estimated. Hovenier et al. (1993a) reviewed a wide range of heritability estimates from 0.00 to 0.63, probably because of the different methods used to measure the trait in their review. Average heritability for water-holding capacity is approximately 0.20. Sellier (1998) also reported in his review an average heritability of 0.16 (0.01 to 0.31) for drip loss and 0.16 (0.00 to 0.51)

Table 2. Genetic correlation (r_G) ± standard deviation and phenotypic correlation (r_P) between meat production traits and meat quality traits[a]

	ADG		LMA		BF	
Traits	r_G	r_P	r_G	r_P	r_G	r_P
IMF	0.25 ± 0.03	0.06	–0.26 ± 0.04	–0.24	0.28 ± 0.03	0.22
TEND	–0.44 ± 0.03	–0.34	0.32 ± 0.04	0.19	–0.59 ± 0.03	–0.39
DL	–0.14 ± 0.05	–0.05	0.64 ± 0.05	0.07	–0.25 ± 0.06	–0.08
CL	0.10 ± 0.07	0.07	–0.01 ± 0.08	0.00	–0.30 ± 0.07	–0.04
PCS	–0.33 ± 0.05	–0.16	–0.08 ± 0.06	0.04	–0.13 ± 0.05	–0.13
L*	0.33 ± 0.05	0.20	–0.13 ± 0.05	–0.11	0.55 ± 0.05	0.23
PH	0.24 ± 0.11	0.08	–0.40 ± 0.12	–0.03	0.47 ± 0.10	–0.01
IMP	–0.28 ± 0.05	0.05	–0.69 ± 0.04	–0.15	0.29 ± 0.05	0.04
COL	0.04 ± 0.05	0.13	0.19 ± 0.07	0.04	–0.35 ± 0.07	–0.07

[a]LMA = LM area; BF = backfat thickness; IMF = intramuscular fat; TEND = tenderness; DL = drip loss; CL = cooking loss; PCS = pork color standard (1 to 5, light to dark); L* = lightness; PH = pH; IMP = electric impedance; and COL = total collagen.

for cooking loss. Heritability estimates for meat color of PCS and L* (0.18 and 0.16, respectively) were lower than the estimate (0.29) presented in a recent study by Hermesh et al. (2000a), as well as mean heritability estimates presented in reviews by Hovenier et al. (1993a) and Sellier (1998); those respective averages were 0.30 and 0.28. Nonetheless, Lo et al. (1992) and Knapp et al. (1997) reported a lower estimate of 0.11 for Landrace and Duroc pigs and 0.12 for Landrace, which are approximately the estimates found for Duroc in this study. Heritability estimates for ultimate pH (0.07) were the least in this study and less than estimates presented in the reviews by Hovenier et al. (1993a) and Sellier (1998), and other estimates presented by Knapp et al. (1997), Larzul et al. (0.13, 1997), Sonesson et al. (1998), and Hermesh et al. (2000a). Comparatively high common environmental effects were shown for DL and PH (0.17 and 0.22, respectively). The L* and CL had values of 0.15 and 0.16, respectively. Heritabilities of IMP and COL were 0.22 and 0.23; their common environmental effects were 0.18 and 0.15. No report exists regarding heritability estimates for IMP and COL. Hovenier et al. (1993b) reported a repeatability estimate of 0.33 for collagen values.

Genetic and Phenotypic Correlations of Meat Production Traits with Meat Quality Traits

Table 2 shows the genetic and phenotypic correlation between meat production traits and meat quality traits. Genetic and phenotypic correlations between ADG and TEND were moderate (–0.44 and –0.34, respectively). Moreover, ADG was correlated moderately with meat color (PCS) and L*. Present results suggest that improvement of growth rate increases the meat softness and lightens the meat color. Lo et al. (1992) reported a negative and low genetic correlation between ADG and shear force as –0.27. Further, Hovenier et al. (1992) reported a positive genetic correlation of 0.46 between ADG and meat color (PCS) in Duroc and Dutch-Yorkshire, whereas NPPC (1995) reported a low genetic correlation of 0.11 between ADG and LM Minolta hunter L* color in various crossbreds. These results suggest that breed difference might influence the genetic correlation. On the other hand, genetic and phenotypic correlations between ADG and IMF were low (0.25 and 0.06, respectively). Longissimus muscle area was highly genetically correlated with DL and showed undesirable genetic correlation with IMF and TEND, although the relationship is weak. In addition, BF was correlated negatively with TEND and positively with L* value. These results suggest that selection for decreased backfat thickness decreases the meat tenderness and darkens the meat color. Sellier (1998) described a general but moderate genetic antagonism with carcass lean-to-fat ratios. Low genetic and phenotypic correlations of 0.28 and 0.22 between IMF and BF suggested a loose relation between them. Intramuscular fat content is associated genetically with carcass fatness, but the average genetic correlation between the two traits is less than 0.30, demonstrating that part of the genetic variation in the lipid content of the muscle is independent of genetic variation in the overall lipid content of the carcass (Sellier, 1998). A high and negative genetic correlation (–0.69) between IMP and LMA was estimated. Longissimus muscle area with a large cross-sectional area seems to engender high water content and low resistance.

Genetic and Phenotypic Correlations among Meat Quality Traits

Genetic and phenotypic correlations among meat quality traits are presented in Table 3. The genetic correlation of –0.09 between IMF and TEND suggests no relationship between the softness of meat and IMF content. De Vries et al. (1994) reported a low negative genetic correlation of –0.10 between IMF and shear force. Sellier (1998) reported a mean genetic correlation of 0.15 between TEND and IMF. Negative high (–0.70) and moderate (–0.42) genetic correlations were estimated for IMF with DL and CL. Those results suggest

Table 3. Restricted maximum likelihood estimates of genetic (r_G) and phenotypic (r_P) correlations between meat quality traits[a]

	TEND		DL		CL		PCS		L*		PH		IMP		COL	
Trait[b]	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P	r_G	r_P
IMF	–0.09	–0.20	–0.70	–0.13	–0.42	–0.07	–0.05	–0.18	0.42	0.43	–0.51	–0.07	0.31	0.07	0.43	0.12
TEND			0.04	0.02	0.24	0.19	0.59	0.19	–0.59	–0.24	–0.16	–0.05	0.26	0.01	0.26	0.00
DL					0.01	0.35	–0.31	–0.13	0.06	0.19	0.20	–0.20	–0.60	–0.44	–0.09	0.03
CL							–0.13	–0.20	–0.22	0.25	0.21	0.00	–0.28	–0.30	–0.64	0.06
PCS									–0.80	–0.50	0.16	0.07	0.68	0.20	0.29	–0.02
L*											–0.10	–0.12	–0.28	–0.12	–0.17	0.18
PH													0.28	0.05	–0.42	0.03
IMP															0.20	0.08

[a]SE of the genetic correlations presented in this table ranged from 0.04 to 0.17.
[b]IMF = intramuscular fat; TEND = tenderness; DL = drip loss; CL = cooking loss; PCS = pork color standard (1 to 5, light to dark); L* = lightness; PH = pH; IMP = electric impedance; and COL = total collagen.

that the water-holding capacities of the fresh meat and the cooked meat were improved as IMF increased; however, Hovenier et al. (1992) reported that genetic and phenotypic correlations between IMF and DRIP were almost zero (–0.07 and –0.03, respectively). Moreover, a mean genetic correlation of –0.08 between IMF and DRIP was reviewed by Sellier (1998). The difference between the present result and that of previous studies may result from the breed difference. The IMF of the present Duroc breed was 4.25%, which is higher than in other reports.

Moderate genetic and phenotypic correlations of 0.42 and 0.43 were estimated between IMF and L*. This result shows that meat having higher IMF is lighter in color. Conversely, the negative high genetic correlation of –0.51 between IMF and PH suggests that higher IMF meat has low pH. Furthermore, a moderate genetic correlation (0.43) between COL and IMF was estimated, suggesting a positive relationship of IMF and connective tissue content. The genetic increase of insoluble collagen (bonding element and film element), which is one element of i.m. fat, may be related to increased fat in the muscle.

It was suggested that genetic improvement for light-colored meat results in soft meat from the genetic correlations of TEND with PCS and L* (0.59 and –0.59, respectively). High and negative genetic and phenotypic correlations (–0.60, –0.44) between DL and IMP also were estimated. Swantek et al. (1992) evaluated a bioelectrical impedance approach in swine to predict the body composition of live swine and pork carcasses. That study reported significant correlation (r = 0.70) between resistance and carcass fat percent. Impedance measured with a LM sampled from the last rib to the second lumbar vertebra was correlated significantly (r = 0.691) with the water-holding capacity measured using filter paper with 0.3 g of muscle tissue (Whitman et al., 1996). Otto et al. (2004) reported a phenotypic correlation of 0.43 between drip loss, as measured by the bag method, and electrical conductivity at 48 h after sampling. Generally speaking, electrical current flows easily in muscular tissue containing much moisture; it flows less easily in fatty tissue with little moisture. Consequently, bioelectrical impedance reflects the body composition in terms of the amount of the body moisture and fat. Human body fat percentage-measuring instruments have been developed based on this principle. This study measured impedance using the single frequency of 50 kHz. Bioelectrical impedance by the single-frequency method can estimate only the sum of intracellular and extracellular fluids; however, the multiple-frequency method can separate information of intracellular and extracellular fluids and accurately reflect moisture both inside and outside of cells. Water in muscle cells is bound water, entrapped (immobilized) water, and free water; the water that is affected the most by the process of converting muscle to meat is the entrapped water (Huff-Lonergan, 2002). Drip loss is defined as the amount of fluid lost from fresh, non-cooked meat via passive exudation. Therefore, electric impedance measurement using the multiple-frequency method suggests the possibility of a simplified and more accurate procedure for estimating the drip loss of fresh meat.

Genetic and phenotypic correlations between DL and CL were 0.01 and 0.35, respectively. A higher value for genetic correlation of 0.66 was reported by Sellier (1998), but Huff-Lonergan et al. (2002) reported a low but statistically significant phenotypic correlation (0.16) between DL and CL. Suzuki et al. (2001) reported a low phenotypic correlation (0.19) between DL and CL measured using the same method used in the present experiment. Drip loss and CL may use different water retention mechanisms.

We expected TEND to be related to COL, but genetic and phenotypic correlations were low (0.26 and 0.00, respectively). Hovenier et al. (1993) also reported a low phenotypic correlation (0.20). Wheeler et al. (2000, 2002) reported that the phenotypic correlation coefficients in pork LM at 1 and 7 d postmortem, respectively, for tenderness and sarcomere lengths were 0.67 and 0.14, and that those for collagen were –0.21 and –0.33, and that those for desmin degradation were –0.08 and 0.67. That is, sarcomere length influences tenderness at 1 d postmortem, and desmin degradation influences

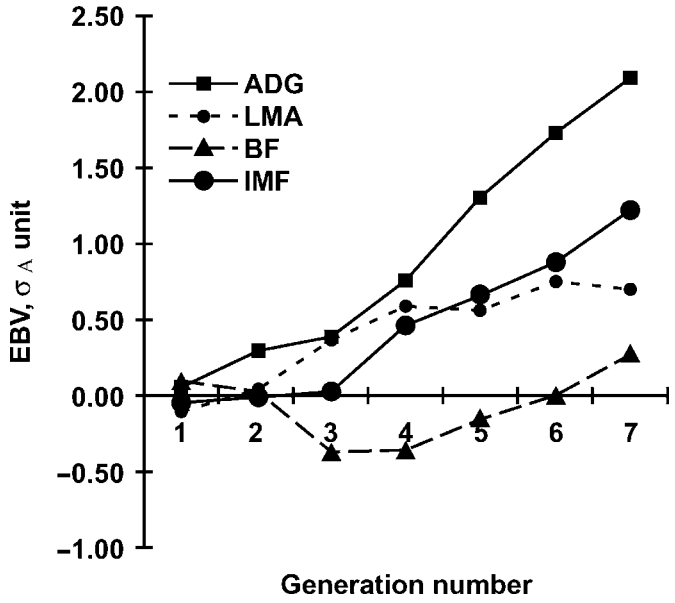

Figure 1. Changes of breeding value expressed per additive genetic SD in selection traits (LMA = LM area; BF = backfat thickness; and IMF = intramuscular fat) with generation.

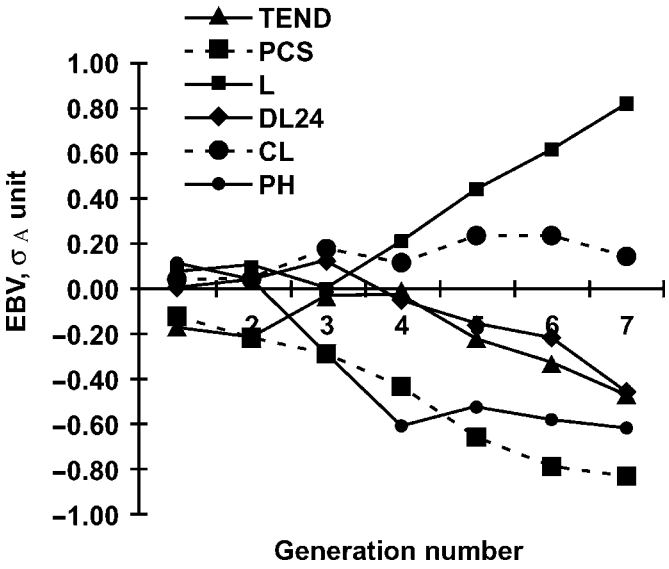

Figure 2. Correlated changes of breeding value expressed per additive genetic SD in meat quality traits (TEND = tenderness; DL24 = drip loss; CL = cooking loss; PCS = pork color standard (1 to 5, light to dark); L* = lightness; and PH = pH) with generation.

tenderness at 7 d postmortem. The present study showed low genetic and phenotypic correlations between TEND and COL (0.26 and 0.00, respectively); consequently, we infer only a slight influence of collagen content on meat tenderness. In contrast, high negative genetic correlation (–0.64) between COL and CL suggested that breeding for high collagen content decreases cooking loss of meat. Genetic correlations of COL and CL were not reported in the literature. The increase of COL seems to stabilize the tissue, thereby reducing the cooking loss of meat. Furthermore, a negative and moderate genetic correlation was shown in COL and pH. Regarding genetic correlation between COL and other meat quality traits, little information is available. Further research is necessary in those areas.

Genetic Trends on Meat Quality Traits

Figure 1 shows genetic changes of selection traits expressed in units of additive genetic SD (σ_A) per generation of selection. The responses of ADG and IMF were large and that of LMA was small, probably because of the small selection differentials (Suzuki et al., 2005). Genetic changes of meat traits per each generation of selection are shown in Figure 2. Responses of meat color (L* and PCS) were largest, suggesting that meat color lightened. The PH measured at 24 h postmortem decreased with selection, and TEND and DL decreased from the fourth generation through the seventh generation. These results suggest that raw meat water-holding capacity is improved and that meat had softened. On the other hand, CL changed little. Cameron (1999) reported that with selection for increased carcass lean weight, the meat becomes less tasty, less juicy, less tender, and lower in overall acceptability. In addition, Lonergan et al. (2001) compared a selection line of Duroc pigs, selected for increased lean growth efficiency, with a contemporary control line. Performance was improved in the lean growth selection line, but early postmortem pH was lower and water-holding capacity was decreased compared with the contemporary selection line.

The present selection experiment confirmed that meat softness was increased and that the meat color lightened as a result of selection for traits including ADG and IMF content of the Duroc breed. Selection response for backfat thickness was not in the desired direction. Consequently, the failure of backfat thickness improvement prevented a decrease in meat quality by selection through the seventh generation.

Implications

Genetic parameters obtained herein indicate that genetic improvement of intramuscular fat is not related to the tenderness of meat, but rather to improved water-holding capacity. This improvement is genetically related to increased collagen content. Furthermore, the use of bioelectrical impedance is suggested as an effective genetic index of drip loss of meat. The measurement of collagen and electric impedance might be effective as an index of genetic improvement of meat quality.

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