

Challenges of Pig Breeding in Japan

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Abstracts

Genetic breeding systems for pigs over the last 30 years in Japan are roughly classifiable into three. Local government experiment stations and the national improvement center have used a closed-line breeding system. A second is an open breeding system used by private breeders and breeding companies. A third is breeding through introduction of hybrid pigs from foreign countries. The closed line breeding system has produced many excellent breeds from lines that have been selected not only for meat production traits, but also for reproductive traits and meat quality traits. Tokyo-X and Shimofuri-red were completed respectively in 1996 and in 2002. These two lines are breeds for which intramuscular fat was adopted as a direct selection trait. These successes achieved through such breeding are attributable to improved measuring methods of meat production traits and meat quality traits, along with improved statistical breeding methods. Now and in the future, breeding for disease resistance will become an important subject that attracts pig breeders' research efforts. One method of breeding for disease resistance is to select for morbid state as a direct selection trait. Aside from this, an indirect selection exists for immunity traits that are related genetically to disease resistance traits. We examine a breeding strategy that unites these two methods, and are performing selection now. Future selection methods might use marker-assisted selection with markers obtained through QTL analysis, for which candidate gene analyses might be effective.

Introduction

Japan has 55% pork self-sufficiency. The number of pig farms decreased to 9,430, representing a decline of about 20% over the 15 years preceding 2003. Pork with a high added value of safety and deliciousness is demanded to compete with increased pork imports. The average number of breeding sows per farm has expanded to 1031, concomitant with

a decreasing number of farms, which has improved production efficiency in Japan. Local official experimental stations in Japan have undertaken improvement of pig breeding stock over the last 30 years. The closed line breeding system has produced many excellent breeds from lines that have been selected not only for meat production traits, but also for reproductive traits and meat quality traits. The Tokyo Metropolitan Livestock Experiment Station has developed a synthetic line called TOKYO-X (Hyodo, 1996). Base breeds of TOKYO-X were Berkshire, Duroc breed, and Chinese Beijing black pigs. This line was selected over five generations for meat production traits and intramuscular fat content (IMF). The author performed selection experiments for meat production traits and IMF for the Duroc breed at the Miyagi Prefecture Livestock Experiment Station (Suzuki et al., 2005a, 2005b). These breeding successes are attributable to improved measuring methods of meat production traits and meat quality traits, along with improved statistical breeding methods. Since December 2004, addition of antifungal agents to domestic animal feed has been planned for prohibition in Japan. Sub-therapeutic antibiotics that are added to pigs' feed engender bacillus' increased resistance to antibiotics. Such practices present the dangerous possibility of bacillus infection of humans. Moreover, antibiotics and antifungal agents present the danger of remaining in the meat after processing. The market also demands meat produced without use of potentially harmful agents. Corresponding to such a situation, breeding for disease resistance is demanded. The Miyagi Prefecture Livestock Experiment Station, along with Tohoku University, has begun a selection experiment of the fifth generation for atrophic rhinitis (AR) and mycoplasma pneumonia (MPS). Furthermore, potential relationships among candidate genes for health and immune response will be investigated. We introduce the outline of the anticipated breeding improvement in our country, especially, improvement

Table 1. Completed and progressing line breed in Japan (1975–2005)

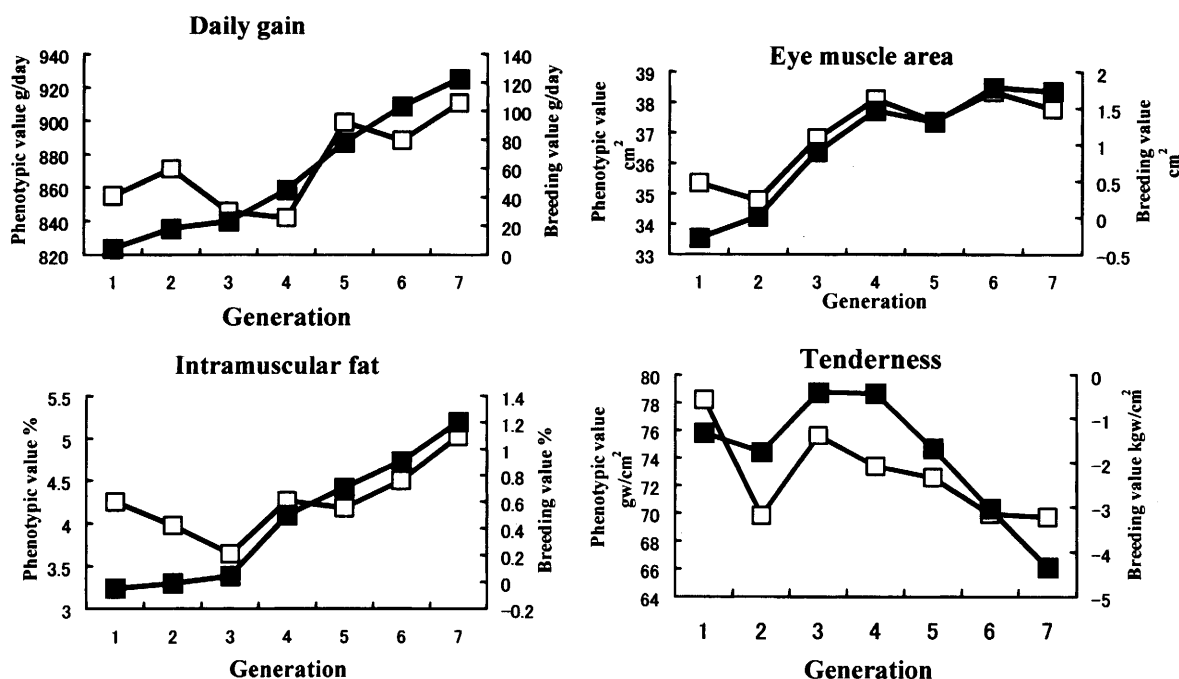
Breeds	Completed Line	Maintained Line	Progressing Line		Total
	a	b	c	a+c	b+c
Landrace	39	18	3	42	21
Large white	21	12	6	27	18
Hampshire	5	0	0	5	0
Duroc	8	5	3	11	8
Berkshire	3	3	0	3	3
Synthetic line	1	1	1	2	2
Total	77	39	13	90	52

of meat quality traits and disease resistance, and the possibility of genetic improvement using DNA markers.

Current situation of pure line breeding

As for pig breeding in our country, the closed population breeding that the late Dr. Takeo Abe advocated has been done for the past 30 years (Abe et al., 1981). The method to produce fattening pigs with crossing of the improved pure breed line has been adopted. The breeds of the line that had been improved in the past 30 years are shown in Table 1 along with the number of lines. The features of line breeding can be summarized as follows. Genetic lines with highly improved growth rates were produced

during ten years. Backfat thickness was constant thickness. This reflects the carcass grading in Japan. Recently, selection methods have changed from index selection to use of breeding values estimated by BLUP method (Suzuki, 2004). Selection traits have changed from meat production traits to reproductive traits, meat quality traits and disease resistance traits. Selection traits with feature and number of lines were as follows. Reproductive traits (Litter size): four Landrace line and four Large White line in these 5 years, meat quality traits (intramuscular fat): One synthetic line (TokyoX) and one Duroc line (Shimofuri Red), leg soundness trait (direct selection trait and independent culling trait): seven lines, Disease resistance: one line (Miyagi prefecture).

**Fig. 1.** Changes of phenotypic and breeding value over seven generations of selection.

□ – phenotypic value, ■ – breeding value.

Selection experiment for high meat quality

To develop an excellent line of Duroc breed in performance traits and meat quality traits, selection was conducted over seven generations for growth rate (DG), real-time ultrasound loin eye muscle area (EM), backfat thickness (BF), and IMF. Meat quality traits were IMF and tenderness (TEND), which were measured after slaughter in *M. longissimus* taken two sections above the last rib. Selection was based on a selection index that comprised four traits (DG, EM, BF, and IMF), at the first and second generations of selection. After the third generation, expected breeding values (EBVs) for four traits were obtained from analyses of performance and meat quality data. Selection of boars and gilts was based on an aggregate genotypic value that was evaluated by the sum of cross products of each EBV and the corresponding relative economic weight. Although the desired gains were not achieved completely for DG, EM, and BF, the total genetic gain of IMF at the seventh generation (1.20%) exceeded the initially intended desired gain (0.7%), and the phenotypic mean of the IMF level reached about 5.0%. Estimates of genetic parameters are useful in aiding selection for pig meat quality. The present experiments also showed that meat quality traits were improved effectively through a selection process that used sibling information regarding IMF and TEND.

Table 2 shows heritability estimates. Respective heritability estimates of DG, EM, and IMF were moderate and around 0.5. That of BF was estimated to be high (0.72). Concerning the meat production trait under *ad libitum* feeding, the respective average

estimates of heritability for DG and BF were 0.31 and 0.49 (Clutter and Brascamp, 1998). Recent heritability estimates for BF reported by Kuhlert et al. were 0.56 for Landrace (2001) and 0.58 for Duroc (2003). In addition, 0.47–0.48 heritability has been reported for EM (Sellier, 1998; Kuhlert et al., 2001). The present estimate was of the same order as that reported previously, but estimates for DG (0.48) and BF (0.72) were higher than previously reported estimates. Therefore, heritability of these traits is moderate or high and improvement of these traits appears possible. The heritability of IMF was moderate (0.46). Hovenier et al. (1993), NPPC (1995) and Sellier (1998) presented mean heritability estimates of around 0.50 for intramuscular 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 Hermes et al. (2000a), and 0.25 for Iberian pigs by Fernandez et al. (2003). In addition, 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 0.06. Moderate heritabilities of 0.52 and 0.34 were estimated, respectively, for the daily feed intake and feed conversion ratios (Clutter and Brascamp, 1998). Heritability estimate for Tenderness of 0.45 were 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 using shear force measurements by a Warner-Bratzler or Universal

Table 2. Numbers of animals (N), means, standard deviations (SD), heritabilities (h^2) \pm standard errors (SE), common environmental effects (c^2) \pm standard errors (SE).

Traits		N	Mean	SD	$h^2 \pm SE$	$c^2 \pm SE$
Daily gain,	g/day	1,642	873.6	109.3	0.48 ± 0.02	0.04 ± 0.01
Eye muscle area,	cm ²	1,639	37.00	4.05	0.45 ± 0.03	0.02 ± 0.01
Backfat thickness,	cm	1,642	2.37	0.43	0.72 ± 0.03	0.01 ± 0.01
Intramuscular fat,	%	543	4.25	1.46	0.46 ± 0.03	0.06 ± 0.02
Tenderness,	kgf/cm ²	544	72.51	12.71	0.45 ± 0.04	0.06 ± 0.02
Feed conversion ratio		379	2.65	0.17	0.34 ± 0.04	0.19 ± 0.03
Daily feed intake,	kg/day	379	2.62	0.23	0.52 ± 0.03	0.06 ± 0.01
Drip loss,	%	543	2.21	1.31	0.14 ± 0.01	0.17 ± 0.02
Cooking loss,	%	545	24.7	3.33	0.09 ± 0.02	0.16 ± 0.02
Pork color standard		541	3.42	0.46	0.18 ± 0.02	0.08 ± 0.01
L* value		543	48.44	3.16	0.16 ± 0.02	0.15 ± 0.02
pH		515	5.97	0.43	0.07 ± 0.02	0.22 ± 0.02

Testing machine. Further, Hovenier et al. (1993) 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. High heritability in the present study suggests that the Tensipresser is an appropriate device to evaluate meat tenderness (Nakai et al., 1992). Low heritabilities for water-holding capacities of DL and CL (0.14 and 0.09, respectively) were also estimated. Hovenier et al. (1993) reviewed a wide range of heritability estimates of 0.00–0.63, probably because of the different methods used to measure the trait in their review. The average heritability for water-holding capacity is about 0.20. In his review, Sellier (1998) also reported average heritability of 0.16 (0.01–0.31) for drip loss and 0.16 (0.00–0.51) 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. (1993) and Sellier (1998); those respective averages were 0.30 and 0.28. However, 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 lowest in this study and lower than estimates presented in reviews by Hovenier et al. (1993) and Sellier (1998) and other estimates presented by Knapp et al. (1997), Larzul et al. (1997), Sonesson et al. (1998), and Hermesh et al. (2000a).

This pure breed Duroc line (named “Shimofuri-red”) produces high-quality pork. Therefore, it sells at a stable price (570–600 yen/dressed carcass kilogram). Production of 10,000 fattened animals per year is planned with this pure breed. It is possible to specifically address production as a farmer because of the steady price offered for this pork. Moreover, the

consumer can taste high-quality pork that is improved in a scientific manner. Its value to the consumer is proven.

New approach for genetic improvement using DNA marker within breed

1) Association of IMF with candidate genes in Duroc pigs

We investigated the association of intramuscular fat with candidate genes in Duroc pigs. The relation between IMF and Heart Fatty Acid Binding Protein (H-FABP) gene, which was the candidate gene, was examined for efficient IMF selection. First, the change in each RFLP frequency of the H-FABP gene according to the selection of generation was examined using the Duroc breed, in which IMF was improved by repeated selection. Next, we examined whether a difference of IMF content existed between H-FABP gene polymorphisms. Moreover, the effect of the genotype on the IMF was presumed; the way in which RFLP of the H-FABP genes influenced IMF content was examined. The H-FABP genotype frequencies genotyped for the HaeIII, HinfI and MspI PCR RFLP changed significantly according to the generation of the selection. A significant difference was detected in the breeding value of IMF between the H-FABP PCR RFLP genotypes. The AA genotype has a significantly larger positive effect on the IMF breeding value than that of the Aa and aa genotypes in MspI RFLP. In addition, the DD genotype has a significantly greater positive effect on IMF breeding value than the Dd and dd genotypes in HaeIII RFLP. In HinfI RFLP, the hh genotype has a significantly larger positive effect on IMF breeding value than the HH genotype. Multiple regression analyses that used the IMF breeding values have referred to the three H-FABP genotypes as independent variables. The dependent variable was the IMF breeding value. Results revealed that the contribution rate of the genotypes was about 40% (Table 3). These results demonstrated that H-FABP RFLPs affect IMF in this Duroc population.

Table 3. Effect of H-FABP genotype on the breeding value of intramuscular fat

Dependent variable	Independent variable	R ^{2a}
IMF breeding value	MspI BV ^b , HaeIII BV, HinfI BV	0.394
IMF breeding value	MspI BV, HaeIII BV,	0.389

^aR²: Coefficient of determination of multiple regression.

^bBV: Breeding value.

Table 4. Results of QTL analysis for selection and correlated traits

Traits	Maximum LOD score	Position of maximum LOD (cM)
Daily gain	0.11	80
Backfat thickness	0.55	81
Loin muscle area	2.77**	70
Intramuscular fat	0.13	15
Tenderness of meat	0.82	71

2) Using DNA marker information (QTL analysis)

Quantitative traits loci (QTL) analysis was executed within Duroc breed on the seventh chromosome for meat production and meat quality traits. Regarding this seventh chromosome, the significant QTL region for intramuscular fat has already been reported (Sato et al., 2003). The polymorphism of 12 microsatellite markers that was arranged at about 20-cM intervals was investigated in about 1004 pigs. A significant region of QTL for intramuscular fat was not detected by QTL analysis using the data corrected with BLUE. Therefore, it was suggested that the QTL does not exist in the seventh chromosome related to intramuscular fat. However, significantly maximum LOD was detected in the 70-cM region for the loin eye muscle area (EM) (Table 4), which suggests that the intra-breed QTL analysis was effective using the population of line breeding of pigs. However, the QTL heritability was 0.07, and the heritability by polygene, aside from the effect of QTL was 0.46. Further QTL analysis is necessary to search the region for other chromosomes that are related to intramuscular fat.

Genetic improvement of chronic disease resistance in pigs

The potential for genetic improvement of resistance against chronic infectious diseases was investigated in Duroc pigs. Five immunities were measured for each. Furthermore, morbid changes caused by AR and MPS were measured in two full-brothers of the candidate. Daily body weight gain was measured. Genetic and phenotypic parameters of delayed type hypersensitivity, phagocyte activity, antibody productivity, morbid changes engendered by AR and MPS, daily body weight gain, back fat thickness, and eye muscle area were estimated using restricted maximum likelihood (REML). Two selection indices were made based on those parameters to delete morbid changes attributable to AR and MPS from the population. One index was based on morbid changes

in the two full-brothers of the candidate; another index was based on the three immunities of the candidate itself. Intensities of selection were assumed as unity in the indices. Seven or eight generations of selection based on the indices were inferred to be sufficient to yield a population showing almost no morbid changes by AR and MPS (Nishida et al., 2001). Based on these results, a selection experiment with Landrace pigs for disease resistance traits and growth began in 2004 at the Miyagi Prefecture Livestock Experiment Station. Selection traits are the degree of morbid states by AR and MPS. In addition, some immune response phenotypes will be used as selection criteria and QTL analyses will be used to investigate immune traits within breeds.

References

- Abe, T., A. Nishida, S. Ito, M. Jimbu, I. Sato and H. Mikami, 1981. Selection experiment with swine in different regional environments. I. Design and Experiment. Jap. J. Swine Science. 18: 159–166.
- Clutter, A. C. and E. W. Brascamp, 1998. Genetics of performance traits. In: Rothschild, M.F., Ruvinsky, A. (Eds.), The Genetics of Pigs. CAB International, New York, pp. 427–462.
- de Vries, A. G., P. G. van der Wal, T. Long, G. Eikelenboom, and J. W. M. Merks, 1994. Genetic parameters of pork quality and production traits in Yorkshire populations. Livest. Prod. Sci. 40:277–289.
- de Vries, A. G., P. G. van der Wal, T. Long, G. Eikelenboom and J. W. M. Merks, 1994. Genetic parameters of pork quality and production traits in Yorkshire populations. Livest. Prod. Sci. 40: 277–289.
- Fernandez, A., E. de Pedro, N. Nunez, L. Silio, J. Garcia-Casco and C. Rodriguez. 2003. Genetic parameters for meat and fat quality and carcass composition traits in Iberian pigs. Meat Sci. 64:405–410.
- Hermesch, S., B. G. Luxford and H. -U. Graser.

- 2000a. Genetic parameters for lean meat yield, meat quality, reproduction and feed efficiency traits for Australian pigs 1. Description of traits and heritability estimates. *Livest. Prod. Sci.* 65:239–248.
- Hermesch, S., B. G. Luxford and H. -U. Graser. 2000b. Genetic parameters for lean meat yield, meat quality, reproduction and feed efficiency traits for Australian pigs 2. Genetic relationships between production, carcass and meat quality traits. *Livest. Prod. Sci.* 65:249–259.
- Hovenier, R., E. Kanis, Th. van Asseldonk and N. G. Westerink. 1993. Breeding for pig meat quality in halothane negative populations – a review. *Pigs News and Information* 14:17N–25N.
- Hyodo, I. 1996. A case study for increasing intramuscular fat content of pork. *Animal Breeding Journal*. 5:1–9.
- Knapp, P., A. Willam and J. Solkner. 1997. Genetic parameters for lean meat content and meat quality traits in different pig breeds. *Livest. Prod. Sci.* 52:69–73.
- Kuhlers, D. L., K. Nadarajah, S. B. Jungst and B. L. Anderson, 2001. Genetic selection for real-time ultrasound loin eye area in a closed line of Landrace pigs. *Livest. Prod. Sci.* 72:225–231.
- Kuhlers, D. L., K. Nadarajah, S. B. Jungst, B. L. Anderson and B. E. Gamble, 2003. Genetic selection for lean feed conversion in a closed line of Duroc pigs. *Livest. Prod. Sci.* 84:75–82.
- Larzul, C., L. Lefaucheur, P. Ecolan, J. Gogue, A. Talmant, P. Sellier, P. Le Roy and G. Monin. 1997. Phenotypic and genetic parameters for longissimus muscle fiber characteristics in relation to growth, carcass, and meat quality traits in Large White pigs. *J. Anim. Sci.* 75:3126–3137.
- Lo, L. L., D. G. McLaren, F. K. McKeith, R. L. Fernando and J. Novakofski. 1992. Genetic analyses of growth, real-time ultrasound, carcass, and pork quality traits in Duroc and Landrace pigs II. Heritabilities and correlations. *J. Anim. Sci.* 70:2387–2396.
- Nakai, H., R. Tanabe, S. Ando, T. Ikeda and M. Nishizawa. 1992. Development of a technique for measuring tenderness in meat using a “Tensipresser”. *Proc. 38th International Cong. Meat Sci. Tech., Clermont-Ferrand, France* 5:947–950.
- Nishida, A., T. Ogawa, Y. Kikuchi, K. Wakoh, K. Suzuki, T. Shibata and H. Kadowaki, 2001. A hopeful prospect for genetic improvement of chronic disease resistance in swine. *Asian-Aust. J. Anim. Sci.* 14, Special issue: 106–110.
- NPPC. 1995. Genetic Evaluation/Terminal Line Program Results. R. Goodwin and S. Burroughs, eds. National Pork Producers Council, Des Moines, IA.
- Sato, S., Y. Oyamada, K. Atsuji, T. Nade, Shin-ichi Sato, E. Kobayashi, T. Mitsuhashi, K. Nirasawa, A. Komatsuda, Y. Saito, S. Terai, T. Hayashi and Y. Sugimoto. 2003. Quantitative trait loci analysis for growth and carcass traits in a Meishan × Duroc F2 resource population. *J. Anim. Sci.* 81:2938–2949.
- Sellier, P. 1998. Genetics of meat and carcass traits. Pages 463–510 in *The Genetics of the Pigs*. M. F. Rothschild, and A. Rubinsky eds. CAB International. New York.
- Sonesson, A. K., K. H. de Greef and T. H. E. Meuwissen. 1998. Genetic parameters and trends of meat quality, carcass composition and performance traits in two selected lines of large white pigs. *Livest. Prod. Sci.* 57:23–32.
- Suzuki, K. 2004. Genetics and breeding. Pig research on ten years in Japan. 40th anniversary issue. *The Japanese Journal of Swine Science*, 41:29–36.
- Suzuki, K., M. Irie, H. Kadowaki, T. Shibata, M. Kumagai and A. Nishida. 2005a. Genetic parameter estimates of meat quality traits in Duroc pigs selected for average daily gain, longissimus muscle area, backfat thickness, and intramuscular fat content. *J. Anim. Sci.* 83:2058–2065.
- Suzuki, K., H. Kadowaki, T. Shibata, H. Uchida and A. Nishida. 2005b. Selection for daily gain, loin-eye area, backfat thickness and intramuscular fat based on desired gains over seven generations of Duroc pigs. *Livestock Production Science*, 97: 193–202.