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Current Situation and Problems of Japanese Beef Cattle Breeding

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Introduction

It is said that the livestock is the product of culture. Japan is located in the subtropics monsoon area and has developed rice crop culture. In addition flesh-eating was prohibited by Emperor Tenmu who was enlightened by Buddhism (675) and the use of milk products was also restricted to medical purposes. Horses and cattle were raised mainly for the methods of transportation and cultivation. After the Meiji Restoration (1868) a rapid civilization was employed and the demand for animal protein increased. However Japan had been away from livestock improvement for 1,200 years and the government had to introduce various cattle breeds from overseas and the attempt, which was failed later, was made to crossbreed and improve the cattle. In the Taisho era (from 1912) Japanese native and crossbred cattle were arranged to produce new breeds and so called "Wagyu" was formed. Wagyu includes four breeds, *i.e.* Japanese Black, Japanese Brown, Japanese Shorthorn, and Japanese Polled cattle, but all four breeds were still maintained for draft and meat was utilized as the by-product. Actual improvement of Wagyu cattle as beef breed has started since 1960s.

Table 1. Shares of beef consumption in Japan

	Domestic production		Importation		
Year	1,000 ton	Ratio to previous year	1,000 ton	Ratio to previous year	Self-sufficing (%)
1990	387	102.7	384	105.6	50.1
1991	406	104.9	326	85.1	55.4
1992	416	102.5	423	129.5	49.5
1993	415	99.7	566	133.9	42.3
1994	423	101.8	583	103.0	42.0
1995	414	97.8	658	112.7	38.6
1996	382	92.4	611	92.9	38.4
1997	370	96.8	658	107.8	35.9

The goal of animal breeding depends on social demands. Accordingly the goal of Wagyu breeding has changed dramatically. In 1991 Japanese beef market was liberalized and imported beef reached 65% of total consumption (Table 1). This shifted the goal of Wagyu breeding to better meat quality and, as the result, percentage of Japanese Black, which shows a unique characteristic of fat deposition, namely less subcutaneous and intermuscular fat but abundant intramuscular accumulation, *i.e.* marbling, increased to more than 92% in breeding females and 42% in fattening animals (Table 1 and Figure 2). A survival competition is taken place within Japan as well as the international competition and approximately 140 beef brands are existed in Japan. This paper describes the current situation and problems of Japanese Black cattle breeding.

Table 2. Breed constitution of breeding females in Japan (%)

Year	Japanese Black	Japanese Brown	Japanese Polled	Japanese Shorthorn	Foreign Breeds	Cross-breds	Total
1960	76.4	22.1	0.3	0.9	0.3		100
1980	86.7	8.9	0.2	3.1	1.1		100
1985	86.5	9.2	0.2	3.0	1.1		100
1991	86.2	8.4	0.1	2.8	1.8	0.7	100
1997	92.0	5.0	0.0	1.5	1.0	0.4	100
1997 No.	628,895	34,204	142	10,215	6,850	3040	683,346

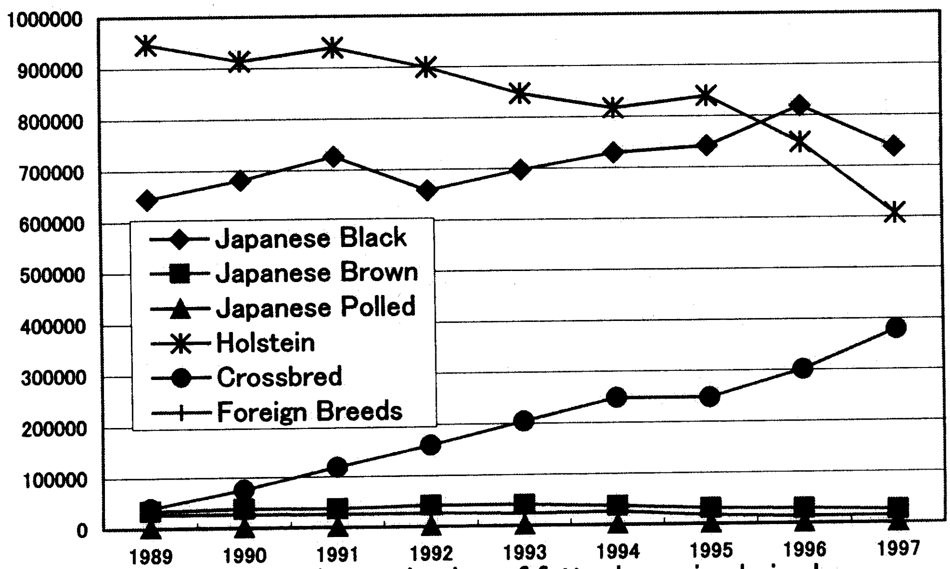

Fig 1. Breed constitution of fattening animals in Japan
Crossbred: progeny mainly from Holstein cows mated with Japanese Black sires

What is the economic trait?

There are various traits that can become targets for improvement. Some traits such as reproduction, maternal ability, longevity, growth ability, feed efficiency, disease resistance, and temperament are primary important traits for livestock. In addition meat production traits including meat quantity and quality also become important targets. These traits show continuous variation depending on the number of genes following Mendel's inheritance laws that control the trait, and also environmental effects. Therefore we have to find out what percent of total phenotypic variation is due to genetic causes. Although meat quantity traits have become breeding target relatively easy because their variation can be observed as body weight, meat quality traits are not easily measured. In 1988 Beef Carcass Grading Standard was revised to the one that can conduct dual evaluation, which is yield and quality grades. In the new standard four meat quality traits are included, marbling, meat color and brightness, meat firmness and texture, and fat color and luster, for quality grading. Although it is not very clear how much of the taste can be expressed by the four traits, at least the meat quality records from unified standard became available for breeding.

History of improvement of Japanese Black cattle

Until mid-1960s when Japanese Black cattle was used as dual purposes, draft and meat, not enough attention was paid for meat production ability. Exterior judgment of conformation was the main standard for the evaluation of breeding animals because beef was the by-product from aged animal. However improving Japanese Black cattle to a beef breed became urgent matter and then performance and progeny testings at official stations were employed as the method of sire selection in 1968. This was because in Japan the proportion of progeny from artificial insemination is the highest in the world (more than 95%) and the genetic influence of sire to the population is much higher than of females. The testings have been established as the method of genetic evaluation of sires, currently about 400 and 100 bulls are performance- and progeny-tested every year, respectively.

Figure 2 shows the averages of daily gain and marbling score at progeny testing after the revision of Beef Carcass Grading Standard. It is clear that until 1994 no change is observed in marbling score and the participants of beef cattle breeding received it as a serious matter. It can be explained by the fact that marbling can be measured only after the animal is slaughtered and cannot be measured from live animals directly. Meat quality, which was chosen as the primary breeding target has such a difficulty for breeding. On the other hand it is the reason that Japanese Black could compete with imported beef after the market liberalization. To improve the efficiency of progeny testing the genetic evaluation using field carcass records and field progeny testing have been conducted since 1991 and 1999, respectively.

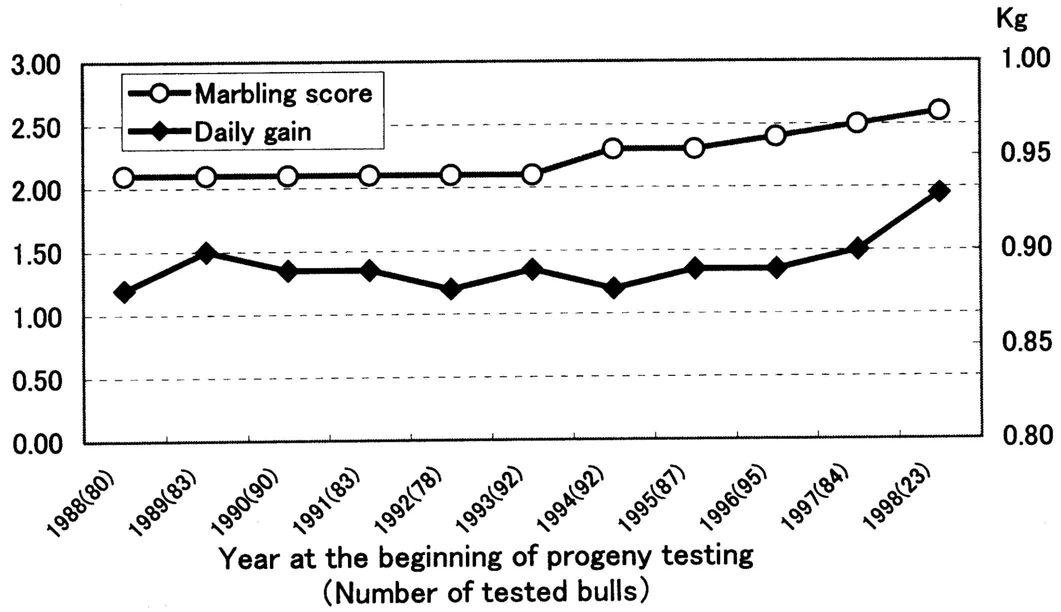

Fig 2. Change of progeny testing results

Principles of animal breeding

Followings are basic principles of animal breeding.

Genetic gain

Livestock improvement will be achieved by two processes, *i.e.* selection and mating. It is very important to predict the genetic gain expected from the employed processes especially when the animal with low reproductive rate and long generation interval, such as cattle, is to be improved. Suppose males and females are selected truncationally and mate randomly, then genetic gain is predicted by

$$\Delta G = \frac{1}{2}\left(i_m r_m \sigma_A + i_f r_f \sigma_A\right)$$

where i_m, i_f: selection intensities of male and female, respectively,
r_m, r_f: accuracies of selection of male and female, respectively,
σ_A: additive genetic standard deviation in parental generation.

To be exact above formula can be available only for the subsequent generation. However practically it can be applied for several generations. Moreover if breeding efficiency is concerned, then

$$\Delta G_E = 100\frac{\sigma\sqrt{h^2}}{\bar{x}}\frac{\left(i_m r_m + i_f r_f\right)}{\left(L_m + L_f\right)}$$

where L_m, L_f: generation intervals of male and female, respectively,
h^2: heritability,
$\bar{x}$: overall mean,
σ: phenotypic standard deviation.

The formula provides the relative annual genetic gain.

Genetic merit of progeny

Although above two formulas give genetic gains or average increase of genetic merits under random mating of selected animals, genetic merit (breeding value) of each progeny varies even for the progeny from the same parents (full-sib) as follows

$$A_O = \frac{1}{2}\left(A_{Sire} + A_{Dam}\right) + \beta\sqrt{\frac{\sigma_A^2}{2}\left(1 - \frac{F_{Sire} + F_{Dam}}{2}\right)}$$

where A_O, A_{Sire}, A_{Dam}: breeding values of progeny, sire, and dam, respectively,
F_{Sire}, F_{Dam}: inbreeding coefficients of sire and dam, respectively,
β: standard normal deviate with mean 0 and variance 1.

The first term of right hand side indicates family index and the second term indicates the sampling error of parental genes (Mendelian sampling). For simplicity suppose inbreeding coefficients of sire and dam are 0 and genetic variances of sire and dam are equal, then variance of progeny breeding value is

$$V(A_O) = \frac{1}{4}\left(\sigma_A^2 + \sigma_A^2\right) + \frac{1}{2}\sigma_A^2 .$$

It is important to know that the first term is resulted from additive breeding values of selected male and female, however the second term is completely random event and cannot be predicted for each progeny. That is why two full-sibs do not have identical breeding values. If parental breeding values are predicted with accuracies r_m and r_f, then accuracy of progeny predicted breeding value is

$$r_o = \frac{1}{2}\sqrt{r_m^2 + r_f^2} .$$

When only sire is progeny-tested and breeding value is specified, breeding value of progeny from the specific sire is

$$A_O = \frac{1}{2}A_{Sire} + \beta\sqrt{\sigma_A^2\left(\frac{3}{4} - \frac{F_{Sire}}{4}\right)},$$

and its variance and accuracy are

$$V(A_O) = \frac{1}{4}\sigma_A^2 + \frac{3}{4}\sigma_A^2$$

$$r_o = \frac{1}{2}\sqrt{r_m^2 + 0}$$

respectively. Compared with the case, which breeding values of both sire and dam are specified, proportion of random event among variation of progeny becomes larger and accuracy of predicted breeding value becomes lower. This indicates that variation among progeny becomes larger even if they have the same family index, and more candidates should be tested to select superior animals.

Problems of sire selection at testing station

The above formulae clearly show that following elements are required for both male and female to accelerate the genetic progress,

1. intensify selection pressure,
2. raise accuracy of selection,
3. shorten generation interval.

Currently about 350 bulls are registered per year. However only 100 bulls are progeny-tested (1 to 10 bulls per prefecture per year) and therefore selection intensity is extremely low. In addition because steers from one bull are maintained in one pen during progeny testing, common environmental effect is confounded with genetic difference between bulls. It lowers accuracy of selection and makes impossible for tested bulls to be compared with bulls in other prefecture and year. This is also the reason for long generation interval of Japanese Black cattle.

For female cattle, as mentioned earlier, there was no effective (*i.e.* high accuracy) indicator for the improvement of meat quality traits and genetic evaluation of meat production ability had been untouched for a long time. When selection intensity and accuracy are not clear, reasonable mating plan for production of superior breeding stock cannot be determined. To solve the problem genetic evaluation using field carcass records was examined and has been functioning.

Improvement using field carcass records

Compared with milking or growth ability the carcass traits can be measured only after the animal is slaughtered. Moreover in Japanese beef cattle industry farmers are functionally separated into cow-calf and fattening operations, and selection objective traits are collected after 30 months later at different site from birthplace. To handle such traits as breeding objectives the information management from the birth to slaughter becomes the most important issue. Fortunately a rapid development in computers and information network in 1990s made unified management of data at Wagyu Registry Association possible and the field carcass records became available for breeding information.

The pedigree information including birth date and producer of each individual is stored in pedigree file at weaning. Collection of carcass information is conducted basically at the market within the birthplace. At data collection individual identification is the essential work, and muzzle pattern and ear tag are used to identify the animal.

Data files are edited from production environmental information, carcass record, and pedigree information following the Meat Production Research Report of each productive region and from 1991 genetic evaluation is carried out periodically at each region or Wagyu Registry Association.

Number of times of the genetic evaluation or evaluation time of the year varies and two or three evaluations are conducted for the regions where carcass records increase rapidly. At present (April 1999) calculation is carried out for 46 regions including 39 prefectures. Table 3 shows the average of carcass records from 210,000 animals collected in major productive regions and Hyogo prefecture.

Table 3. Means of carcass traits and their heritabilities

Place	Hyogo		All	
Term	Mean±S.D.	Heritability	Mean±S.D.	Heritability
Slaughter age (month)	31.8±1.9		29.9±2.2	
Carcass weight (kg)	377.3±40.2	0.33	403.9±49.1	0.52
Rib eye area (cm^2)	48.0±6.5	0.42	48.5±6.7	0.49
Rib thickness (cm)	6.7±0.8	0.31	7.1±0.9	0.38
Fat thickness (cm)	2.0±0.6	0.43	2.6±0.8	0.50
Estimated yield (%)	73.47±1.08	0.45	73.07±1.27	0.53
Marbling score (unit)	1.98±0.82	0.50	1.62±0.79	0.56

All carcass traits are evaluated between 6th and 7th ribs section

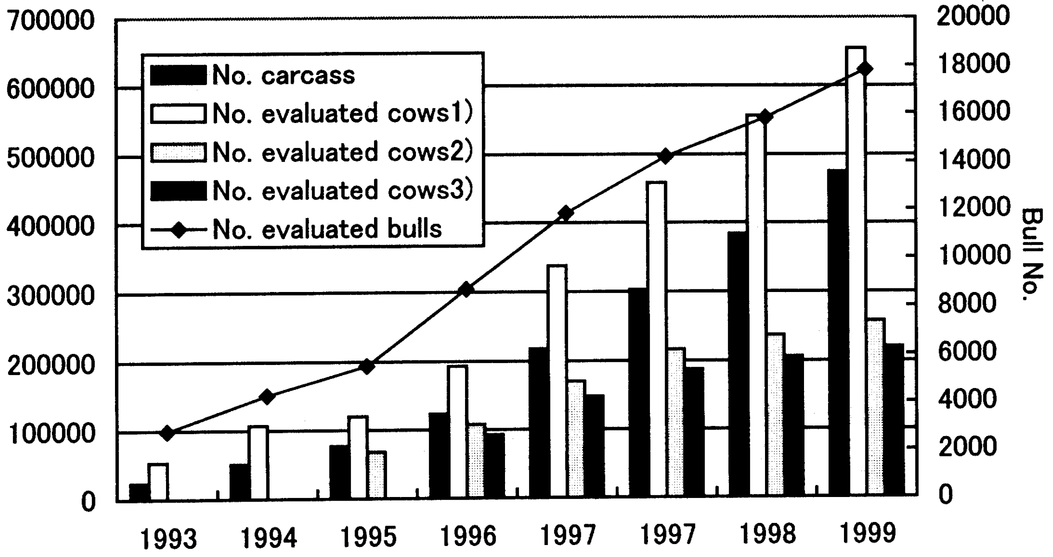

Fig 3. Number of evaluated carcasses and animals

1) Total number of evaluated cows

2)Number of evaluated cows used now

3)Number of evaluated cows used now in breeding units

The number of carcass records used in the evaluation and evaluated breeding stock are indicated in Figure 3. Carcass records reached 475,000 and 90,000 records have been collected every year since 1995. Proportion of Japanese Black graded at markets is 85% among so called Wagyu. This corresponds to about 430,000 of Japanese Black records per year and, therefore, approximately 20% of Japanese Black records are incorporated for the evaluation. If we limit to fattening animals, proportion of records newly added to the evaluation becomes more than 30% because culled cows are included in 430,000 records.

Evaluation of breeding values

The animal model BLUP is used for prediction of breeding values. This model has a property to predict breeding values even for the animals without carcass records through all the genetic relationship in the population. Breeding values are calculated by solving following mixed model equations based on linear model. The solutions (breeding values) are unbiased and have minimum prediction error variances.

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Za} + \mathbf{e},$$

where $\mathbf{y}$: vector of observation,
$\mathbf{X}$: incidence matrix of fixed effects,
$\mathbf{b}$: vector of unknown fixed effects,
$\mathbf{Z}$: incidence matrix of individual breeding values,
$\mathbf{a}$: vector of unknown individual breeding values,
$\mathbf{e}$: vector of residuals,

$$\begin{bmatrix} \mathbf{X'X} & \mathbf{X'Z} \\ \mathbf{Z'X} & \mathbf{Z'Z} + \mathbf{A}^{-1}\alpha \end{bmatrix} \begin{bmatrix} \tilde{\mathbf{b}} \\ \hat{\mathbf{a}} \end{bmatrix} = \begin{bmatrix} \mathbf{X'y} \\ \mathbf{Z'y} \end{bmatrix}, \text{ where } \alpha = \frac{\hat{\sigma}_e^2}{\hat{\sigma}_a^2},$$

$\mathbf{A}^{-1}$: Inverse of additive relationship matrix.

In BLUP it is essential to use unbiased variance components ($\hat{\sigma}_a^2$, $\hat{\sigma}_e^2$) and they are estimated from REML with AI algorithm. By using AI-REML hundreds of thousands of animals can be evaluated even on commercial personal computers.

The evaluated carcass traits are carcass weight, rib eye area, rib thickness, subcutaneous fat thickness, estimated yield, and marbling score. Generally single-trait BLUP is used but multi-trait evaluation is also conducted when genetic correlations are required.

In analytical model (mixed linear model) marketing year, sex (steer or female), and carcass market are treated as fixed effect, and linear and quadratic regression to marketing age and linear regression to inbreeding coefficient are also included. However in some regions carcass market cannot be incorporated due to the problem of data connection. Individual breeding value, fattening farm, and residual are regarded as random effects. In the model fattening farms are treated as random in order to reduce prediction error variance.

Proportion of proved breeding stock and the outcome

Because the number of proved breeding stock depends on the number of related animals ascended from fattening animals, the base year for the evaluation is set in 1975 in most regions. Animal model BLUP gives predicted breeding values of all the related animals, however predicted breeding values of those animals, which have at least one progeny carcass record are exploited from the view of accuracy. As shown in Figure 3 a total of 17,800 bulls have been evaluated and they include all the bulls used for breeding since 1975. On the other hand a total of 660,000 cows have been evaluated. Out of proved cows 260,000 are currently in use and 220,000 are in use within their birthplaces. There are approximately 550,000 cows of Japanese Black cattle at present. It means 40% of cows have been proved from their progeny carcass records. Since selection and mating are practiced basically within each productive region, proportion of proved animals and utilization system in the region are important breeding information.

Publication of the evaluation result varies because the evaluation is carried out for each productive region. All the sires now have predicted breeding values and in most regions the breeding values for own sires are indicated in service sire list.

Publication methods of cows' predicted breeding values are much different from sires. One reason is that cows are owned by small-scale farms. The other is that parental predicted breeding values can be a criterion for economic values of calves at calf market and therefore many of the cows without breeding values might receive economic handicaps. At the same time differences in proportion of proved animals make difficult to establish a uniform publication system across all productive regions.

Figure 4 shows proportions of proved cows, which are in use at present, and of cows, which are not proved but have average of parental breeding values (expected breeding value, family index). The proportion is more than 60% in the highest region and around 10% in some regions. It is expected to prove 50 to 60% of the population constantly as culling by aging or genetic reason proceeds. On one hand young cows cannot be proved by their progeny carcass record until four to five years of age. Although expected breeding value obtained from their proved parental breeding values is not highly accurate (around 0.5), it is easily calculated when parents mate. In some regions proportions of proved cows plus cows with expected breeding values among all registered cows exceed 90%.

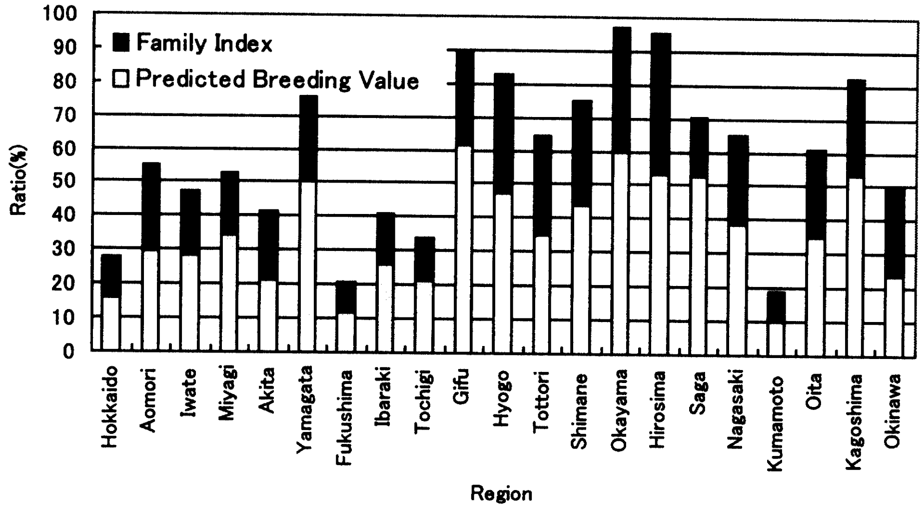

Fig 4. Frequency of evaluated cows relative to all breeding cows by each evaluated region

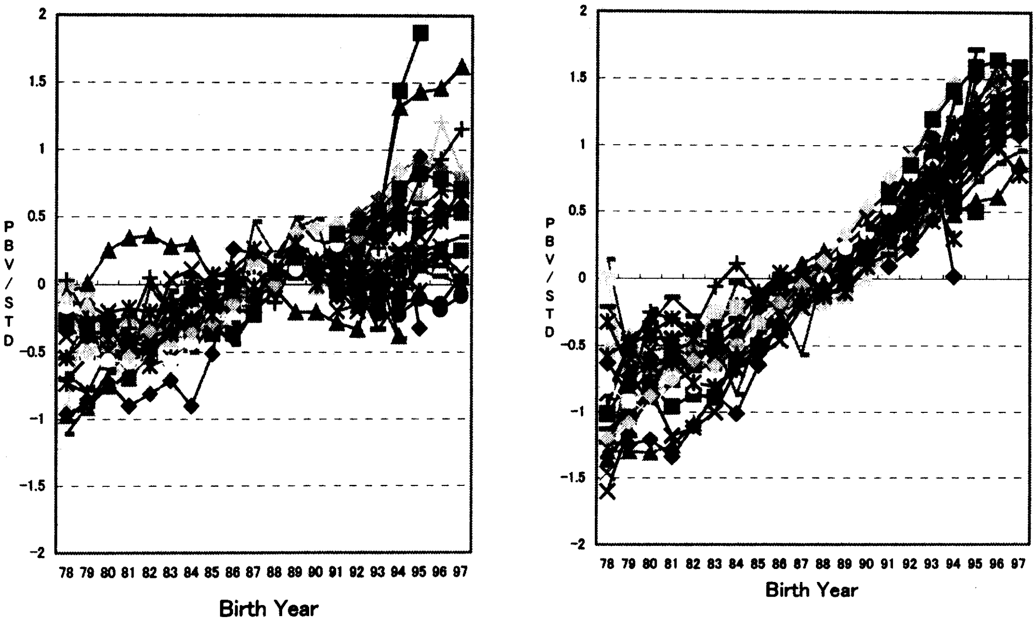

Figure 5. Change of predicted breeding values of cows in standard deviation unit by evaluated regions (left: Carcass weight, right: Marbling score)

Figure 5 indicates genetic trend of the average predicted breeding values (including expected breeding values) of cows at each productive region by birth year in additive genetic standard deviation unit. Beef marbling score has been increasing in many regions since 1988. On the basis of this fact the information from breeding value evaluation is used for not only developing breeding herds but a criterion for cow replacement. In addition predicted breeding values have been indicated in registration certificate or calf auction list in some regions.

Proportion of performance-tested bulls with breeding values and its trend

Traditionally young bulls are selected for performance testing by their sires, pedigrees, or visual appraisals. However little selection pressure has been applied at selection of bulls to be tested for performance. If expected breeding values are used for the selection, strong selection intensity can be applied though accuracy is not so high.

Proportion of performance-tested bulls with expected breeding values by major breeding regions is shown in Table 4. The bulls are born in and after 1991. Proportions vary from 92% in Okayama and 52% in Tottori and the average is around 70%. Having expected breeding value is becoming required condition for performance testing. Figure 6 shows the change of average expected breeding values in standard deviation unit. The averages are increasing in many regions as well as breeding cows. It is thought that the increase of marbling score found in Figure 2 at progeny testing was resulted from the increases in proportion of bulls with expected breeding values and in average of expected breeding values.

Table 4. Percentages of bulls whose parents were evaluated to total performance tested bulls* by major breeding regions

	Region															
	A	I	M	Y	F	Ib	G	H	T	S	O	H	N	Oi	K	Ok
Evaluated bulls	81	124	103	73	99	59	47	122	146	155	137	117	122	142	269	88
Tested bulls	122	176	147	100	141	99	62	180	280	174	149	129	148	160	324	115
Percentage	66.4	70.5	70.1	73.0	70.2	59.6	75.8	67.8	52.1	89.1	92.0	90.7	82.4	88.8	83.0	76.5

A: Aomori, I: Iwate, M: Miyagi, Y: Yamagata, F: Fukushima, Ib: Ibaraki, G: Gifu, H: Hyogo, T: Tottori, S: Shimane, O: Okayama, Hi: Hiroshima, N: Nagasaki, Oi: Oita, K: Kagoshima, Ok: Okinawa

*Bulls born after 1991

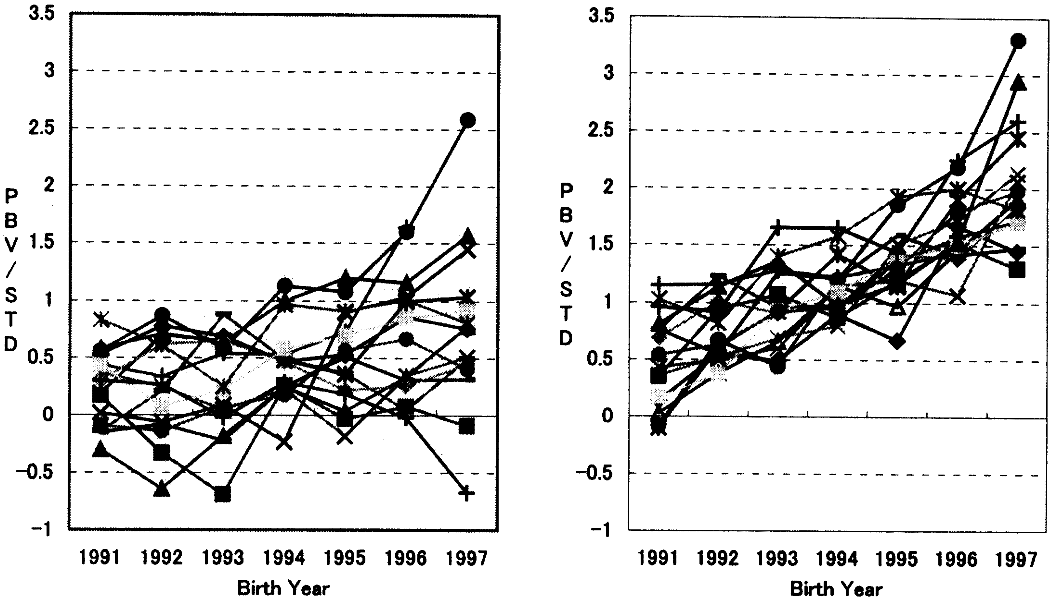

Figure 6. Change of predicted breeding values of performance tested bulls in standard deviation unit by major breeding regions (left: Carcass weight, right: Marbling score)

Problems that Japanese Black cattle confront

Due to the international competition from 1991 the eagerness to improve meat quality has intensified but at the same time some kinds of problems have arisen.

Decrease in effective population size of Japanese Black cattle

Unlike Holstein and other imported breeds, Japanese Black cattle is a closed breed for overseas. Keeping effective population size at large level is an essential work when we think about the future breeding strategies. Japanese Black cattle has the history to be produced based on breeding policy of each prefecture and maintained relatively large effective size until 1960 (Table 5). However with wide spread use of artificial insemination the effective size decreased dramatically and has been around 50 since 1991. If this figure is applied to human population, it genetically equals to just 25 men and 25 women. Intensive use of a few sires is the reason of the decrease because breeding goal is mainly set for meat quality. Although many foreign breeds can receive other genetics since they are regional breeds, Japanese Black cattle has no other genetic source in the world.

Table 5. Comparison of effective population size of Japanese Black with foreign breeds

Breeds	Effective size (Ne)	Registry female number per year
Japanese Black in 1960	1724	ca.50,000 heads
Japanese Black in 1980	125	ca.70,000 heads
Japanese Black between 1985 and 1990	82	ca.60,000 heads
Japanese Black between 1991 and 1996	50?	ca.60,000 heads
Hereford (USA)	79	
Holstein (USA)	122	ca.300,000 heads
Brownswiss (Germany)	109	ca.10,000 heads
Hafringer (Germany)	96	200～300 heads

Importance of effective population size can be expressed as follows.

1. Inbreeding depression: The accumulation rate of inbreeding is inversely proportional to the effective size ($\Delta F = \frac{1}{2Ne}$), and therefore decrease in effective size leads inbreeding upward soon. As the result inbreeding depression may appear in not only fitness (*e.g.* reproduction traits) but target traits for breeding. In addition appearance of defective traits, which are genetically recessive may become higher.
2. Decrease in genetic variation: Genetic variance between two subsequent generations (t-1, t) is $\sigma^2_{At} = \left(1 - \frac{1}{2Ne}\right)\sigma^2_{At-1}$, and in the population with small effective size the most of additive genetic variance disappear in a few generations. Since the amount of genetic improvement depends on the magnitude of additive genetic variance, decrease in the effective size results in less improvement. Moreover those genes, which are related to traits not to be selected now also lose their variations in small effective size population. Genetic diversity within a breed should be maintained as high as possible to react to the change of breeding targets.
3. Random drift of genetic improvement: When a selection experiment with small effective size population replicates several times, the amounts of genetic improvement largely vary by replications. It is not realistic to conduct a selection experiment with large livestock like Japanese Black cattle. However when effective size is small, there is high possibility to

achieve less improvement than expected and to bring huge economical loss.

Prolongation of fattening period

Although daily gain of Japanese Black cattle has been increasing since the beginning of official tests, fattening period has been prolonging. In 1988 average age at slaughter was 29.2 months with 662kg live weight and in 1995 the average was 30 months with 680kg. There is a large difference between the average of 15 to 16 months with 550kg for standard crossbreed in USA. It can be said that we produce the largest carcass in the world spending twice of American fattening period. This is clearly the result of chasing the highest meat quality and profit per fattening animal due to expensive feeder stock. However beef marbling is highly heritable and it is impossible for genetically inferior animals to achieve the best quality even if fattening period becomes longer. From the view of feed efficiency the type of fattening is not efficient. It is required to reconsider the fattening because low food self-sufficiency (41%) is largely due to grain imports. We need new breeding strategy, which can develop various lines with different genetic merits, immediately since at present a certain improvement has been achieved on marbling and, as mentioned earlier, the breeding focusing on marbling only reduces the effective population size.

Improvement of maternal ability

Japanese Black cattle have gentle temperament compared with foreign breeds. However cows' maternal ability (milking and rearing ability) has not been considered due to the use of synthetic milk and milk replacer. From the point of productivity in cattle herd the reproduction and maternal abilities of cows become important. They both have received natural selection for long time and, as the result, the variations are not very large but they still have some genetic variations to be used for improvement. To improve the productivity it is an essential ability and should be picked up as one of the genetic evaluation traits as well as carcass traits.

Future approach and perspective

Along with developments in carcass data collection and evaluation method the proportions of proved sires and dams have dramatically increased. It enabled us to conduct efficient selection and mating design, selection of its progeny, and to construction of functional breeding herd. However there still be large differences among productive regions in how to use the evaluation results and more work is needed to settle the gaps and to expand the system. By exchange use of breeding stock and frequent move of feeder stock, genetic connectedness among productive regions intensifies and a genetic evaluation including several regions becomes possible. By doing so there is no doubt that results from the evaluation will be used as useful information at calf auction across productive regions as well as breeding information. On the other hand since selection based on predicted breeding values results in reduction of effective population size (increase in inbreeding), selection and mating system that can control both inbreeding and genetic improvement will be required. At the same time the evaluation system should be developed for reproduction and maternal abilities and genetic diversity should be maintained to correspond to the sudden change of breeding goals.

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