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Progress in Breeding Techniques for Effective Beef Cattle Production in Japan

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Abstract

Considerable genetic improvement of Japanese beef cattle has been achieved using traditional on-station testing schemes. To make full use of the characteristics of Japanese beef cattle, however, it is more appropriate to carry out on-farm progeny testing programs, based on the BLUP (best linear unbiased prediction) animal model. The introduction of MOET (multiple ovulation and embryo transfer) could lead to dramatic changes in conventional beef cattle improvement schemes, rather than replacing traditional breeding schemes. In the near future, biotechnology will enable to obtain easier and more accurate assessments through the determination of the specific DNA segment responsible for the desired phenotypic trait. This paper describes the progress in breeding techniques for effective beef cattle production in Japan.

Discipline: Animal industry
Additional key words: genetic resources, on-farm progeny test, BLUP

Introduction

With the complete liberalization of beef imports implemented in 1991, beef market competition became very severe. Competition within Japan, both with international and amongst home market producers, greatly intensified. To deal with such, especially international, competition some survival strategies need to be developed. The strategies include cost reduction (use of low-cost feeds), economical production systems (optimum fattening period), high quality meat (grade improvement and uniformity), safe meat (healthy and without additives), etc.

However, genetic improvement is the basis for the successful outcome of these strategies. The following aspects are very important: (1) utilization of valuable genetic resources based on unique cross-breeding history, (2) genetic improvement using traditional breeding methods through the spread of computers (on-station and on-farm progeny test, BLUP procedure using animal model), and (3) introduction of new breeding technology (multiple ovulation and embryo transfer, DNA marker-assisted selection).

This paper describes the progress in breeding techniques for effective beef cattle production, especially for indigenous beef cattle (Wagyu) in Japan.

Background of beef cattle production

1) Historical background of cattle production in Japan

The history of beef cattle raising in Japan is very short compared to that of Europe, due to the following 2 reasons. At first, the climatic conditions of Japan are suitable for the cultivation of grain and the only purpose for cattle raising was to support rice cultivation. And second, the predominance of Buddhism for a long period of time prevented the consumption of meats, especially that of 4-legged animals. Though meat has been consumed in Japan only for about 130 years since the beginning of the Meiji era, it only reached widespread popularity in the last 30 years. Therefore, Japanese beef cattle were not subjected to improvement for meat production until the mid-1950s.

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In the Meiji era, many foreign cattle were introduced to Japan and initially extensively crossbred with the native cattle under the guidance of the government. As a result, the gene pool of Japanese beef cattle was diluted and greatly expanded. After the initial spur of crossbreeding was over, cattle breeders started to improve their breeds without such crossbreeding. As these activities were promoted by each prefecture, the unique characteristics of Japanese cattle persist even now[6,8].

2) Description of Japanese beef cattle breeds

In total in 1995 there were 2,965,000 beef cattle in Japan. These can be classified into 2 basic types: one, 1,872,000 indigenous Japanese beef cattle and the other, 1,093,000 non-indigenous fattening dairy cattle and crossbreeds. The category of crossbreed accounts for a small but expanding part of the total due to the current popularity of crossbreeding of Japanese Black with Holstein cattle. The indigenous beef cattle breed is called Wagyu. There are 4 breeds, Japanese Black (90.2%), Japanese Brown (7.6%), Japanese Poll (0.1%), and Japanese Shorthorn cattle (2.1%). Each breed has its own history and distinct characteristics which are described in detail in the next paragraph.

(1) Japanese Black

As most Japanese Black were crossbred, a modern type of this breed evolved. However the original type of Japanese Black cattle can still be found in Mishima cattle designated as a natural treasure in Japan. They are late maturing breeds with a narrower body compared to the modern Japanese Black[9].

In Chugoku district, several pre-crossbred strains (Tsuru) had been developed during the Edo era (1600–1867) and they were used for carrying firewood to ignite iron sand for steel production. They were used as draft animals. After the Meiji restoration in 1867, the government promoted the introduction of foreign cattle breeds for crossbreeding with native cattle in order to improve body size and milk production. As shown in Table 1, various kinds of breeds were introduced and crossbred with each regional native cattle. As a result, the genetic diversity of the indigenous cattle markedly expanded.

After the mid-1950s, agricultural machinery predominated and the use of chemical fertilizers became popular in agriculture, supplanting and reducing the role of draft cattle. As a result, these cattle were raised for beef production.

Japanese Black can be found in all the regions of Japan. Recently, the number of this breed has increased in the Kyushu and Hokkaido regions. In contrast, in the Chugoku region, which was once the main production area of this breed, it has been decreasing.

Overall this breed shows a dull black coat and

Table 1. Foreign breeds crossed with native cattle in each prefecture

Name of modern breed	Prefecture	Foreign breeds used for crossing
Japanese Black	Kyoto	Brown Swiss
	Hyogo	Shorthorn, Devon, Brown Swiss
	Okayama	Shorthorn, Devon
	Hiroshima	Simmental, Brown Swiss, Shorthorn, Ayrshire
	Tottori	Brown Swiss, Shorthorn
	Shimane	Devon, Brown Swiss, Simmental, Ayrshire
	Yamaguchi	Devon, Ayrshire, Brown Swiss
	Ehime	Shorthonr
	Ohita	Brown Swiss, Simmental
	Kagoshima	Brown Swiss, Devon, Holstein
Japanese Brown	Kochi	Simmental, Korean cattle
	Kumamoto	Simmental, Korean cattle, Devon
Japanese Poll	Yamaguchi	Aberdeen-Angus.
Japanese Shorthorn	Aomori	Shorthorn
	Iwate	Shorthorn
	Akita	Shorthorn, Devon, Ayrshire

skin, horns, but no humps are observed. The body size is small to medium. The withers' height and body weight of the mature female and male are 124 cm, 420 kg and 137 cm, 700 kg, respectively. The milk yield for 180 days is about 1,000 kg. The records of the performance and progeny tests are shown in Tables 2 and 3[3]. Compared to the other Japanese indigenous breeds, Japanese Black are noted for their capacity to produce beef with a high degree of fat marbling but with a thin fat layer beneath the skin and surrounding the internal organs.

Table 2. Performance testing records of Japanese beef cattle[a]

(1993)

Items		Japanese Black	Japanese Brown[c]	Japanese Shorthorn
Number of tested bull calves		406	30	80
Birth weight	(kg)	31.7	34.9	39.1
Initial weight	(kg)	264.1	319.8	313.0
Final weight	(kg)	400.2	469.5	491.1
365-day weight	(kg)	426.1	448.1	451.0
Daily gain	(kg)	1.21	1.34	1.27
Concentrate intake	(kg)	632	764	772
Forage intake[b]	(kg)	340	297	618
TDN/kg gain	(kg)	4.52	4.86	4.93

a): Performance testing period lasted 140 days in all breeds.
b): Air-dry basis.
c): Kumamoto strain.

Table 3. Progeny testing records of Japanese beef cattle

(1993)

Items		Japanese Black	Japanese Brown[d]	Japanese Shorthorn
Number of tested bulls[a]		76	5	6
Testing period	(day)	364	329	308
Initial age	(day)	263.0	306.1	277.0
Initial weight	(kg)	258.0	329.5	270.9
Final weight	(kg)	580.6	672.4	616.2
Daily gain	(kg)	0.89	1.04	1.12
Concentrates intake	(kg)	2586	3121	2307
Forage intake[b]	(kg)	672	–	984
Carcass weight	(kg)	348.5	416.5	364.8
Dressing weight	(%)	63.2	64.1	61.7
Marbling score[c]		7.1	4.7	3.3
Rib eye area[c]	(cm)	45.0	48.3	43.7

a): Eight to 10 steer progenies per bull were used.
b): Air-dry basis.
c): Carcass measurements were performed at the level of the 6th to 7th rib section.
d): Kumamoto strain.

(2) Japanese Brown

The Japanese Brown breed consists of 2 distinct strains. One is mainly reared in Kumamoto Pref. and the other in Kochi Pref. Since the developmental processes of these strains are quite different, they are usually described separately.

Kumamoto strain: Originally in Kumamoto Pref., a strain of red-colored cattle was reared. This strain was developed from imported Korean cattle. After the late 1900s, many foreign breeds such as Simmental and Devon were imported and crossed with this breed. When a crossing was performed with Simmental cattle, in particular, cattle with a large body size were produced. This breed is characterized by a high rate of body-weight gain and a large rib eye area.

Kochi strain: Kochi strain was developed from crossing Simmental with Korean cattle introduced from Kyushu island. The period during which this crossing was practiced was substantially shorter than that for the Kumamoto strain. As a result, the dilution of the original breed's characteristics was reduced and important differences were maintained. They also have a yellow brown coat, with a much lighter color, than that of the Kumamoto strain. The cattle with black skin at their horns, hoofs, eyelids, muzzle, tongue, switch and anus fetched a higher value because they were typical of the original Korean breed. The beef production performance of this strain is very similar to that of the Kumamoto strain.

(3) Japanese Poll

This breed has been developed since 1916 from a cross between the indigenous cattle with Aberdeen Angus bulls imported from England. Japanese Black bulls were crossed with those females in order to improve their meat quality in 1975, and it is likely that there are not many pure bred Japanese Poll cattle left. Their coat color is black and they lack horns. Neither performance nor progeny tests have been practiced since 1986.

(4) Japanese Shorthorn

This breed is the result of crossbreeding, begun in 1871, between the indigenous cattle from the northern part of Honshu island (Tohoku region) and the imported dairy Shorthorn cattle. It is assumed that this breed is more adapted to rough summer grazing in the mountainous parts of this region, than other breeds. They are mainly distributed in the Tohoku and Hokkaido regions.

The coat color of this breed which is deep red brown, is darker than that of the Japanese Brown. The Japanese Shorthorn seems to be superior to the

Japanese Black for milk production, forage intake and growth rate.

Current rearing conditions and average performance

1) Rearing conditions

On-farm cattle rearing, for calf production, is a small operation, with 4.6 head on average, due to the lack of productive basis for grazing or forage production areas. Grazing is generally limited to mountainous areas, hilly regions and highlands, where rice cannot be cultivated. Cattle are grazed rotationally on fenced ranges or pastures in the summer from May to October, but they are usually kept in barns in the winter, because foliage is not available in most of the grazing areas, due to withering or heavy snow in the winter. In the southwestern region of Japan, where all year round the temperature is higher than in the northern region, yearlong grazing is possible.

All the bull calves except those retained for breeding purposes are castrated during the suckling period, because castrated calves are marketed as feeders for fattening. Castration is carried out before the calves are 3 months old. Almost all the calves are fed on supplements from the age of 2 or 3 months up to the weaning age of 6 or 7 months. The average number of calves in fattening farms is larger than in calf production farms, 24.7 head per farm.

2) Reproduction

In Japan, about 94% of the cows are artificially inseminated and about 99% of the inseminated cows are served with frozen semen. As only selected superior males are used in the system, the ratio of males to females is very low. The semen of young bulls is collected first at about 18 months of age, and thereafter periodically.

Heifers have their first service when they are 13 to 16 months old. The first parturition is expected when they are about 2 years old without any calving difficulties. In order to shorten the calving interval, cows have the next service within 40 to 60 days after calving. The conception rate was about 88% in 1994 and the calf-crop rate was 84%. The natural rate of twinning is very low, accounting for 0.11% in Japanese Black. The average calving interval is estimated at about 13.5 months. The management of cattle is so intensive that the mortality of cattle is fairly low.

3) Meat production

Japanese beef cattle fattening methods are quite different from those common in other countries. Steers are finished at 696 kg live weight and 29.8 months of age on average, spending about 20.2 months for fattening after weaning. During this time, they consume about 3 t of concentrate rations and gain 0.68 kg a day. Such a fattening system is too long and not rational, but can be profitable at present, as a result of the strong demand for high quality beef.

There are many cattle strains based on their genetic background. One typical cattle line is found in Hyogo Pref. These cattle are characterized by the superior meat quality. Their finely marbled beef is famous under the name of "Kobe-beef" or "Matsuzaka-beef". It is a general misconception that high quality beef is produced by special feeding and management techniques. Since these animals have unique genetic traits, they should be conserved and optimum use should be promoted.

Major changes in beef cattle breeding

Since 1968, 2-stage selection, based on the performance and the progeny testing, has been practiced on a station testing system. Fig. 1 shows the outline of the 2-stage selection program.

1) On-station beef bull testing program

In the performance testing program, male progenies from the planned matings are chosen at weaning and transferred to the breeding station within each prefecture and/or Livestock Improvement Association (LIA). The duration of the performance testing is 112 days (16 weeks). The selection criteria include growth rate, 365-day weight, feed efficiency, semen quality, type score, etc., and the selection intensity is 10 to 20%. Selected growing bulls can proceed to the progeny testing program.

In the progeny testing program, half-sib steer calves sired by particular bulls are fattened (the prefectural stations use 8 paternal half-sibsteer calves and the LIA stations 15). The duration of the progeny testing period is 364 days (52 weeks). The selection criteria include marbling score at the eye muscle at the level of the 6–7th rib section, rib eye areas, fat thickness, growth rate, etc., and the selection intensity is about 30%. Marbling score at the eye muscle is given priority in the assessment of performance. In all breeds, about 500 animals were subjected to the performance test and about 100

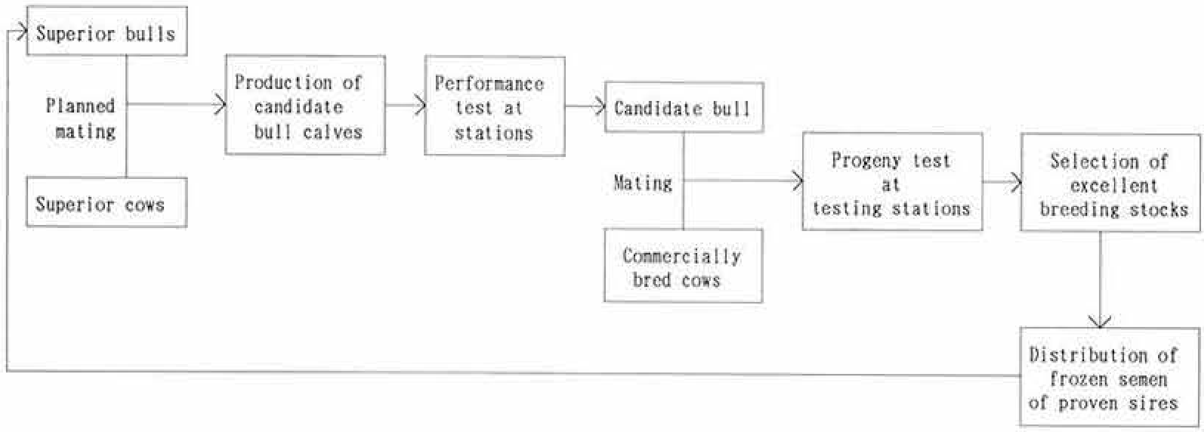

Fig. 1. Outline of the on-station beef bull progeny testing program

animals to the progeny test each year at 21 official stations in 1994.

Although these testing programs have played a major role in beef cattle breeding, there are at least 3 important defects in these programs. Firstly, at the initial selection stage, the performance of carcass quality traits, especially marbling score, was not evaluated in the test. Secondly, the performance and progeny tests in a station testing system are costly. Thirdly, only males are tested.

2) Changes in the conditions of testing program

Four major factors led to the change of the conditions of the testing program as follows: (a) new reproductive technologies, (b) innovation in computer technology, (c) standardization of carcass grading, and (d) optimum utilization of Japanese beef cattle.

Recently, many reproductive technologies, e.g. multiple ovulation, embryo transfer, cloning, *in vitro* embryo production, embryo sexing, etc., have been developed for advancing genetic improvement. Such reproductive technologies, especially multiple ovulation and embryo transfer (MOET), require that data on the performance of females be known. Although previously data on the genetic potential of bulls only were necessary, presently data on cows are required for the carcass performance, etc.

As the BLUP (best linear unbiased prediction) procedure has become widely used for estimating breeding values, technical innovation in computers enables to calculate large equations on personal computers, an operation which was impossible 10 years ago. Advances in computer technology have recently contributed significantly to the increase of the power of personal computers and equally reduced the cost. As a result, the use of BLUP has expanded for beef cattle improvement. It is now possible to carry out multi-factorial calculations that provide a more accurate prediction of the breeding value through the use of cattle pedigree data and that enable to make suitable corrections for environmental factors. Moreover, such calculations can now easily be performed on personal computers.

In 1988, the beef carcass grading standard was revised. The separation of carcasses between the 6th and the 7th ribs was standardized throughout Japan. Standardized evaluation system was also introduced, e.g. meat yield grade was classified into 3 ranks (A, B, C) based on the numerical value while meat quality grade was classified into 5 ranks (1–5) with standard marbling and color figures.

The rearing system of Japanese beef cattle is very different from that of other countries: (a) more than 90% of cattle are pure breed, (b) more than 95% of mating is practiced by artificial insemination, (c) more than 98% of the cattle are registered and have their pedigree records, and (d) more than 80% of cattle for slaughtering are graded at the meat markets by standardized carcass grading systems.

To fit these changes and to take advantage of these traits, the field progeny testing program was introduced.

3) On-farm progeny testing program

Fig. 2 gives an outline of the on-farm progeny testing program. All feeder calves that participated in this scheme were ear-tagged with an individual code at the weaning age. When they were slaughtered at the meat markets, the data on identified field carcass were collected and used to estimate the breeding value for both the sire and the dam by matching with pedigree information. This type of

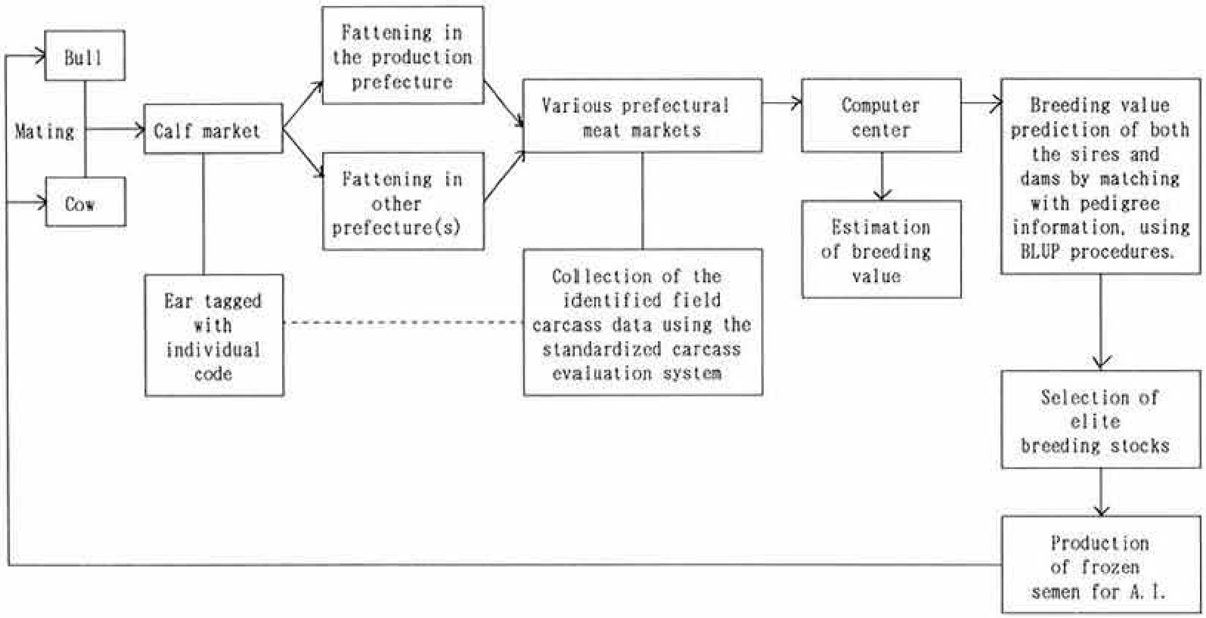

Fig. 2. Outline of the on-farm beef bull progeny testing program

estimation became possible through the development of the calculation procedure that is designated as Animal Model BLUP and the application systems for personal computer[5].

The on-farm progeny testing program has 4 major advantages: (a) more cattle can be tested, and a higher selection pressure and faster improvement achieved, (b) the cost of testing is reduced, (c) before the performance testing, it is possible to evaluate the performance of young bulls, and (d) by planned mating between sire and cow with a high breeding value, it is possible to produce elite breeding stocks.

Until recently, various conditions had not been satisfactory and the on-farm progeny testing program was not implemented nationwide. Presently, however, more than 30 prefectures are trying to introduce this system and considerable progress has already been achieved. In the near future, it is anticipated that the breeding values of all breeding stocks of beef cattle will be calculated on a nationwide scale, as in the case of dairy cattle.

Future breeding techniques

1) Developmental programs using new reproductive technology

In 1993, 10,230 calves were produced through embryo transfer and 1,317 calves through IVF (*in vitro* fertilization) in Japan. MOET (multiple ovulation and embryo transfer) offers new opportunities for genetic improvement in cattle. While such techniques remain expensive, they will mainly be used for breed improvement, rather than commercial production. Improved reproduction rates in females through these methods enable the following: (a) more intensive selection (since there are more individuals to choose from), (b) more accurate selection (since there are records on more relatives), (c) most importantly, a shorter generation interval (since there are more replacements available), and (d) a shorter reproductive period (since with IVF techniques it is possible to initiate breeding procedures in females approximately 1 month old, significant reductions in the generation interval can be achieved[4]). Each or all of these methods could contribute to faster rates of genetic change.

To investigate the advantages of the MOET and IVF techniques, computer simulations were conducted to predict the value of genetic improvement. Due to the success of the progeny test schemes and the prospect of their continuation in Japan, schemes were simulated in which MOET and IVF were incorporated, rather than replacing progeny testing. In other words, MOET and IVF were used to create large full-sib families that were introduced into regular progeny test programs.

Proposed improvement scheme is outlined in Fig. 3. Five different approaches are used to carry out that scheme, each with different sets of procedures

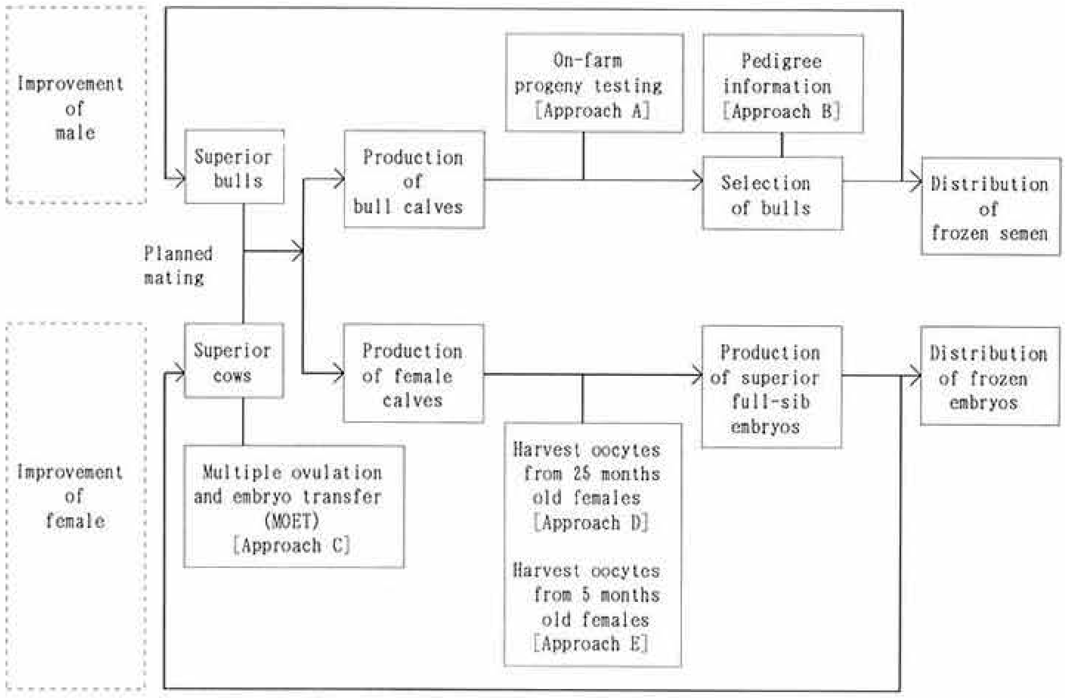

Fig. 3. Schematic diagram of progeny test programs, incorporating MOET and IVF

and varying levels of efficacy. Improvement can be achieved through either the male or the female. Two of these approaches are applicable to male improvement and 3 to female improvement. These can be summarized as follows: Approach A is the regular progeny test, approach B is an improved progeny test (which uses pedigree information covering 3 generations). Approach C is a MOET scheme which uses standard genetic parameters. Approach D, where oocytes are harvested from 25 months old females and approach E, where oocytes are harvested from 5 months old females are MOET-IVF schemes, that include the use of IVF for genetically elite females to improve stock. Pregnancy rates of 50% were assumed.

Table 4 shows the annual genetic improvement expected from the 5 approaches. By simply improving the current progeny testing programs, as in approach B, expected gains substantially increased. By incorporating MOET procedures into progeny testing (approach C), annual genetic improvement was expected to be 5.8 to 7.1% higher than that obtained from the current progeny test (approach A). The most significant increase in genetic improvement (up to 20.1% higher than that obtained through approach A) is predicted for approach E, when IVF is used in addition to MOET procedures. Approach D gives values slightly lower than those by approach E.

Table 4. Annual genetic improvement of carcass grade and genetic improvement relative to standard progeny testing method (A)

Method	Annual genetic improvement of carcass grade rG[b]			Relative to standard progeny testing method (A) rG[b]		
	−0.2	0.0	0.2	−0.2	0.0	0.2
A	0.101[a]	0.112	0.121	1.000	1.000	1.000
B	0.105	0.119	0.127	1.049	1.063	1.050
C	0.107	0.120	0.128	1.059	1.071	1.058
D	0.112	0.124	0.141	1.109	1.110	1.166
E	0.120	0.132	0.145	1.188	1.180	1.201

a): Genetic standard deviation units.
b): Genetic correlation between growth rate and carcass grade.

On the basis of this study, significant increases in the rate of genetic improvement could be achieved by combining the MOET and IVF techniques in progeny testing programs. Indeed, results from selection experiments and from industry confirm that these rates can be achieved in practice. However, one disadvantage of these techniques is the coincidental increase in inbreeding[9].

2) Application of molecular genetics to genome analysis

Traditional cattle breeding methods depend on the phenotypic assessment of performance, i.e. of average daily gain, marbling score, rib-eye area, etc. Obviously, such complex phenotypes are the product of both genetic and environmental factors, the relative importance of each is difficult to ascertain. Contemporary breeding methods using genome analysis are quite different. All of the genetic information in the cattle genome is contained in about 3 billion (3×10^9) base pairs of DNA which are packed into 30 chromosomes. It is impossible to clearly identify the entire DNA sequence in the bovine genome with the technology currently available. Rather than attempting to identify the precise gene responsible for any particular trait, we use marker genes which identify the segment in which these genes are located.

Recently, an integrated linkage map totaling several hundred microsatellites (MS) and restriction fragment length polymorphism (RFLP) type markers has been developed for each chromosome of the bovine genome[1,2]. On the genetic map, marker genes, such as MS and RFLP, are used as 'Landmarks' that enable us to follow the inheritance of fragments of chromosomes. By using the markers the segments of DNA inherited from each parent can be identified. These can be linked to the measured phenotypic differences among offspring that show these important traits. Once these segments are identified using MS and/or RFLP type markers, the marker can be used to trace the linked alleles in the marker-assisted-selection (MAS) of animals. Combining MAS technology with advanced reproductive technologies such as prepubertal oocyte, IVF, etc., should lead to shortened generation intervals, increased selection intensity and more rapid genetic progress in beef cattle breeding programs[10,11].

Conclusion

There are 4 cattle beef breeds in Japan: Japanese Black, Japanese Brown, Japanese Poll and Japanese Shorthorn. These breeds are considered to be indigenous to Japan, but were crossed with European breeds in the Meiji era. As a result of the introduction of European genetic background, Japanese beef cattle have acquired an expanded and more diverse gene pool. Furthermore, both the breed used for crossing and the selection criteria employed varied significantly from prefecture to prefecture. Consequently, a number of distinct strains have been established. At present, however, the gene pool is becoming increasingly centered around a limited number of strains noted for their superior meat quality. From the genetic conservation view point, it is necessary to stock minor strains by frozen semen and embryos for future requirements of genetic resources.

Very considerable genetic improvement of Japanese beef cattle has been achieved by using traditional on-station testing schemes. To make full use of Japanese beef cattle traits, however, it is more appropriate to carry out on-farm progeny testing programs, based on the individual animal model. The introduction of multiple ovulation and embryo transfer (MOET) could lead to dramatic changes in conventional beef cattle improvement schemes, rather than replacing conventional breeding schemes. In the near future, biotechnology will enable to obtain easier and more accurate assessments through the determination of the specific DNA segment responsible for the desired phenotypic trait, which may exert a significant impact on cattle improvement. Until now, the use of molecular genetics had been mostly confined to the laboratory research stage and only a few techniques had involved practical application for cattle breeding. Further basic studies are required to make it more readily available and practical for everyday use in the field.

In conclusion, a new era in beef cattle breeding has begun. For beef cattle improvement, therefore it is necessary that a combination of new breeding techniques and conventional breeding procedures be simultaneously pursued.

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