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Estimation of Genetic Parameters, and Genetic and Environmental Effects on Progeny Carcass Traits of a Nucleus Breeding Population in Japanese Black Cattle

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Summary

Genetic parameters of body weight at the start of fattening (BSF), carcass weight (CWT), subcutaneous fat thickness (SFT), rib thickness (RBT), meat quality grade (MQG), beef marbling score (BMS) and rib eye area (REA) in Japanese Black cattle were estimated. The effects of genetic and environmental factors on fattening performance and carcass quality traits of the progeny were also analyzed. The averages of BSF, CWT, SFT, RBT and REA were 189 kg, 408 kg, 24.9 mm, 69.3 mm and 47.5 cm^2, respectively. CWT was significantly affected ($p<0.01$) by sire, while BSF ($p<0.01$), CWT ($p<0.01$), SFT ($p<0.01$), RBT ($p<0.01$) and REA ($p<0.05$) were significantly affected by dam, indicating the scope of the applicability of selective breeding for improving the dam population for producing beef cattle with greater genetic ability to carcass traits. The sex of the calf had a significant ($p<0.01$ or $p<0.05$) effect on all the traits studied except REA. BSF, RBT, MQG and BMS were significantly ($p<0.01$) affected by the year and season of the birth of calves. The fattening farm exerted a significant influence ($p<0.01$) on BSF, CWT, MQG and BMS. The heritability estimates for BMS, CWT, RBT, BSF and MQG were 0.36, 0.34, 0.31, 0.26 and 0.23, respectively. Genetically, REA correlated negatively with BSF (-0.57) and SFT (-0.69), as did BMS with CWT (-0.35), SFT (-0.50) and RBT (-0.44). All the other traits correlated positively with one another.

Estimates of genetic parameters are requisite for implementing sound breeding programs and for accelerating the progress of ongoing programs. Selection for growth rate has received considerable attention in most beef improvement projects. Japanese Black cattle, the dominant beef breed in Japan, are distributed all over the country. A testing program has been established since 1968 in each prefecture. The testing program was adopted not only for the performance test, but also for progeny test.

The cow population of the National Livestock Breeding Station, Tottori is one of the nucleus breeding populations, where selection of young bulls has been conducted based on a performance-testing program. The population bears of not only sire selection but also improvement of cow populations. Thus genetic improvement of the female population is vitally important for nucleus breeding populations. Genetic parameters have been estimated (Yang *et al.*, 1985 ; Oikawa *et al.*, 2000) to help the institution for the improvement of the testing program. However, only few estimates are available for the improvement of a nucleus population of cows.

Carcass traits of cattle have been the subject of numerous studies, and most of the traits have been of high or moderate heritability (Robinson *et al.*, 1990 ; Lamb *et al.*, 1990 ; Arnold *et al.*, 1991 ; Gregory *et al.*, 1994). Generally however, the results cannot be easily applied to the Japanese Black population, because most of the studies have involved European beef breeds, which are only of marginal importance in Japan. The aim of this study was to estimate the genetic parameters and genetic and environmental effects on carcass traits of progeny from a nucleus breeding population and to provide genetic information for the improvement of the program for Japanese Black population.

Materials and Methods

Animals and Management

In Japan, beef production systems are generally divided into two operations, a cow-calf operation and feedlot (fattening farm) operation in National Livestock Breeding Stations. Cow-calf operations generally involve only a few cows. Calves are sold at calf-markets and purchased by feedlot farmers. The size of feedlot operations ranged from small (fewer than five animals) to large (more than 1,000 animals). A two-stage selection employing performance testing combined with progeny testing has been established. Data on 7 carcass traits of 610 progeny (448 steers and 162 heifers) of Japanese Black cattle were collected from the National Livestock Breeding Station of Tottori prefecture during the period from 1986 to 1998. Pedigrees of the recorded animals were traced back to three generations and, including the tested animals, totaled 4,897. The calves were transferred to fattening farms at the average age of 211 days (117-366 days). The animals were given *ad libitum* intake to concentrate mixed with 10% chopped rice straw by weight. The Concentrate consisted of 20 parts ground barley, 35 parts ground yellow corn, 20 parts wheat bran, 17 parts defatted rice bran, 6 parts soybean meal, 1 part NaCl and 1 part calcium carbonate with total digestible nutrients (TDN) of 73% and digestible crude protein (DCP) of 10%. After

Table 1. Data Structure

Item	Number
Sire	90
Dam	528
Birth year	13
Birth season	4
Fattening farm	5

fattening, the progeny were slaughtered at the average age of 859 days (678–1,022 days). The effect of season was based on spring (March-May), summer (June-August), autumn (September-November) and winter (December-February) and the fattening farm was based in 4 prefectures and the Tottori station. The data structures are presented in Table 1.

Traits in Study

The traits studied were body weight at the start of fattening (BSF), carcass weight (CWT), subcutaneous fat thickness (SFT), rib thickness (RBT), meat quality grade (MQG), beef marbling score (BMS) and rib eye area (REA). The CWT was obtained by weighing the slaughtered steers after the removal of the lungs, heart, liver, intestines and ancillary organs or mesenteries, bladder, reproductive organs and blood. MQG was ranked on a scale of 1 to 5 and obtained by aggregating the scores based on marbling, color, gloss and quality of fat, and color, gloss, texture and firmness of meat by visual assessment according to the JMGA (1988). REA, SFT and BMS were measured from the section between the 6^{th} and 7^{th} ribs.

Statistical Analysis

Collected data were analyzed by the mixed model equation of MIXED procedure of the SAS statistical package (SAS, 1991). In the model, all effects were considered fixed ones except for error. The statistical model used for the analysis of carcass traits was as follows:

$$Y_{ijklmno}=\mu+S_i+D_j+(S\times D)_{ij}+X_k+N_l+Y_m+F_n+b_1(A_{ijklmno}-\bar{A}) + b_2(A_{ijklmno}-\bar{A})^2+e_{ijklmno}$$

where $Y_{ijklmno}$ = observation for the traits; μ = population mean; S_i = effect of i*th* sire; D_j = effect of j*th* dam; $(S\times D)_{ij}$ = interaction effect between i*th* sire and j*th* dam; X_k = effect of k*th* sex; N_l = effect of l*th* birth season; Y_m = effect of m*th* birth year; F_n = effect of n*th* fattening farm; b_1 = linear regression coefficient of the observation on age; b_2 = quadratic regression coefficient of the observation on age; $A_{ijklmno}$ = age of the animal at slaughter; $\bar{A}$ = average age of the animal at slaughter ; $e_{ijklmno}$ = random residual.

(Co) variance components, heritability and correlations were estimated by REML with the VCE (ver. 4.2.5) program according to Neumaier and Groeneveld (1998). The genetic parameters were estimated by the following model :

$$Y_{ijk}=a_i+F_j+YNX_k+b_1(A_{ijk}-\bar{A})+b_2(A_{ijk}-\bar{A})^2+e_{ijk}$$

where Y_{ijk} = phenotypes of the animal ; a_i = random additive genetic effect of i*th* animal ; F_j = fixed effect of j*th* fattening farm ; YNX_k = fixed effect of k*th* year-season-sex ; b_1 = linear regression coefficient of the observation on age ; b_2 = quadratic regression coefficient of the observation on age ; A_{ijk} = age of the animal at slaughter ; $\bar{A}$ = average age of the animal at slaughter ; e_{ijk} = random residual.

The genetic parameters were estimated by two-trait model and the estimated genetic variances, heritabilities and their standard errors (SE) were the medians of the estimates.

Results and Discussion

Carcass Traits

The means with their standard deviations and coefficient of variations of carcass traits are presented in Table 2. The mean values for all the traits were consistent with other reports (Fukuhara *et al*., 1989 ; Oikawa *et al*., 2000 ; Uchida *et al*., 2001 ; Hoque *et al*., 2004) in the same breed. The present CWT was within the range of progeny data of two subdivided populations (slaughtered at the age of 879.3 and 966.9 days, respectively) reported by Sasaki (2001), who showed the mean carcass weight for 375.0 and 433.9 kg, respectively for Japanese Black cattle. The mean values for SFT and RBT were also close to those in the same breed by Oyama *et al*. (1995) who reported SFT and RBT to be 31.0 mm and 73.0 mm, respectively.

In the present study, the BMS was higher than that (2.49) reported by Oikawa *et al*. (2000) but lower than those (6.15 and 6.88 for two subdivided populations, respectively) reported by Sasaki (2001) for the same breed. These

Table 2. Means with Standard Deviations (SD) and Coefficient of Variations (CV) of Carcass Traits†

Statistic	BSF (kg)	CWT (kg)	SFT (mm)	RBT (mm)	MQG	BMS (No.)	REA (cm^2)
Means	189	408	24.9	69.3	3.3	4.7	47.5
SD	45.9	58.4	7.6	9.1	0.8	1.9	7.2
CV (%)	24.3	14.3	30.5	13.1	24.2	40.4	15.2

†BSF, body weight at the start of fattening ; CWT, carcass weight ; SFT, subcutaneous fat thickness ; RBT, rib thickness ; MQG, meat quality grade ; BMS, beef marbling score ; REA, rib eye area.

differences might be reflected due to the differences in slaughter age and fattening environment. A larger REA is associated with a higher production of lean in the carcass (Baik *et al.*, 2002). The REA of the present study is in close agreement with those reported by Oyama *et al.* (1995), Oikawa *et al.* (2000) and Bugiwati *et al.* (2000). Oyama *et al.* (1995) and Oikawa *et al.* (2000) showed that REA of Japanese Black cattle to be 48.4 and 46.7 cm^2, respectively while Bugiwati *et al.* (2000) reported that REA of Japanese Brown cattle to be 48.7 cm^2. The slight differences might be appeared due to different slaughter age of the animals. The coefficient of variation of BMS was the largest (40.4%) compared with the other traits.

Effect of Genetic Factors on Carcass Traits

The effects of sire, dam and sex of calves on carcass traits are presented in Table 3. The effect of sire was significant only on CWT. These results are partially in agreement with those of Baik *et al.* (2003), where CWT significantly affected by the sire effect, but back fat thickness was not. An analysis of carcass data of Japanese Brown cattle, using a fixed sire effect, has shown that SFT, RBT and BMS are significantly affected by the sire effect (Bugiwaki *et al.*, 2000).

The genetic improvement of the female population is vitally important for nucleus breeding population. In the present study, BSF, CWT, SFT, RBT and REA were significantly affected by the dam. Comparable results about the effect of the dam on carcass traits of Japanese Black cattle have not been found in the literature. These genetic differences among dam could be utilized in selective breeding for improving the dam population to produce beef cattle with greater genetic ability to carcass quality and quantity.

All the traits studied, except REA were significantly affected by the sex of calves. A similar conclusion for Japanese Brown cattle has been drawn by Bugiwati *et al.* (2000), noting that SFT, RBT and BMS are significantly ($p<0.001$) affected by the sex of calves. They also indicated that body weight and proportion of fat intramuscular of steers were heavier and higher than those for

Table 3. Mean Squares of the Effects of Sire, Dam and Sex of Calves on Carcass Traits†

Effects	BSF	CWT	SFT	RBT	MQG	BMS	REA
Sire	1,045.6	5,734**	66.04	95.7	0.818	5.114	42.60
Dam	1,552.9**	7,330**	54.56**	222.16**	0.859	2.216	73.92*
Sex of calves	55,264**	289,284**	1,105**	781.73**	6.597**	30.41*	88.47

** $p<0.01$; * $p<0.05$; †BSF, body weight at the start of fattening ; CWT, carcass weight ; SFT, subcutaneous fat thickness ; RBT, rib thickness ; MQG, meat quality grade ; BMS, beef marbling score ; REA, rib eye area.

heifers while heifers were thicker of fat subcutaneous. Steers produce significantly heavier carcasses and lower marbling scores than heifers do, heifers are more prone to store fat with aging, differences in carcass quality between the sexes increase with aging (Parkkonen *et al.*, 2000).

Effect of Environmental Factors on Carcass Traits

The effects of birth year and season of calves and fattening farm on carcass traits are presented in Table 4. Birth year and birth season had a significant effect on BSF, RBT, MQG and BMS, however, environmental factors did not have significant effect on SFT. Bugiwati *et al.* (2000) showed that cattle were fattened from winter tended to have the biggest REA (49.1 cm^2), and thickest RBT (70.3 mm) and SFT (26.6 mm), and the highest BMS (0.89) then those were fattened from other seasons.

In the present study, BSF, CWT, MQG and BMS were significantly affected by the fattening farm. Similar results were obtained by Baik *et al.* (2003) suggest that the fattening farm has a significant effect on live weight at slaughter and on quality of meat. Hence, management seems to play an important role in the production of heavier live-weight as well as in better meat quality. The linear regression of BSF on age was significant, whereas most of the traits were quadratically related to the age of the calves because they were recorded at a later stage of their growth.

Genetic Parameters

Heritabilities and correlations (r_g and r_p) of different carcass traits are presented in Table 5. Estimated heritabilities for CWT, RBT and BMS were moderate, indicating that in Japanese Black cattle at the Tottori Station a fairly large genetic variability still remains, which can be used for the improvement of carcass quality and quantity. Estimated heritability for CWT corresponds with the estimates by Mukai (1994) and Mukai *et al.* (1995) for the same breed, by Hirooka *et al.* (1996) for Japanese Brown steers, by Wilson *et al.* (1993) for Angus steers and heifers and by Baik *et al.* (2002) for Korean Native cattle. However, the present estimate is considerably higher than the estimates of 0.14 from Japanese Black steers by Fukuhara *et al.* (1989) and 0.17 from Japanese Brown steers by Sasaki (1991). The heritability of RBT was slightly higher than those estimated (0.23) by Fukuhara *et al.* (1989) in the same breed and (0.22) by Bugiwati *et al.* (2000) in Japanese Brown steers. Estimated heritability for BMS was slightly lower than the estimates of 0.46 by Mukai (1994) and of 0.52 by Mukai *et al.* (1995) for Japanese Black steers but close to an average estimate (0.35) from a literature summary by Marshall (1994), and 0.40 by Hirooka *et al.* (1996) for Japanese Brown steers.

Estimated heritability for SFT was considerably lower than the estimates of

Table 4. Mean Squares of the Effects of Sex, Birth Year and Season of Calves on Carcass Traits†

Effects	BSF	CWT	SFT	RBT	MQG	BMS	REA
Birth Year	2,405**	3,570**	61.11	134.11**	1.526**	5.762**	58.75**
Birth Season	27,527**	3,592	93.50	209.22**	3.933**	20.61**	102.74
Fattening farm	57,546**	8,151**	4.168	25.79	2.908**	22.51**	15.88
Linear reg. (Age)	1,104*	38,068*	16.69	448.06	11.627	52.14	127.20
Quadratic reg. (Age)	3,185	31,916**	192.69	740.35**	4.659**	12.79**	325.26**

**$p<0.01$; *$p<0.05$; †BSF, body weight at start of fattening ; CWT, carcass weight ; SFT, subcutaneous fat thickness ; RBT, rib thickness ; MQG, meat quality grade ; BMS, beef marbling score ; REA, rib eye area.

Table 5. Heritabilities (h^2), Genetic and Phenotypic Correlations among Carcass Traits

Traits†	BSF	CWT	SFT	RBT	MQG	BMS	REA
$h^2 \pm$SE	0.26±0.08	0.34±0.08	0.08±0.05	0.31±0.08	0.23±0.07	0.36±0.08	0.20±0.07
Correlations‡							
BSF		0.46±0.17	1.00±0.01	0.28±0.20	0.36±0.19	0.20±0.19	−0.57±0.37
CWT	0.42		0.78±0.28	0.88±0.07	−0.04±0.21	−0.35±0.18	0.14±0.23
SFT	0.14	0.35		1.00±0.00	0.02±0.38	−0.50±0.33	−0.69±0.49
RBT	0.20	0.65	0.27		−0.16±0.25	−0.44±0.21	0.35±0.20
MQG	−0.02	0.21	0.05	0.36		1.00±0.00	0.17±0.24
BMS	−0.02	0.19	0.04	0.33	0.80		0.08±0.21
REA	0.12	0.43	0.04	0.44	0.45	0.47	

†BSF, body weight at the start of fattening ; CWT, carcass weight ; SFT, subcutaneous fat thickness ; RBT, rib thickness ; MQG, meat quality grade ; BMS, beef marbling score ; REA, rib eye area.
‡genetic (±SE) and phenotypic correlations are above and below the diagonal, respectively

0.55 by Mukai *et al.* (1995), of 0.33 by Bugiwati *et al.* (2000) and of 0.21 by Uchida *et al.* (2001) for the same breed and the reviewed averages (0.44) by Koots *et al.* (1994). The differences of heritability may depend on source of data and method of estimation. However, Fukuhara *et al.* (1989) reported that the heritability of SFT to be 0.13 for Japanese Black steers supporting our result. The low heritability for REA in the present study was close to the estimates (0.28 and 0.29, respectively) reported by Fukuhara *et al.* (1989) and Oikawa *et al.* (1994) in the same breed. Estimated low heritability for BSF in the present study was close to those reported in the same breed (0.31) by Oikawa *et al.* (2000) and (0.35) by Hoque *et al.* (2004). In Hereford and some other beef breeds, heritability of carcass traits have been moderate (Lamb *et al.*, 1990 ; Arnold *et al.*, 1991 ; Gregory *et al.*, 1994 ; Wheeler *et al.*, 1996). Our estimates were, thus, within the range of those estimates.

The genetic correlations showed that the BSF and SFT correlated negatively with REA, as did BMS with CWT, SFT and RBT. Yang *et al.* (1985) and Hirooka *et al.* (1996) reported negative correlations between BMS and SFT in Japanese Black cattle (−0.10 and −0.12, respectively), and Wilson *et al.* (1993) have reported a similar estimate in Angus field data (−0.13). The genetic correlations among most of the traits were positive. The negative genetic correlation between BMS and SFT is considered a positive indication for further improvement of BMS, which can be achieved without increasing subcutaneous fat. The genetic correlations of BSF with CWT (0.46), RBT (0.28) and MQG (0.36) are favorable for the breeding goal of high levels of carcass traits. The genetic correlations of RBT with BSF (0.28) and of REA with CWT (0.14) and MQS (0.17) were low. Fukuhara *et al.* (1989) and Hirooka *et al.* (1996) reported similar estimates (0.15 and 0.24) in Japanese Black and Japanese Brown steers, respectively.

The phenotypic correlations were lower than the genetic ones. Positive and high phenotypic correlations were found between RBT and CWT (0.65) and also between BMS and MQG (0.80). These results can be implemented into a genetic evaluation system to select superior breeding sires for producing better meat potential for the future generation.

Conclusions

Significant variations between progeny performance of individual dams in most of the carcass traits suggest the scope of the applicability of selective breeding for improving the dam population to produce beef cattle with greater genetic ability to carcass quality and quantity. The variations in meat quantity and beef marbling are moderately controlled by genetic effects and their genetic relation might be slightly negative. Thus genetic improvement of both these characteristics could be developed simultaneously in the nucleus population of Japanese Black cattle although the genetic progress may be slightly slow. Factors determining subcutaneous fat thickness need to be identified for further investigation.

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