Genetic Relationships Among Traits Recorded at Registry Judgment, Reproductive Traits of Breeding Females and Carcass Traits of Fattening Animals in Japanese Black Cattle

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Abstract Genetic relationships among traits recorded on breeding females and carcass traits of fattening animals in Japanese Black cattle were estimated using REML procedure under multiple-trait animal models. Traits analyzed were five exterior judging traits, three body measurements at registry judgment, two reproductive traits (age at first calving, AFC ; average calving interval, ACI) of breeding females and five carcass traits collected in Hiroshima prefecture. Heritabilities of exterior judging traits, body measurements and carcass traits were estimated at moderate to high, while those of reproductive traits were very low. Genetic correlations among exterior judging traits and body measurements were high when the ratio of body weight to withers height was not included in analytical model. Generally exterior judging traits, body measurements and carcass traits correlated favorably with AFC. However carcass beef marbling score correlated unfavorably with ACI. Because selection on carcass traits will be more intense, considerations will be necessary on ACI.

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Key words : Genetic parameter, Reproductive trait, Carcass trait, Registry judgment, Japanese Black cattle

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Carcass characteristics, especially meat qualities are the main breeding objectives in Japanese Black cattle. Evaluation and selection systems using best linear unbiased predictor[6)] (BLUP) are getting arranged in many prefectures and regions. On the other hand, a reproductive performance is of primary importance not only for Japanese Black cattle but all the economic animals. Also in Japanese Black cattle this importance has been realized and extensive studies have been undertaken[7,15,16,20)]. However no report was found on genetic relationships among carcass traits and reproductive traits of breeding females. As the selection of females on carcass traits using BLUP is becoming more common and intense, influences on reproductive traits should be considered more carefully. Because the improvement or depression in reproductive traits directly affects production efficiency of the beef

[1)] To whom correspondence should be addressed cattle herd.

Therefore the objective of this study was to investigate genetic relationships among traits recorded on breeding females including reproductive traits and carcass traits of fattening animals in Japanese Black cattle.

Materials and Methods

Data. For analyses of field carcass traits the records of 4,383 finished animals were used. These animals were fed on farms in Hiroshima prefecture and marketed during 1988 to 1994. Traits analyzed were carcass weight (CW), *longissimus* muscle area (LMA), rib thickness (RT), subcutaneous fat thickness (SFT) and beef marbling score (BMS) according to the Japanese meat grading system (*e.g.*, Mukai *et al.*[14]).

For analyses of traits recorded on breeding females 4,955 dams, which appeared in pedigree data of finished animals were used. These females were born during 1970 to 1990 and judged for nine sections, *i.e.*, body capacity & conformation (CC), quality & refinement (QR), head & neck, forequarters, body (BD), hindquarters ramp & hips, hindquarters thighs (TH), mammary system & external genitalia and legs, feet & walking according to Japanese Black Cattle Judging Standard. These traits were indicated as the percentages of discontent. Therefore smaller was more superior in its section. The QR included qualities of facial expression, skin, hair, bone, clear cut and so on. Each section had its own allotted score and section score was calculated as follows :

$$\text{section score} = (\text{allotted score}) \times \left(1 - \frac{\text{percentage of discontent}}{100}\right).$$

In this study CC, QR, BD, TH and judging score (JS) were analyzed and these traits were called collectively as exterior judging traits. The JS was the sum of the scores of nine sections. In addition as body measurements, chest girth (CG), chest depth (CD) and thurl width (TW) at registry judgment and as reproductive traits, age at the first calving (AFC) and average calving interval (ACI) were also analyzed. The ACI was defined as an average of the first two calving intervals of each female. Those females, which fell below approximately 20 months in AFC or 300 days in ACI, or exceeded the average plus 12 months in AFC or the average plus 3 SD in ACI were eliminated.

Analytical procedure. In analytical models of carcass traits, sex of finished cattle (two levels), place of fattening (four levels) and year of slaughter (seven levels) were included as fixed effects, and age at beginning of fattening and period of fattening were considered as linear and quadratic covariates. Genetic (11,162 levels) and residual effects were also included as random effects in the models.

Analytical models of female traits slightly differed as shown in Table 1. Year and place of judgments included in the models for reproductive traits were for adjustments of birth year and birth place of females, respectively. Because the effect of calf sex on gestation length was reported by MacNeil and Newman[9], sex of the first calf and number of male calves were considered as fixed effects in models for AFC and ACI, respectively. Genetic (5,409 levels) and residual effects were also included as random effects in the models. The model, which included the ratio of body weight to withers height (BW/WH) as covariates was also prepared to adjust body condition of breeding females. The model without and with BW/WH were called Model 1 and Model 2, respectively.

Variance and covariance components were estimated by restricted maximum likelihood[17] (REML) with expectation maximization[3] (EM) algorithm under multiple-trait animal models. In carcass traits all the finished animals had all five traits (no missing records) and the same models with only one random factor besides residual factor were applied for all traits. Therefore the application of canonical transformation[21] was possible to make a multi-

Table 1. Fixed effects and covariates considered in analytical models of traits recorded on breeding females (Model 1/Model 2)

Effect	Exterior judging trait and body measurement	AFC	ACI
Fixed effect (number of levels)			
Year of judgment (18)	Yes/Yes	Yes/Yes	Yes/Yes
Place of judgment (17)	Yes/Yes	Yes/Yes	Yes/Yes
Season of judgment (4)	Yes/Yes		
Sex of first calf (2)		Yes/Yes	
Season of first calving (4)		Yes/Yes	Yes/Yes
Number of male calves (4)			Yes/Yes
Covariate (L : linear, Q : quadratic)			
Age at judgment (L & Q)	Yes/Yes		
Body weight/withers height (L & Q)	No /Yes	No /Yes	No /Yes
Inbreeding coefficient (L)	Yes/Yes	Yes/Yes	Yes/Yes

AFC : age at first calving, ACI : average calving interval.
Year and place of judgments in AFC and ACI were for adjustments of birth year and place of each female, respectively.

ple five traits analysis to five single trait analyses. However as different models were applied for female traits, observations were pre-adjusted for the fixed effects and covariates except for common effects (*i.e.*, year of judgment, place of judgment and inbreeding coefficient in case of Model 1) by best linear unbiased estimators (BLUE) obtained from the same animal models, and then canonical transformation was applied.

Genetic covariances between carcass and female traits were estimated from the pair-wise analysis of two traits at a time. Residual covariances were assumed not to exist. Genetic base year was set at 1970 for both carcass and female traits.

For female traits linear regression coefficients of average of phenotypes and of predicted breeding values within birth year on birth year were calculated to examine the chronological changes.

Results and Discussion

Phenotypic averages of reproductive traits (Table 2) were 26.4 and 13.3 months in AFC and ACI, respectively. Although in Japan 'one calf per year' is recommended to attain an efficient management, a large difference was observed between ideal and actual averages. The average of ACI was similar to that reported by Okano *et al.*[16]. However as our average covered 21 years, regression coefficients of phenotypes on birth year were calculated. Except for ACI all female traits were highly significant ($P<0.01$) in desirable directions. Therefore only ACI has not changed in neither desirable nor undesirable direction for these two decades.

Heritability. Heritability estimates of exterior judging traits and body measurements using Model 1 ranged from 0.38 to 0.50 and from 0.31 to 0.44, respectively as shown in Table 2. An estimate of TW was comparable with the estimate of Mukai *et al.*[13] using Japanese Black cattle from Kagoshima prefecture, however estimates of CG and CD were higher in this study. Although no literature was available on heritabilities of exterior judging traits, estimates were close to those of body measurements. This might indicate exterior judging traits had the characteristics of 'visual body measurements' and it seemed certain objectivi-

Table 2. Basic statistics and heritabilities of traits recorded on breeding females

Trait	Mean	SD	Heritability	
			Model 1	Model 2
Age at judgment, mo	23.4	2.23		
Body weight/withers height, kg/cm	3.7	0.27		
Inbreeding coefficient, %	1.1	3.24		
CC*, %	20.5	2.25	0.48	0.32
QR*, %	20.0	1.77	0.44	0.35
BD*, %	17.6	2.70	0.44	0.29
TH*, %	22.3	1.36	0.38	0.27
JS, point	79.7	1.71	0.50	0.36
CG, cm	184.3	6.26	0.44	0.30
CD, cm	65.6	1.87	0.42	0.32
TW, cm	45.8	1.58	0.31	0.12
AFC, mo	26.4	3.22	0.04	0.04
ACI, mo	13.3	2.28	0.05	0.05

n=4,955.
CC : body capacity & conformation, QR : quality & refinement, BD : body, TH : thighs, JS : judging score, CG : chest girth, CD : chest depth, TW : thurl width, AFC : age at first calving, ACI : average calving interval.
* Trait indicated as the percentage of discontent.

ty was held in judgment through the standard.

Heritability estimates for reproductive traits were very low in either Model 1 or 2. Estimates for AFC were similar to estimates of 0.07 by Bourdon and Brinks[2]. Because natural mating is not common in Japan, an optimum age for the first service depends on breeder's decision. This may be one reason for low estimates in AFC. Calving interval is the sum of the days to conception after calving and gestation length. However it is a very complicated characteristic, because these days are also influenced by many factors such as size of calf, conception rate, nutritional management or efforts to detect estrus by breeders. As moderate heritabilities were reported by Oishi *et al.*[15] and Azzam and Nielsen[1] in gestation length, calving interval was affected mainly by days to conception. Generally reproductive traits indicate low heritabilities because of natural selection over a long period of time. In addition Meyer *et al.*[12] reported that reproductive potential in temperate zones has less genetic determinants than in tropical environments, and there is no breeding female with severe reproductive problems, which leads to naturally selective reporting[10] of reproductive records. These also might be the reasons for low heritabilities in reproductive traits.

When Model 2 was used, heritabilities of exterior judging traits and body measurements decreased (Table 2). In those traits both genetic and residual variances were explained by BW/WH in some degree (results not presented), however percentages of reduction were smaller in residual variances than in genetic variances. Randel[19] reviewed that energy status, *i.e.*, nutritional management, affected reproductive traits. Maintaining a female in adequate energy status is important, however its effect may have to be removed in estimation of variance components. Although BW/WH was used to adjust body condition, its effect on reproductive traits was small. However for exterior judging traits and body measurements, including BW/WH as the covariates in the model might have adjusted not only nutritional conditions, but body shapes of breeding females. For example a cattle with average withers height and shorter legs may have larger value of BW/WH. The exterior judging traits or body measurements were adjusted to the measurements when this cattle had an average body shape (*i. e.*, average leg length). The heritabilities of TH and TW were lower using either Model 1 or 2. This might indicate hindquarters were relatively uniform in breeding females of Hiroshima prefecture.

Heritability estimates of carcass traits ranged from 0.38 to 0.54 as shown in Table 3. Our estimates were generally a little higher than those reviewed by Koots *et al.*[8] and Marshall[11] and comparable with the estimates by Mukai *et al.*[14] using Japanese Black cattle.

Genetic correlation. Genetic correlations among exterior judging traits (Table 4) were very high using either Model 1 or 2. When

Table 3. Basic statistics, heritabilities (diagonals), genetic (upper diagonals) and environmental (lower diagonals) correlations of carcass traits

Trait	Mean	SD	Heritability and correlation				
			CW	LMA	RT	SFT	BMS
Age at beginning of fattening, mo	9.0	0.83					
Period of fattening, mo	20.8	2.04					
CW, kg	410.1	44.10	0.44	0.55	0.62	0.42	0.14
LMA, cm^2	47.8	6.21	0.43	0.54	0.42	0.02	0.17
RT, cm	6.5	0.74	0.62	0.34	0.38	0.45	0.40
SFT, cm	2.7	0.87	0.36	0.06	0.23	0.50	−0.03
BMS	1.35	0.659	0.08	0.17	0.06	0.07	0.50

n=4,383.
CW : carcass weight, LMA : *longissimus* muscle area, RT : rib thickness, SFT : subcutaneous fat thickness, BMS : beef marbling score (0 to 5).

Table 4. Genetic correlations among traits recorded on breeding females using Model 1 (upper diagonals) and Model 2 (lower diagonals)

Trait	CC*	QR*	BD*	TH*	JS	CG	CD	TW	AFC	ACI
CC*		0.87	0.99	0.95	−0.99	−0.80	−0.73	−0.68	0.45	−0.02
QR*	0.80		0.89	0.82	−0.91	−0.64	−0.55	−0.42	0.40	0.05
BD*	0.99	0.84		0.94	−0.99	−0.80	−0.72	−0.70	0.43	−0.05
TH*	0.90	0.69	0.87		−0.96	−0.72	−0.59	−0.67	0.43	0.13
JS	−0.99	−0.88	−0.99	−0.90		0.79	0.70	0.66	−0.45	−0.01
CG	−0.40	−0.29	−0.38	−0.28	0.36		0.88	0.74	−0.37	−0.18
CD	−0.38	−0.20	−0.35	−0.12	0.32	0.72		0.63	−0.42	−0.02
TW	0.00	0.28	0.00	−0.06	−0.08	−0.08	−0.08		−0.46	−0.15
AFC	0.28	0.24	0.22	0.23	−0.27	−0.08	−0.20	−0.21		0.17
ACI	−0.29	−0.09	−0.33	0.00	0.21	0.07	0.23	0.05	0.05	

CC : body capacity & conformation, QR : quality & refinement, BD : body, TH : thighs, JS : judging score, CG : chest girth, CD : chest depth, TW : thurl width, AFC : age at first calving, ACI : average calving interval.
* Trait indicated as the percentage of discontent.

Model 1 was used, high relationships were also found between exterior judging traits and body measurements, indicating a larger female in any of the body measurements tended to have finer exterior. However these relationships were reduced to certain degrees or disappeared when Model 2 was used. Favorable genetic correlations between AFC and exterior judging traits or body measurements were consistently observed using either Model 1 or 2. Because the heritability of AFC was very low, more genetic improvement on AFC might be expected through these genetic correlations. These correlations indicated a female with better exterior and (or) larger size calved earlier. This was because as age at judgment was included in the models, superior females in body developments at a constant age reached sexual maturities earlier. Regression coefficients of predicted breeding values on birth year were highly significant ($P<0.01$) in all female traits except for CD, TW and ACI in desirable directions using Model 1. It seemed the significance in AFC was caused not only by selection on AFC itself, but rather by correlated response through improvements of growth ability, such as exterior judging traits and (or) body measurements. Genetic correlations between ACI and other female traits were generally low.

High genetic relationships were obtained among CW, LMA and RT (Table 3). The RT indicated an undesirable moderate relationship with SFT, but a desirable relationship with BMS. No genetic relationship was observed between two fat deposition traits (SFT and BMS), indicating these two traits were controlled by different genes. This relationship was favorable, because breeding objectives of these two traits are opposite directions. Fukuhara *et al.*[4], Mukai *et al.*[14] from Japanese Black cattle and Wilson *et al.*[22] from Angus breed found similar relationships between these two traits. However as Marshall[11] reviewed, generally these two traits correlated positively.

In Table 5 genetic relationships between traits recorded on breeding females and carcass traits were shown. These relationships were informative, because they were the basic

Table 5. Genetic correlations between traits recorded on breeding females and carcass traits

Trait	Model 1					Model 2				
	CW	LMA	RT	SFT	BMS	CW	LMA	RT	SFT	BMS
CC*	−0.11	−0.09	0.03	0.08	0.07	0.08	−0.05	0.19	0.16	0.06
QR*	−0.01	−0.04	0.09	0.19	−0.01	0.12	0.00	0.19	0.26	−0.04
BD*	−0.07	−0.07	0.02	0.01	0.03	0.16	−0.02	0.20	0.07	0.01
TH*	−0.10	−0.04	−0.01	0.06	0.08	0.11	0.02	0.13	0.14	0.07
JS	0.09	0.06	−0.03	−0.07	−0.04	−0.11	0.01	−0.20	−0.16	−0.02
CG	0.14	0.09	0.12	0.09	−0.06	−0.16	0.03	−0.05	0.11	0.00
CD	0.08	0.02	−0.11	0.03	−0.03	−0.14	−0.06	−0.32	0.01	0.01
TW	0.31	0.03	0.03	0.00	−0.04	0.21	−0.10	−0.18	−0.01	0.02
AFC	−0.29	−0.28	0.23	0.19	−0.36	−0.26	−0.28	0.28	0.22	−0.39
ACI	−0.16	−0.20	−0.10	−0.14	0.26	−0.15	−0.20	−0.09	−0.13	0.25

CC : body capacity & conformation, QR : quality & refinement, BD : body, TH : thighs, JS : judging score, CG : chest girth, CD : chest depth, TW : thurl width, AFC : age at first calving, ACI : average calving interval.

CW : carcass weight, LMA : *longissimus* muscle area, RT : rib thickness, SFT : subcutaneous fat thickness, BMS : beef marbling score (0 to 5).

* Trait indicated as the percentage of discontent.

information to examine the effects of selection based on carcass characteristics on female traits. Although no strong relationship was found, reproductive traits correlated with carcass traits more than exterior judging traits and body measurements did. Genetic correlations between AFC and carcass traits were favorable except for relationship between AFC and RT using either Model 1 or 2. Carcass traits were also adjusted to constant age, therefore a female, which sexually matured earlier tended to produce fattening offspring with better carcass. The ACI correlated favorably with carcass traits, which concerned meat quantity, however it correlated unfavorably with carcass traits, which concerned fat deposition.

In this study it became clear that selection on carcass traits and (or) exterior judging traits did not give undesirable influences on AFC. However to attain an efficient management it is more important to improve ACI rather than AFC. Because selection on BMS would tend to lead ACI upward, some criteria have to be introduced in selection of breeding females.

Although two models were examined, heritabilities of ACI were very low and there was no trait, which strongly correlated with ACI. Therefore it should be necessary to look for other strongly correlated traits or to conduct direct selection on ACI using BLUP. Low heritabilities do not necessarily mean low genetic variations. Predicted breeding values of sires ranged from −25.5 to 17.7 days in AFC and from −22.4 and 29.1 days in ACI when Model 2 was used. These ranges of predicted breeding value indicated the possibility of genetic improvements in reproductive traits. However when a heritability of objective trait is low, a caution will always be needed on rapid increase of inbreeding[5,18].

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黒毛和種繁殖雌牛の登録審査時の諸形質ならびに繁殖能力と枝肉成績との遺伝的関連性

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黒毛和種繁殖雌牛の登録審査時に測定されている諸形質，ならびに繁殖能力と枝肉成績との遺伝的関連性を多形質アニマルモデルによるREML法により推定した．分析形質は，広島県下で収集された外貌審査による減率4項目および審査得点，体測定値3形質，繁殖能力2形質（初産月齢および分娩間隔）ならびに枝肉成績5形質である．外貌審査形質，体測定値および枝肉成績の遺伝率は中位から高めで推定されたが，繁殖能力の遺伝率は非常に低い値であった．外貌審査形質と体測定値間の遺伝相関は，体重体高比を加えないモデルでは高く推定された．初産月齢は，外貌審査形質，体測定値および枝肉成績と好ましい遺伝的関連性を示したが，分娩間隔と脂肪交雑評点の間には正の好ましくない関係が認められた．今後，枝肉成績に対する選抜圧が強くなることが予想されるため，分娩間隔の増加に注意する必要性が示唆された．

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