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Number of Calves Produced at Specified Age as a Measure of Reproductive Performance in Beef Cattle under Artificially-Inseminated Breeding Scheme

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ABSTRACT : Reproductive abilities in beef cattle herds are receiving increased attention due to recent rises in production costs. To achieve more efficient management, a measure of fertility, namely the number of calves produced at k yr of age (NCP_k), was developed and its genetic parameters were estimated from Japanese Black cows by restricted maximum likelihood procedures. The k examined were distributed from 2 to 10 yr of age and NCP_2 averaged 1.077 calves over 43,536 cows. The averages increased by approximately 0.9 calf with each additional 1 yr increment in k. Heritabilities of NCP_k were estimated to be low ranging from 0.083 to 0.162, which seemingly suggested a difficulty of genetic improvement. However, large genetic variation and high accuracy were observed in predicted breeding values of NCP_k. For example, the breeding values of NCP_7 were predicted between -0.303 and +0.213 with average accuracy of 0.607 for cows with observations. Genetic correlations among different k were generally high and positive (0.474 to 0.995). The analyses showed that at least NCP_4 was required to maintain the genetic correlations of 0.8 or higher with subsequent NCP_k. Also NCP_5 maintained the genetic correlations of 0.9 or higher with subsequent NCP_k. The results suggested some possibilities for NCP_k to be a selection criterion considering its genetic variation, high accuracy and consistency with subsequent performance. (**Key Words** : Beef Cattle, Genetic Parameter, Number of Calves Produced, Reproductive Performance)

INTRODUCTION

Reducing production costs is of primary importance for all livestock producers. It is receiving increased attention from beef cattle producers because of recent remarkable rises in production costs, especially in crude oil and feed crops. The reduction may be achieved through several measures, e.g. improving growth ability, feed efficiency, nursing ability, etc. Reproductive performance is regarded as one of such abilities. For a commercial cow/calf producer, no factor plays a more vital role than the reproductive fitness of females (Doyle et al., 2000). To explore effective breeding strategies for reproductive performance, extensive research has been conducted on a large variety of traits: days to calving, calving interval, calving success, calving difficulty, etc. (e.g., Donoghue et al., 2004; Phocas and Sapa, 2004; Gutiérrez et al., 2007).

For the improvement of reproductive ability of Japanese Black cattle, calving interval and age at the first calving have been employed. Genetic evaluations by BLUP are conducted for both traits but only the interval between first and second calvings is used for the observation of calving interval. This is mainly because adaptation of a repeatability model is too computationally demanding for the breed. Every year the computing loads keep increasing by the amount of 60,000 cows, which newly enter the breeding herds of Japanese Black. Thus a measure of fertility that is less computationally demanding is eagerly desired.

Therefore, the objectives of this study were to 1) propose a measure of fertility, which was less demanding and also easy to understand; and 2) estimate the genetic parameters of the trait to examine the usefulness for improving the fertility of the breed.

MATERIALS AND METHODS

We defined the number of calves produced at k yr of age

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(NCP_k) as a measure of reproductive performance. Let t be the age at x-th and first calving after the cow becomes k yr ($k \leq t$), then

$$\mathrm{NCP}_k = \frac{k \times x}{t}$$

For example, NCP_6 for a cow, which delivered a 5-th calf at 6.524 yr of age, would be

$$\mathrm{NCP}_6 = \frac{6 \times 5}{6.524} = 4.598$$

Arthur et al. (1993) investigated a similar trait, namely number of calves born, but this trait was intended to express lifetime productivity and measured when a cow was disposed. Martinez et al. (2004) also surveyed the number of calves born to Hereford cows. Although NCP_k proposed here has some similar nature to their measurement, they differ in that the number of calves born in Martinez et al. (2004) was measured as an integer value under seasonal breeding schemes. One of the aspects of NCP_k is that it contains the factors of both calving interval and age at the first calving in one trait.

Data of 54,962 Japanese Black cows were extracted from the database of the Wagyu Registry Association together with their 305,859 parturition records. The cows were those registered in three adjacent prefectures in Japan from 1988 to the present. Almost all parturitions were obtained under a year-round artificially-inseminated breeding scheme.

The following criteria were applied to arrange the dataset for genetic analysis of NCP_k: 1) the cows should have a parturition record at t yr of age, which is equal to or greater than k yr of age, 2) the cows should have only normal parturition records until t yr of age ("normal" here means that cows are not used as donors and do not have abortion, premature or late birth), 3) the parturition at t yr of age should be done in one of the three prefectures, 4) twins are counted as a single calving by removing one parturition record, 5) calving interval of the cows until t yr of age should be between 300 and 650 d, 6) age at the first calving of the cows should be between 589 and 1,228 d of age, and 7) each breeding farm should have records of NCP_k from at least two cows.

Criteria 5) and 6) were added to remove extreme observations, which may be due to an intentional decision by producers. Criterion 5) was followed by Oyama et al. (2002). Criterion 6) was determined by looking at the distribution of age at the first calving and it excluded 2% of original data.

Variance components of NCP_k were estimated by the average information restricted maximum likelihood (AI-REML) procedure fitted with a single-trait animal model:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Tf} + \mathbf{Zu} + \mathbf{e}$$

where $\mathbf{y}$ = vector of observations; $\mathbf{b}$ = vector of fixed effects; $\mathbf{f}$ = vector of random farm effects at the calving of t yr of age; $\mathbf{u}$ = vector of random additive genetic effects; $\mathbf{e}$ = vector of random residuals; and $\mathbf{X}$, $\mathbf{T}$, $\mathbf{Z}$ = known incident matrices relating observations to each effect. The model included year and month at the calving of t yr of age as fixed effect and also inbreeding coefficient as a linear covariate. The k examined were 2, 3, ..., 9, and 10 yr.

Two datasets of NCP_k of different ages were combined to estimate the covariance components using expectation maximization restricted maximum likelihood (EM-REML) procedure under a two-trait animal model implemented in REMLF90 (Misztal, 2002). The model was as follows:

$$\begin{pmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{X}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_2 \end{pmatrix} \begin{pmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \end{pmatrix} + \begin{pmatrix} \mathbf{T}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{T}_2 \end{pmatrix} \begin{pmatrix} \mathbf{f}_1 \\ \mathbf{f}_2 \end{pmatrix} + \begin{pmatrix} \mathbf{Z}_1 & \mathbf{0} \\ \mathbf{0} & \mathbf{Z}_2 \end{pmatrix} \begin{pmatrix} \mathbf{u}_1 \\ \mathbf{u}_2 \end{pmatrix} + \begin{pmatrix} \mathbf{e}_1 \\ \mathbf{e}_2 \end{pmatrix}$$

where subscript 1 and 2 denote dataset 1 and 2, respectively. The records from breeding farms, which did not appear in both datasets, were omitted. The effects included were the same as with a single-trait model.

Assumed expectation and (co)variance structures were

$$E\begin{pmatrix} \mathbf{f}_1 \\ \mathbf{f}_2 \\ \mathbf{u}_1 \\ \mathbf{u}_2 \\ \mathbf{e}_1 \\ \mathbf{e}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix} \text{ and } Var\begin{pmatrix} \mathbf{f}_1 \\ \mathbf{f}_2 \\ \mathbf{u}_1 \\ \mathbf{u}_2 \\ \mathbf{e}_1 \\ \mathbf{e}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{I}\sigma^2_{f1} & \mathbf{I}\sigma_{f1f2} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ & \mathbf{I}\sigma^2_{f2} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ & & \mathbf{A}\sigma^2_{a1} & \mathbf{A}\sigma_{a1a2} & \mathbf{0} & \mathbf{0} \\ & & & \mathbf{A}\sigma^2_{a2} & \mathbf{0} & \mathbf{0} \\ & Sym. & & & \mathbf{I}\sigma^2_{e1} & \mathbf{I}\sigma_{e1e2} \\ & & & & & \mathbf{I}\sigma^2_{e2} \end{pmatrix},$$

respectively, where $\mathbf{A}$ = additive relationship matrix; $\mathbf{I}$ = identity matrix; σ^2_{fi} = farm variance, σ_{f1f2} = farm covariance, σ^2_{ai} = additive genetic variance, σ_{a1a2} = additive genetic covariance, σ^2_{ei} = residual variance, and σ_{e1e2} = residual covariance. Then heritability and genetic correlation were assumed to be

$$h^2 = \frac{\sigma^2_{ai}}{\sigma^2_{ai} + \sigma^2_{fi} + \sigma^2_{ei}} \text{ and } r_G = \frac{\sigma_{a1a2}}{\sqrt{\sigma^2_{a1} \cdot \sigma^2_{a2}}},$$

respectively.

Pedigrees were traced back to animals born in 1965 using pedigree information from the Wagyu Registry Association and the ancestors were included in calculation of the additive relationship matrix. The numbers of ancestors without records ranged from 13,459 for NCP_{10} to

Table 1. Summary statistics of number of calves produced at *k* yr of age (NCP_k)

NCP_k	*n*	Mean±SD	CV (%)	Minimum	Maximum
$k = 2$	43,536	1.077±0.231	21.5	0.594	1.611
$k = 3$	35,835	1.933±0.287	14.9	0.892	2.647
$k = 4$	29,369	2.833±0.327	11.5	1.581	3.701
$k = 5$	23,708	3.747±0.374	10.0	1.976	4.708
$k = 6$	19,307	4.658±0.429	9.2	2.837	5.845
$k = 7$	15,603	5.571±0.482	8.7	3.479	6.793
$k = 8$	12,304	6.490±0.527	8.1	3.975	7.769
$k = 9$	9,484	7.409±0.574	7.7	4.965	8.876
$k = 10$	6,932	8.325±0.619	7.4	5.660	9.765

40,343 for NCP_2.

RESULTS AND DISCUSSION

One calving a year is a symbol of efficient cow-calf operation. Summary statistics revealed that the cows constantly produced approximately 0.9 calf every year (Table 1). The 0.9 calf per year is equivalent to a calving interval of 406 d. Thus an improvement of 41 d is required in days open to attain one calving a year in Japanese Black. However, it should be noted that the statistics at older ages were from selected animals since the cows with severe reproductive problems tended to be culled at younger ages.

Research on days open in Asturiana de los Valles demonstrated 52% of its cows attained one calving a year (Goyache et al., 2005). In order to attain the level, a cow should have three calves for NCP_4 assuming first calving at 2 yr of age and one calving a year. Data in our study showed much lower performance and only 22% had NCP_4 greater or equal to three. These percentages decreased with each additional 1-yr increment. Martinez et al. (2004) reported number of calves born for Hereford cows at various ages. They showed that the averages were 0.72, 1.87 and 2.38 for 2, 5 and 7 yr of age, respectively. In contrast, their averages were much lower that those found in this study. However, it may not be appropriate to compare directly because their phenotypes were the integer values under natural mating and seasonal breeding schemes.

Coefficient of variation decreased as *k* increased. The numbers of cows decreased with increment of *k*, reflecting the result of culling, and might have caused the change in phenotypic variation. However, the variations existed even in older ages. We observed a cow producing 9.765 calves at 10 yr of age, probably suggesting the existence of genetically superior cows. In contrast there was another cow which produced only 5.660 calves at the same age. These observations indicated a large phenotypic variation in the breeding population and knowing what proportion of such variation is due to genetic cause is a matter of interest.

Heritability estimates at all *k* examined were generally low ranging from 0.083 to 0.162 (Table 2). The heritabilities estimated by Martinez et al. (2004) were also low ranging from 0.08 to 0.14 for number of calves born. Reproductive performance is a complex trait with many components (Urioste et al., 2007) and usually is not highly heritable. For example, an extensive review by Koots et al. (1994) summarized the heritabilities of calving interval and calving date as 0.10 and 0.07, respectively. More recent studies in beef cattle reported the heritabilities ranging 0.04 to 0.13 for calving interval (Oyama et al., 2002; Roughsedge et al., 2005; Gutiérrez et al., 2007). Low heritabilities for NCP_k are expected because it must carry similar genes to calving interval.

The heritability estimates for NCP_k were decreasing

Table 2. Estimates of variance components, proportion of phenotypic variance attributed to farm variance, and heritability for number of calves produced at *k* yr of age (NCP_k)

NCP_k	σ_a^2	σ_f^2	σ_e^2	σ_p^2	σ_f^2/σ_p^2	h^2±SE
$k = 2$	0.0055	0.0065	0.0394	0.0515	0.127	0.108±0.012
$k = 3$	0.0087	0.0100	0.0625	0.0812	0.123	0.107±0.014
$k = 4$	0.0087	0.0156	0.0813	0.1056	0.148	0.083±0.015
$k = 5$	0.0122	0.0221	0.1050	0.1393	0.158	0.088±0.017
$k = 6$	0.0199	0.0326	0.1324	0.1848	0.176	0.107±0.020
$k = 7$	0.0252	0.0435	0.1646	0.2333	0.187	0.108±0.023
$k = 8$	0.0454	0.0503	0.1846	0.2803	0.179	0.162±0.031
$k = 9$	0.0397	0.0637	0.2235	0.3269	0.195	0.122±0.032
$k = 10$	0.0462	0.0795	0.2543	0.3800	0.209	0.121±0.035

σ_a^2 = Additive genetic variance; σ_f^2 = Farm variance; σ_e^2 = Residual variance; σ_p^2 = Phenotypic variance; h^2 = Heritability.

Table 3. Summary statistics of predicted breeding values and their average accuracy for number of calves produced at *k* yr of age (NCP_k)

NCP_k	Mean±SD	Minimum	Maximum	Accuracy
k = 2	-0.020±0.031	-0.156	0.121	0.627
k = 3	-0.017±0.036	-0.191	0.135	0.623
k = 4	-0.013±0.038	-0.169	0.122	0.602
k = 5	-0.012±0.050	-0.185	0.155	0.601
k = 6	-0.026±0.066	-0.256	0.164	0.611
k = 7	-0.027±0.078	-0.303	0.213	0.607
k = 8	-0.044±0.107	-0.472	0.277	0.635
k = 9	-0.044±0.106	-0.425	0.265	0.603
k = 10	-0.051±0.121	-0.420	0.269	0.594

toward 4 to 5 yr of age. At younger ages, NCP_k are considered to be affected more by age at the first calving, which is generally more heritable (e.g., Oyama et al., 2002). The estimates of heritabilities reach the bottom and then increase. A similar increase in heritabilities for number of calves born was reported by Martinez et al. (2004) and they pointed out that it might be due to increased opportunity for genetic differences to be expressed. In the meantime, the variances due to breeding farm were consistently larger than genetic variances at all ages. Thus, of course, there is no doubt that an approach from nutritional and management practices are important for raising herd fertility.

In principle, low heritability suggests a difficulty for the trait to be a selection criterion. This is because such a low-heritable trait has two major concerns out of three factors to determine genetic response, i.e. genetic variation and accuracy of selection. However, a certain amount of genetic variation can be observed in NCP_k. For example, predicted breeding values for cows with observations had a standard deviation of 0.078 calf and was distributed from -0.303 to +0.213 calf in NCP_7 (Table 3). It meant genetic difference of more than a half calf was observed. These are not negligible especially in countries where calf prices are expensive. In addition the accuracy of selection is relatively high (Table 3) despite the low heritabilities. Theoretically the accuracy of selection would be 0.316 for a trait with heritability of 0.1 under phenotypic selection. The average accuracy was approximately 0.6 regardless of the heritabilities and was twice the theoretical value. Increase in relationship coefficient is a major concern in breeding of Japanese Black cattle (Honda et al., 2004) but it can be an advantage for genetic evaluation with the animal model BLUP, which utilizes all available information from relatives.

It is probable that a selection criterion, which can be obtained earlier, is more valuable than the one obtained later because usually more candidates are available for selection. However, selection on female fertility from measurements taken at an early age is meaningful only when the relationship with fertility at an older age is high (Goyache et al., 2005). Therefore NCP_k at younger age is more preferable for the criterion if it provides certain consistency with subsequent NCP_k. Genetic and phenotypic correlations (Table 4) are useful information to examine the relationships. As expected, the correlations were high and positive reflecting their part-whole relationships. The lowest genetic correlation was 0.474, estimated between NCP_2 and NCP_{10}. The correlation seems reasonable because female cattle at around 2 yr of age are those which started to calve for the first time. NCP_3, NCP_4 and NCP_5 retained genetic correlations of more than 0.7, 0.8 and 0.9 with subsequent NCP_k, respectively. Similar high genetic correlations were also observed for number of calves born at various ages in Martinez et al. (2004) and days open at adjacent calvings in Goyache et al. (2005).

Figure 1 shows the relationships between predicted breeding values for cows with observations. NCP_k with lowest genetic correlations were chosen and illustrated for each of NCP_3, NCP_4 and NCP_5. Relatively dispersed cows in Figure 1(a) showed some inconsistency of NCP_3 with

Table 4. Estimates of genetic (below diagonals) and phenotypic (above diagonals) correlations for number of calves produced at *k* yr of age (NCP_k)

NCP_k	*k* = 2	*k* = 3	*k* = 4	*k* = 5	*k* = 6	*k* = 7	*k* = 8	*k* = 9	*k* = 10
k = 2		0.803	0.697	0.626	0.573	0.523	0.487	0.455	0.426
k = 3	0.918		0.908	0.824	0.764	0.709	0.668	0.633	0.604
k = 4	0.858	0.965		0.936	0.873	0.818	0.777	0.739	0.705
k = 5	0.787	0.909	0.972		0.952	0.900	0.857	0.820	0.789
k = 6	0.737	0.846	0.929	0.984		0.962	0.922	0.886	0.856
k = 7	0.680	0.767	0.872	0.948	0.985		0.970	0.935	0.903
k = 8	0.678	0.792	0.843	0.924	0.973	0.984		0.974	0.943
k = 9	0.590	0.788	0.841	0.919	0.947	0.959	0.995		0.976
k = 10	0.474	0.817	0.875	0.928	0.942	0.955	0.986	0.983	

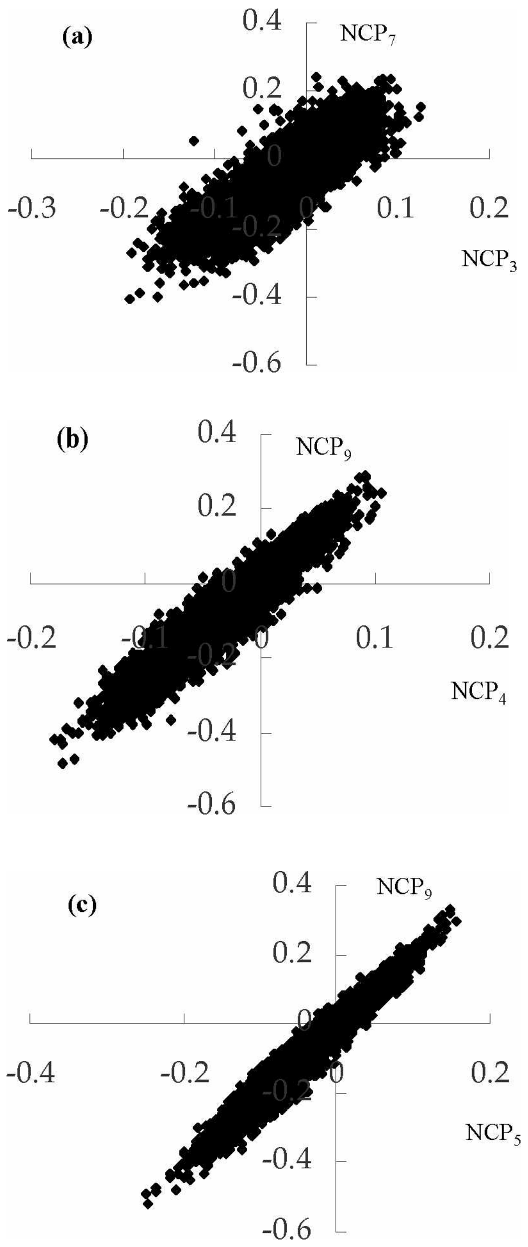

Figure 1. Scatter diagrams of predicted breeding values for number of calves produced at k yr of age (NCP$_k$). Plots are (a) NCP$_3$ and NCP$_7$, (b) NCP$_4$ and NCP$_9$, and (c) NCP$_5$ and NCP$_9$.

NCP$_7$. This means that a cow having good breeding value for NCP$_3$ is not always superior in NCP$_7$. This inconsistency itself is not a problem. It probably reflects some true nature of NCP$_3$ and NCP$_7$. However, selection based on such a measure can confuse breeders because they usually expect that the cow performs similarly afterward.

As a measure of reproductive performance, we can also consider the age at certain parity. It must have similar aspects to NCP$_k$ proposed here. However, NCP$_k$ has an advantage that it can be obtained at relatively similar ages for candidate cows. Although NCP$_k$ indicated low heritabilities, the present study showed that NCP$_k$ had fairly large genetic variation and high accuracy of selection. In addition, NCP$_k$ maintained consistency with subsequent NCP$_k$ by choosing appropriate age. The rank correlation coefficients of Figure 1 are 0.844, 0.951 and 0.980 for NCP$_3$, NCP$_4$ and NCP$_5$, respectively. There is no logical way to decide the adequate one but it seems at least NCP$_4$ should be chosen considering the inconsistency observed in NCP$_3$ and little increment in rank correlation from NCP$_4$ to NCP$_5$. Ages that cows have NCP$_4$ or NCP$_5$ are about the time when the breeding values for carcass traits are predicted in Japan. Since information on both carcass and reproductive performances become available at the same time, NCP$_4$ or NCP$_5$ seems a good measurement to contribute to a more efficient breeding scheme for a beef breed.

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REFERENCES

Arthur, P. F., M. Makarechian, R. T. Berg and R. Weingardt. 1993. Longevity and lifetime productivity of cows in a purebred Hereford and two multibreed synthetic groups under range condition. J. Anim. Sci. 71:1142-1147.

Donoghue, K. A., R. Rekaya, J. K. Bertrand and I. Misztal. 2004. Threshold-linear analysis of measures of fertility in artificial insemination data and days to calving in beef cattle. J. Anim. Sci. 82:987-993.

Doyle, S. P., B. L. Golden, R. D. Green and J. S. Brinks. 2000. Additive genetic parameter estimates for heifer pregnancy and subsequent reproduction in Angus females. J. Anim. Sci. 78:2091-2098.

Goyache, F., J. P. Gutiérrez, I. Fernández, L. J. Royo and I. Alvarez. 2005. Genetic analysis of days open in beef cattle. Livest. Prod. Sci. 93:283-289.

Gutiérrez, J. P., F. Goyache, I. Fernández, I. Alvarez and L. J. Royo. 2007. Genetic relationships among calving ease, calving interval, birth weight, and weaning weight in the Asturiana de los Valles beef cattle breed. J. Anim. Sci. 85:69-75.

Honda, T., T. Nomura, Y. Yamaguchi and F. Mukai. 2004. Monitoring of genetic diversity in the Japanese Black cattle population by the use of pedigree information. J. Anim. Breed. Genet. 121:242-252.

Koots, K. R., J. P. Gibson, C. Smith and J. W. Wilton. 1994. Analyses of published genetic parameter estimates for beef production traits. 1. Heritability. Anim. Breed. Abstr. 62:309-338.

Martinez, G. E., R. M. Koch, L. V. Cundiff, K. E. Gregory and L. D. Van Vleck. 2004. Number of calves born, number of calves weaned, and cumulative weaning weight as measures of lifetime production for Hereford cows. J. Anim. Sci. 82:1903-1911.

Misztal, I. 2002. REMLF90 manual. The University of Georgia, Athens, Georgia.

Oyama, K., T. Katsuta, K. Anada and F. Mukai. 2002. Heritability and repeatability estimates for reproductive traits of Japanese black cows. Asian-Aust. J. Anim. Sci. 15:1680-1685.

Phocas, F. and J. Sapa. 2004. Genetic parameters for growth, reproductive performance, calving ease and suckling performance in beef cattle heifers. Anim. Sci. 79:41-48.

Roughsedge, T., P. R. Amer, R. Thompson and G. Simm. 2005. Genetic parameters for a maternal breeding goal in beef production. J. Anim. Sci. 83:2319-2329.

Urioste, J. I., Y. M. Chang, H. Naya and D. Gianola. 2007. Genetic variability in calving success in Aberdeen Angus cows under extensive recording. Anim. 1:1081-1088.