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Genetic relationships among calving ease, birth weight and perinatal calf survival in Charolais cattle*

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Perinatal calf mortality affects profitability of beef cattle production systems, hence, it would eventually be beneficial to include this trait in a breeding goal. The objectives of this study were to estimate the environmental effects and heritabilities of and genetic correlations among birth weight (BW), calving ease (CE) and calf survival (CS) in Charolais cattle, in the Czech Republic. The dataset contained 27,402 field records. Fixed effects in the 3-trait model were year of birth, age of dam, sex, and litter size of calf. Random effects in the model were direct and maternal genetic effects, maternal permanent environment, contemporary group (herd x year x season), and residual. Birth weight was modelled as a normally distributed trait, while for calf survival a linear logit model was applied. The CE score was either transformed to be normally distributed (T1) or treated as a binary trait (T2). For T1, heritabilities for the direct genetic effect were 0.23, 0.21 and 0.05 for BWd, CEd and CSd, respectively; while heritabilities for maternal genetic effects were 0.10, 0.02 and 0.05 for BWm, CEm, and CSm. Genetic correlations among BW, CE and CS were close to zero for both direct and maternal genetic effects with the exception of that between BWd and CEd (0.21 for T1 and 0.24 for T2). Results suggest that low additive direct and maternal genetic variances for calf survival and low to modest direct and maternal genetic correlations between BW, CE and CS would limit effectiveness of selection for calf survival in a breeding program, in spite of its economic importance in beef cattle production.

KEYWORDS: beef cattle / calving traits / threshold / variance components

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Calf survival is of primary economic importance in beef cattle production, while the perinatal period is especially critical. Difficult calving can result in anoxia of the foetal brain that interferes with postpartum reflexes of calves and may cause their subsequent death. Berger *et al.* [1992] reported that excessive birth weight was the most common cause of stillbirths associated with dystocia. Wolfová *et al.* [2005] documented a substantial economic importance of calf survival, calving easy and cow longevity for the Charolais cattle, in the Czech Republic. Although calf survival and calving ease are scored categorically, most studies have used standard mixed model methodology in their analysis, even though this assumes a continuous distribution of the trait [Eriksson *et al.* 2004, Cervantes *et al.* 2010]. Several studies suggested that the threshold or logistic models, which assume the existence of an underlying normally distributed variable, are theoretically appropriate and computationally feasible for genetic analysis of categorical traits [Heringstad *et al.* 2007, Guerra *et al.* 2006]. Linear logistic mixed models were used in those studies, which was more appropriate for calf survival because of the trait's binary distribution.

Because of the importance of calf survival in the beef cattle production systems, the objectives of the present study were to estimate environmental effects and genetic parameters for calf survival, genetic relationships among calf survival, calving ease and birth weight and to evaluate the possibility of including this information in the beef cattle breeding programs.

Material and methods

Field test data for birth weight (BW), calving ease (CE) and perinatal calf survival (CS) of the Charolais cattle provided by the Czech Beef Breeders Association (www.cschms.cz) were analysed. Animals with 88-100% of the Charolais ancestry and born in within years 1990-2005 (n=27,402) were included. Calf survival was coded as 1 if a calf survived 24 h after birth and 0 if the calf was stillborn or died within 24 h of birth. Four calving ease scores were easy calving (1), assisted calving (2), difficult calving (3) and Caesarean section (4). Animals were included in the data set only if they descended from sires with at least five offspring, with offspring in two or more herd×year×season subclasses and born to dams with two or more offspring.

Statistical analysis

Variables BW, CE and CS were analysed as traits of the calf. Vostrý *et al.* [2014] reported that calving ease transformations, by means of the Snell score [Snell, 1964], are the most appropriate for genetic parameter estimation for CE of beef cattle breeds under conditions of the Czech Republic. Therefore, analyses were performed using multiple-trait animal models for two calving ease data transformations.

Transformation T1: BW and CE were fitted as normally distributed traits. CE phenotypes, recorded as four categorical scores, were transformed to a continuous scale by means of the Snell score [Snell, 1964]. Because CS was treated as binary trait, the residuals could not be normally distributed. Therefore, a linear logit model was used for the statistical analysis of CS.

Transformation T2: In contrast to transformation T1, CE was transformed to a binary trait: 0 for any normal birth with no complications and 1 for any birth requiring assistance. Subsequently this trait was analysed in the same way as CS.

The binary dependent CS variables can assume the value of 1 with π_i probability of survival or the value of 0 with a probability of death $1 - \pi_i$ for observation *i*. The conditional mean value of the binary variable is then expressed as a nonlinear function of explanatory variables:

$$g(\pi) = \log\left[\frac{\pi}{1-\pi}\right] = Xb + e$$

where: π is the probability of CS or CE, X is incidence matrix of effects and β is the vector of independent variable parameters.

Variance components and their ratios for CS, CE and BW were estimated with a three-trait animal model based on the procedure currently used to estimate breeding values for CE in the Czech Republic [Přibyl *et al.* 2003]. For all three traits, the same systematic effects were included in the classification: age of dam, combined effect of sex and litter size (male or female × single or twin-born), and year of calving were all treated as fixed, while the effects of direct animal additive genetics, maternal genetic, permanent maternal environment, contemporary group (herd × year × season), and residual were assumed random. The effect of the contemporary group was treated as random because of the numerous levels of this effect, the preponderance of small subclasses and weak genetic connectedness among them, caused by the limited use of AI in the population. The effect of year of calving was included in the model as a time factor to avoid overestimation of genetic trends [Schaeffer 2009].

The expectation of relationships was that all twins were all fraternal.

Snell score (Snell, 1964): The basic assumption of the Snell score is that for the categorical trait (CE) there exists a latent discrete distribution for which the Snell score represents the middle of the interval. The Snell score was computed by an approximation procedure of Snell [1964]. In this procedure a logistic model is applied to compute the score that may be generalized for a normal distribution. For more details see Tong *et al.* [1977]. Estimated Snell scores were transformed to a relative range as follows: easy calving with no assistance (original scale 1) was transformed into Snell score 0 and Caesarean section (original scale 4) was transformed to Snell score 100.

The DMU package [Madsen and Jensen, 2008] was used to calculate SE values of the genetic and non-genetic variances. The following population parameters were derived from the estimated variance-covariance components: σ^2_y – phenotypic variance [$\sigma^2_y = \sigma^2_a + \sigma^2_m + \sigma_{am} + \sigma^2_{pe} + \sigma^2_e$], h^2_a – direct heritability [$h^2_a = \sigma^2_a/\sigma^2_y$], h^2_m – maternal heritability [$h^2_m = \sigma^2_m/\sigma^2_y$], r_{am} – genetic correlation between direct and maternal effects [$r_{am} = \sigma_{am}/(\sigma_{a} \sigma_m)$], c^2 - proportion of the phenotypic variance corresponding to permanent environment effect of the dam [$c^2 = \sigma^2_{pe}/\sigma^2_y$], e^2 - proportion of the phenotypic variance corresponding to the residual [$e^2 = \sigma^2_e/\sigma^2_y$], where , σ^2_a – additive genetic variance of direct effect, σ_{am} – genetic covariance of direct and maternal effects, σ^2_m – maternal additive genetic component, σ^2_{hys} – component for the contemporary group, σ^2_{pe} – variance of the maternal permanent environment effect, and σ^2_e – variance of the residual. Traditionally herd-year-season is included in the systematic effects. For this reason, if *hys* is defined as random effect, it does not necessary need to form part of phenotypic variance.

The pedigree dataset included three generations of ancestors. Errors of the heritabilities were approximated according to the method of Klei and Tsuruta [2008]. Estimates of the effects in the multiple-trait animal model were computed on the logit scale and subsequently transformed back to the original scale (probability) using the inverse link function:

$$\pi = \frac{\exp(\mathit{Estimation\ of\ effect})}{1 + \exp(\mathit{Estimation\ of\ effect})}$$

Results and discussion

Descriptive statistics for the studied traits are given in Table 1.

Table 1. Structure of data used for estimation of genetic parameters for birth weight (BW), calving ease (CE) and calf survival (CS)

	Numbers
Sires	470
Dams	6,605
Calves per sire	58.30
Calves per dam	4.15
Calves per contemporary group	18.80
Sires per contemporary group	4.66
Contemporary groups per sire	14.46
Farms per sire	3.63
Calves with records	27.40
Animals in pedigree	39,546
	Means/SD
Birth weight (kg)	40.84/6.12
Calving ease[1]	9.49/2.23
Calf survival[2]	0.92 / 0.26

[1]Calving ease in Snell score expressed as percentage of assisted calving.
[2]Calf survival in the corresponding scoring units: 1 (calf alive at birth) and 0 (stillborn).

Environmental effects

Estimates of fixed effects for traits analysed by T1 are shown in Table 2. The lowest estimated CS probability (in %) occurred between the second and fourth years of a dam's age, and the highest was between the fourth to fifth year of age of dam class. Lower CS from younger cows may be due to their inexperience as mothers. Further, young cows have offspring with lower average BW than mature cows. This is in agreement with the observation that cows between their second and third year of age had the lowest average birth weight calves and the poorest value for calving ease. Hansen *et al.* [2003] similarly reported highest postnatal mortality of Danish Holstein calves born to young cows. Riley *et al.* [2004] reported that maternal instinct of primiparas heifers was poorer than that of older cows and therefore negatively affected the calf survival.

Table 2. Estimates of fixed effects for traits analysed with the T1 model

Item		Age of dam (years)						Sex × Litter size			
		2-3	3-4	4-5	5-6	6-7	>7	bull	bull twins	heifer	heifer twins
BW	Est.	35.79	36.12	36.07	36.28	36.27	36.07	41.00	33.82	37.94	31.64
	SE	0.30	0.30	0.30	0.30	0.29	0.29	0.49	2.28	0.64	0.11
CE	Est.	9.32	6.63	5.79	5.23	4.93	5.89	10.21	5.22	5.01	4.75
	SE	0.11	0.08	0.07	0.06	0.05	0.06	0.74	5.90	7.63	2.11
CS	Est.	2.41	2.51	2.62	2.59	2.55	2.52	2.03	2.77	2.57	2.75
	SE	0.40	0.42	0.41	0.41	0.41	0.40	0.73	5.3	3.83	0.86
	%[1]	91.73	92.48	93.21	93.01	92.74	92.52	88.36	94.13	92.89	94.02

T1 – Transformation by means of the Snell score [Snell 1964]; BW – birth weight in kg; CE – calving ease expressed as Snell score – percentage of difficult calvings; CS – calf survival expressed as log (odds ratio).

[1]Probability of survival expressed in % as: πij=exp(Estimation)/(1+exp(Estimation).

Generally, female calves had higher survival probability than males, as also reported by Riley *et al.* [2003], Riggio *et al.* [2008] and Vostrý and Milerski [2013]. Mandal *et al.* [2007] reported that higher losses of male calves might be a sex-associated that has not yet been defined. Perinatal survival was higher in twin calves of both sexes (bulls and heifers) than in single-born calves. Single calves are usually heavier than twins, which may lead to a higher percentage of dystocia, which is related to lower calf survival. In agreement with this speculation, less desirable values for calving ease and higher birth weights were recorded for single than for twin calves.

The age of dam effect followed the same pattern as for BW-T1 and CE-T1 (Tab. 3). However, differences between age of dam classes were not detected for CS. On the contrary, large differences between sex classes (ca 50%) were found for CS-T2 and for BW and CE-T1.

Table 3. Estimates of fixed effects for traits analysed with the T2 model

Item		Age of dam (years)						Sex × Litter size			
		2-3	3 -4	4-5	5-6	6-7	>7	bull	bulls twins	heifer	heifer twins
BW	Est.	35.45	35.81	35.78	36.00	36.04	35.79	40.72	33.52	33.68	31.33
	SE	*0.38*	*0.39*	*0.39*	*0.38*	*0.38*	*0.38*	*0.69*	*3.30*	*0.95*	*0.16*
CE	Est.	-1.94	-2.34	-2.54	-2.58	-2.74	-2.74	-1.99	-2.60	-2.69	-2.66
	SE	*0.46*	*0.48*	*0.47*	*0.47*	*0.46*	*0.46*	*0.66*	*5.05*	*24.05*	*0.39*
	%[1]	12.61	8.76	7.33	7.03	6.07	6.09	12.25	6.69	6.64	6.65
CS	Est.	8.73	8.92	9.21	9.18	9.07	9.03	2.52	12.28	4.06	9.27
	SE	*10.81*	*10.82*	*10.71*	*10.82*	*10.82*	*10.81*	*4.03*	*47.67*	*8.42*	*23.10*
	%[2]	99.98	99.98	99.98	99.99	99.99	99.98	92.56	99.98	98.03	99.99

T2 – Transformation to a binary trait, BW – birth weight, CE – calving ease expressed as log(odds ratio), CS – calving survival expressed as log(odds ratio).
[1] probability of assisted calving (in %) calculated as:
π_{ij}=exp(Estimation)/(1+exp(Estimation)).
[2] probability of calf survival (in %) calculated as:
π_{ij}=exp(Estimation)/(1+exp(Estimation)).

Genetic parameters

By both transformations, direct heritabilities for BW (Tab. 4) were relatively low compared with those reported by Eriksson *et al.* [2004] and Mujibi and Crews [2009] for the Charolais breed. Direct heritability was more than two times higher than the maternal one. Maternal heritability was within the range of heritabilities reported by authors cited above. The value of c^2 estimated by T1 (0.19) was higher than that estimated by T2 (0.05).

Direct heritability for CE modelled with T1 and as a binary variable (T2) resulted in similar values as to direct heritability of BW (Tab. 4). Corresponding maternal heritabilities were lower than direct heritabilities. In contrast to BW, h^2_m for CE for T1 was 10-fold lower than h^2_a. Similar trends between maternal and direct heritability were also reported by Luo *et al.* [2002] and Mujibi and Crews [2009]. The heritability of CE estimated in this study was within the range of estimates presented by Erikson *et al.* [2004] and Mujibi and Crews [2009], but current estimates are larger than those of Eaglen and Bijma [2009] and Wiggans *et al.* [2003] for dairy cattle. A comparison of h^2_m and c^2 values for CE between T1 and T2 shows that for T1, the maternal genetic effect had greater impact on CE than the non-genetic effects of the dam.

Direct and maternal heritabilities for calf survival were low for both transformations. A comparison of h^2_a and h^2_m shows that maternal genetic and direct additive genetic effects had different influence on calf survival. Estimated direct and maternal heritabilities for CS were comparable with estimates reported in the literature for beef cattle [Guerra *et al.* 2006**,** Riley *et al.* 2004] and for dairy cattle [Meyer *et al.* 2001, Heringstad *et al.* 2007].

Table 4. Estimates of the genetic parameters (standard errors in parentheses)

Parameter	T1			T2		
	BW	CE	CS	BW	CE	CS
σ^2_a	2.58(0.41)	35.02(0.01)	0.77(0.31)	3.28(0.41)	2.52(1.13)	0.65(0.53)
σ_{am}	-0.16(0.01)	0.73(0.01)	-0.09(0.05)	-0.38(0.24)	-0.68(0.58)	-0.11(0.36)
σ^2_m	1.12(0.54)	3.81(0.01)	0.80(0.38)	1.11(0.24)	1.71(1.01)	0.66(0.54)
σ^2_{hys}	6.31(0.18)	61.44(0.05)	0.10(0.05)	9.94(0.42)	0.27(0.28)	0.06(0.08)
σ^2_{pe}	2.05(0.36)	27.12(0.10)	0.32(0.15)	0.96(0.16)	0.35(0.51)	0.21(0.17)
σ^2_e	5.47(0.02)	98.08(0.50)	14.30(0.61)	13.91(0.26)	8.89(0.34)	17.81(0.79)
σ^2_y	11.06	164.76	16.10	18.88	12.79	16.18
h^2_a	0.23 (0.02)	0.21 (0.00)	0.05(0.05)	0.17(0.02)	0.20(0.00)	0.03 (0.03)
h^2_m	0.10 (0.03)	0.02 (0.00)	0.05(0.04)	0.06 (0.02)	0.13 (0.00)	0.03 (0.03)
r_{am}	-0.09(0.03)	0.06(0.01)	-0.11(0.04)	-0.20(0.03)	-0.40(0.15)	-0.17(0.05)
c^2	0.19	0.16	0.02	0.05	0.03	0.01
e^2	0.49	0.60	0.89	0.74	0.70	0.93

T1 – Transformation by means of the Snell score [Snell 1964]; T2 – Transformation to a binary trait, BW – birth weight; CE – calving ease; CS – calving survival; σ^2_a – additive genetic variance of the direct effect; σ_{am}– genetic covariance between the direct and maternal effects; σ^2_m – additive genetic variance of the maternal effect; σ^2_{hys} – variance of the herd×year×season effect; σ^2_{pe} – variance of the maternal permanent environment effect; σ^2_e– variance of the residual term; σ^2_y – phenotype variance; h^2_a – direct heritability; h^2_m – maternal heritability; r_{am} – genetic correlation between the direct and maternal effects; c^2 – proportion of the phenotypic variance due to the dam's permanent environment effect; e^2 – proportion of the phenotypic variance due to the residual.

The direct by maternal correlations (r_{am}) for the three evaluated traits were negative or close to zero (Tab. 4). Negative correlations between direct and maternal genetic effects on CE might be explained by the speculation that smaller calves may be born more easily but grow up to be smaller cows that subsequently give birth with more difficulty [Meijering and Postma 1985]. This line of thinking holds true only if one can demonstrate reasonably high genetic correlations among birth weight, adult weight of the female and subsequent calving difficulty. The estimated correlations between direct and maternal effects indicate the importance of the maternal effect upon the calving traits.

Estimates of the direct genetic correlation between BW and CE were medium for T1 and T2 (Tab. 5). Maternal genetic correlation estimates were less than half the value of corresponding direct genetic correlations. Our estimates differed from those of Varona *et al.* [1999] and Lee *et al.* [2002]. Koots *et al.* [1994] reported an average direct correlation of 0.58 between CE and BW. This high correlation evokes the necessity to maintain birth weight of calves within an optimal range because calving ease is a very important trait from an economic perspective.

Table 5. Correlations among direct genetic (d), maternal and maternal genetic (m) effects, proportions of phenotypic variance corresponding to maternal permanent environment effect (*c*) and residual (e) effects for birth weight (BW), calving ease (CE), and calf survival (CS) (standard errors in parentheses)

Model	T1		T2	
Traits	CEd	CSd	CEd	CSd
BWd	0.21(0.01)	0.00(0.00)	0.24(0.11)	0.00(0.00)
CEd		0.05(0.02)		-0.07(0.03)
	CEm	CSm	CEm	CSm
BWm	0.10(0.01)	0.00(0.00)	0.06(0.03)	0.00(0.00)
CEm		-0.01(0.00)		0.01(0.00)
	CEc	CSc	CEc	CSc
BWc	0.21(0.01)	0.00(0.08)	0.20(0.10)	0.00(0.00)
CEc		-0.13(0.06)		-0.14
	CEe	CSe	CEe	CSe
BWe	0.24(0.01)	0.01(0.04)	0.16(0.02)	0.16(0.07)
CEe		-0.19(0.05)		-0.28(0.10)

T1 – Transformation by means of the Snell score [Snell 1964], T2 – Transformation to a binary trait.

All estimated correlations between BW and CS were low and negative, except for that between residual effects, for both T1 and T2. Koots *et al.* [1994] estimated the average genetic correlation for direct effects of these traits to be high and positive (0.65). Eriksson *et al.* [2004] reported genetic correlations of 0.74 and 0.92 for Charolais and Hereford populations between birth weight and calf survival. Differing correlation estimates among studies could be caused by different analytical approaches or methods of estimation. They might also be due to the fact that low birth weight calves can have higher risk of perinatal mortality. Luo *et al.* [2002] reported that correlations of birth weight with body weight and pelvic area of cows might be used to predict correlations between BW and CS. Correlations between CE and CS were low and negative for T1 and T2. Our results differ from those of Ericsson *et al.* [2004], who reported correlations from 0.95 to 0.98 for direct and maternal effects, and of Luo *et al.* [1999] who reported -0.58 for direct effect and -0.34 for maternal effect. Cervantes *et al.* [2010] predicted that strong selection for CE would result in a significant correlated response in CS. As stated by Koots *et al.*, [1994] intensive selection for calving ease could be exerted through the genetic correlation between calving ease and live weight at calving. When sires with low breeding value for BW are used, however, it could result in inferior growth rate and subsequently, in lower body weight of offspring. Moreover, our performance test data show that 75% of stillborn calves did not experience a difficult calving. Thus, a major proportion of stillbirths result from deliveries that are reported as normal. Berger *et al.* [1992] noted that at least some of such cases could be due to a reduction in vitality of low BW calves. These results are consistent with the very low genetic correlation between CE and CS estimated in our study.

Present results provide additional information about genetic parameters and genetic relationships among traits affecting calf survival. Our analyses suggest that non-genetic effects have a substantially higher influence on calf survival than genetic effects. Because of the very low genetic correlations among traits analysed in our study, the benefit of using BW and CE as correlated traits in a genetic evaluation of CS seems limited. The results suggest that response to selection for CS would be small. This significantly reduces possibilities of efficient breeding for calf survival beyond natural selection and slaughter of cows that lose a calf, even though calf survival is economically a very important trait. The results indicate that with good herd management calf perinatal survival is conditioned mainly by random uncontrolled factors.

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REFERENCES

1. BERGER P.J.,CUBAS A.C., KOEHLER K. J., HEALEY M.H., 1992 – Factors affecting dystocia and early calf mortality in Angus Cows and Heifers. ***Journal of Animal Science*** 70, 1775-1788.
2. CERVANTES I., GUTIÉRREZ J.P., FERNÁNDEZ I., GOYACE F., 2010 – Genetic relationships among calving ease, gestation length, and calf survival to weaning in the Asturana de los Valles beef cattle breed. ***Journal of Animal Science*** 88, 96-101.
3. EAGLEN S.A.E.,BIJMA P., 2009 – Genetic parameters of direct and maternal effects for calving ease in Dutch Holstein-Friesian cattle. ***Journal of Dairy Science*** 92, 2229-2237.
4. ERIKSSON S., NÄSHOLM A., JOHANSSON K., PHILIPSSON J., 2004 – Genetic parameters for calving difficulty, stillbirth, and birth weight for Hereford and Charolais at first and later parities. ***Journal of Animal Science*** 82, 375-383.
5. GUERRA J.L.L.,FRANKE D.E.,BLOUIN D.C., 2006 – Genetic parameters for calving rate and calf survival from linear, threshold, and logistic models in a multibreed beef cattle population. ***Journal of Animal Science*** 84, 3197-3203.
6. HANSENM. MADSEN P., JENSEN J., PEDERSEN J., CHRISTIANSEN L.G., 2003 – Genetic parameters of postnatal mortality in Danish Holstein calves. ***Journal of Dairy Science*** 86, 1807-1817.
7. HERINGSTAD B., CHÁNY Y.M., SVENDSEN M., GIANOLA D., 2007 – Genetic analysis of calving difficulty and stillbirth in Norwegian red cows. ***Journal of Dairy Science*** 90, 3500-3507.
8. KOOTS K.R., GOBSON J.P., SMITH C., WILTON J. W., 1994 – Analyses of published genetic parameter estimates for beef production traits. 2. Phenotypic and genetic correlations. ***Animal Breeding Abstract*** 62, 825-853.

9. KLEI B., TSURUTA S., 2008 – Approximate variance for heritability estimates. http://nce.ads.uga.edu/html/projects/AI_SE.pdf
10. LUO M.F., BOETTCHER P.J., SCHAEFFER L.R., DEKKERS J.C.M.,2002 – Estimation of genetic parameters of calving ease in first and second parities of Canadian Holstein using Bayesian methods. ***Livestock Production Science*** 74, 175-184.
11. LEE D.H., 2002 – Estimation of Genetic Parameters for Calving Ease by Heifers and Cows Using Multi-trait Threshold Animal Models with Bayesian Approach. ***Asian-Australian Journal of Animal Science*** 15, 1085-1090.
12. MADSEN P., JENSEN J., 2008 – DMU – a package for analysing multivariate mixed models. Version 6, release 4.7. 33 pp. Available from http://dmu.agrsci.dk
13. MANDAL A., PRASAD H., KUMAR A., ROY R., SARMA N., 2007 – Factors associated with lamb mortalities in Muzaffarnagari sheep. ***Small Ruminant Research*** 71, 273-279.
14. MEIJERING A., POSTMNA A., 1985 – Responses to sire selection for dystocia. ***Livestock Production Science***, 13, 251-266.
15. MEYER C.L.,BERGER P.J., THOMPSON J.R.,SATTLE C.G., 2001 – Genetic evaluation of Holstein sires and maternal grandsires in the United States for perinatal survival. ***Journal of Dairy Science***84,1246-1254.
16. MUJIBI F.D.N, CREWS D.H., 2009 – Genetic parameters for calving ease, gestation length and birth weight in Charolais cattle. ***Journal of Animal Science*** 87, 2759-2766.
17. PŘIBYL J., MISZTAL I., PŘIBYLOVÁ J., ŠEBA K., 2003 – Multiple-breed, multiple-traits evaluation of beef cattle in the Czech Republic. ***Czech Journal of Animal Science*** 48, 519-532.
18. RIGGIO V.R., FICCHIARO R., BISHOP S.C., 2008 – Genetic parameters for early lamb survival and growth in Scottish Blackface sheep. ***Journal of Animal Science*** 86, 1758-1764.
19. RILEY D.G., CHASE JR. C.C., OLSON T.A., COLEMAN S.W., HAMMOND A.C., 2004 – Genetic and non-genetic influences on vigor at birth and preweaning mortality of purebred and high percentage Brahman calves. ***Journal of Animal Science*** 82, 1581-1588.
20. SCHAEFFER L. R., 2009 – Contemporary groups are always random. www.aps.uoguelph.ca/~lrs/LRSsite/ranfix.pdf
21. SNELL E.J., 1964 – A scaling procedure for ordered categorical data. ***Biometrics*** 20, 592-607.
22. VARONA L., MISZTAL I., BERTRAND J.K., 1999 – Threshold-linear versus linear-linear analysis of birth weight and calving ease using an animal model: I. Variance component estimation. ***Journal of Animal Science*** 77, 1994-2002.
23. VOSTRÝ L., VESELÁ Z., SVITÁKOVÁ A., VOSTRÁ VYDROVÁ H., 2014 – Comparison among models for estimation of genetic parameters and prediction of breeding values for birth weight and calving ease in Czech Charolais cattle. ***Czech Journal of Animal Science*** 59, 302-309.
24. VOSTRÝ L., MILERSKI M., 2013 – Genetic and non-genetic effects influencing lamb survivability in the Czech Republic. ***Small Ruminant Research*** 113, 47-54.
25. WIGGANS G.R., MISZTAL I., VAN TASSELL C.P., 2003 – Calving Ease (Co)Variance Components for a Sire-Maternal Grandsire Threshold Model. ***Journal of Dairy Science*** 86, 1845-1848.
26. WOLFOVÁ, M., WOLF J., ZAHRÁDKOVÁ R., PŘIBYL J.,DAŇO J., KRUPA E.,KICA J., 2005 – Breeding objectives for beef cattle used in different production systems-2. Model application to production systems with the Charolais breed. ***Livestock Production Science***95, 217-230.