Estimation of breeding values for functional productive life in the Slovak Holstein population

E. Strapáková[1], P. Strapák[2], J. Candrák[1]

[1]Department of Genetics and Breeding Biology, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic
[2]Department of Animal Husbandry, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

ABSTRACT: Genetic evaluation of length of functional productive life was carried out using a Weibull proportional hazard sire-maternal grandsire model. The database included 405 624 Holstein cows with 19.24% censoring. The analyzed effects were parity × stage of lactation, within-herd standard deviations of milk production, herd × year × season interaction, change of herd size with respect to the previous year, age at first calving, and sire and maternal-grandsire effects. Parity × stage of lactation had the most important influence on functional productive life. The results of the analysis confirmed more intensive selection at the beginning of each lactation, whereby the risk ratio increased with each other lactation. Heritability of functional productive life was 0.13 on the original scale. Breeding values of sires were expressed as relative breeding values with a mean of 100 and genetic standard deviation of 12.

Keywords: cattle; longevity; survival analysis; risk ratio

Productive life has a great impact on the decrease of replacement costs and higher proportion of cows that are in later, high producing lactations (Vukasinovic et al., 1997). Productive life is defined as the number of days from the first calving until culling from a herd. It is dependent on production. Functional productive life reflects the ability of cows to delay involuntary culling because of sterility or disease (Ducrocq, 1994). Hence, level of production is added to the model to distinguish voluntary and involuntary culling (van der Linde, 2007). The major problem with genetic evaluation of longevity is an absence of complete length of productive life (censored data) in live cows at the end of the study period.

Ducrocq (1994), Vukasinovic et al. (1997), and Forabosco et al. (2006) confirmed suitability of Weibull proportional hazard model, which can be used for estimation of breeding values of longevity. The hazard rate is described as a product baseline hazard function, representing the aging process and function of explanatory variables affecting culling rate of cows (Caraviello et al., 2004).

Low heritability is a further problem of selection for longevity. Páchová et al. (2005), van der Linde et al. (2006), Potočnik et al. (2008), Menjo et al. (2009), M'hamdi et al. (2010) reported heritability on original scale between 0.04–0.17. It appears that culling of cows is heavily influenced by herd management practices.

The objective of this study was to evaluate the influence of chosen fixed and random effects on the length of productive life, the estimate of genetic effects and heritability, and the estimate of breeding values of sires based on the length of functional productive life in their daughters.

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MATERIAL AND METHODS

The raw dataset was provided by the Slovakia Breeding Services s.r.o. and the Breeding Book of Holstein Breed. The data consist of records of the productive life of 405 624 registered cows with the first calving between 1996–2010 belonging to 701 herds in the Slovak Republic. The length of functional productive life was calculated as the number of days from the first calving until culling or censoring. The animals with unknown culling day, with more than 6 lactations, and cows, which were sold for other purpose, were considered as censored (19.24%).

The average length of functional productive life of Holstein cows was 785.8 days for censored and 658.2 days for uncensored records.

The analysis was carried out using Weibull hazard sire maternal-grandsire model:

$$\lambda(t) = \lambda_0(t)\ exp\ (pls + m + hs + a + hys + s + 1/2\ mgs)$$

where:

$\lambda(t)$ = hazard function of a cow *t* days after calving

$\lambda_0(t)$ = Weibull baseline hazard function

pls = fixed time-dependent effect of the parity × stage of lactation interaction. Parity involved 6 classes (1–6+), stage of lactation 3 classes with changes at day 100, 200, and at the end of lactation

m = fixed time-dependent effect of milk production class, expressed as a standard deviation (SD) from within-herd-year average. Five classes were defined with changes after each calving: (1) +1 SD from herd-year average, (2) –1 SD from herd-year average, (3) more than +1 SD from herd-year average, (4) less than –1 SD from herd-year average, (5) class including non-standard or uncompleted lactations

hs = time-dependent effect of annual change in herd size with 5 classes: (1) decrease > 30%, (2) decrease of 0–30%, (3) unchanged state, (4) increase of 0–30%, (5) increase > 30%

a = fixed time-independent effect of age at first calving with 5 age classes: (1) 600–690 days, (2) 691–780 days, (3) 781–870 days, (4) 871–960 days, (5) 961–1200 days

hys = random time-dependent effect of the herd × year × season interaction, following a normal distribution with change points at April 1st and October 1st of each year (n = 13 556)

s = time-independent random effect of the sire of the cow, assuming to follow a multinormal distribution

1/2 *mgs* = random effect of maternal grandsire

The pedigree included 4563 sires and the total bulls number was 9247.

Likelihood ratio test was used to check the influence of the factors on functional productive life of cows. The proportion measure of the model explained variation was calculated by Maddala (1983):

$$R^2_M = 1 - (L_R/L_U)^{2/n}$$

where:

n = total sample size

L_R, L_U = restricted and unrestricted maximum likelihoods

The influence of the fixed factors was expressed as a relative culling rate, defined as the ratio between the estimated risk of culling and mean risk setting to 1. The level with the highest number of uncensored records was assumed as the average risk for fixed effects.

Heritability on the original scale was calculated by Back and Lidauer (2007) as:

$$h^2 = 4\sigma^2_s/[\sigma^2_s + \sigma^2_{hys} + (1/p)]$$

where:

σ^2_s = sire variance

σ^2_{hys} = herd × year × season interaction variance

p = proportion of culled cows

The breeding value for functional productive life was expressed by the formula:

$$RBV = [(eval - a)/sd] \times 12 + 100$$

where:

RBV = sire's relative breeding value

eval = sire's breeding value

a = mean of the base adjustment

sd = standard deviation of the base

Reliability of the breeding value estimation was calculated by Ducrocq (2005) as:

$$R = N\,h^2/[(N - 1)\,h^2 + 4]$$

where:

N = number of all sires' daughters

h^2 = heritability

SAS software (Statistical Analysis System, Version 9.2, 2008) was used for preparation of the databases, and Survival Kit (Version 6.0, 2010) was used for the estimate of breeding values for the length of functional productive life.

Table 1. Influence of individual factors on functional productive life

Effects	–2 Change in log likelihood	R^2
s	11 055	*
s, mgs	1 470.5	0.03
s, mgs, pls	283 550	0.51
s, mgs, pls, m	45 535	0.56
s, mgs, pls, m, hys	49 112	*
s, mgs, pls, m, hys, a	1 223.7	0.61
s, mgs, pls, m, hys, a, hs	1 751.8	0.62

s = sire effect, *mgs* = effect of maternal-grandsire, *pls* = effect of parity × stage of lactation interaction, *m* = effect of milk production classes, *hys* = effect of herd × year × season interaction, *a* = effect of age at first calving, *hs* = effect of herd size variation

*random effect

RESULTS AND DISCUSSION

Table 1 shows the results of the likelihood ratio test. All factors included in the model were highly significant. The two most important fixed factors were parity × stage of lactation interaction and milk production class. Very small changes in log likelihood were observed after the effect of age at first calving and the effect of variation of herd size were included in comparison with the other effects. Reliability according to Maddala (1983) reached 0.62.

The influence of the fixed factors on the functional productive life was expressed as a relative risk of culling. The cows with the relative risk of culling less than 1 accomplished longer productive life.

Effect of the parity × stage of lactation interaction on the risk ratio. Six lactations, of 3 stages each, were evaluated in the present study. The results of analysis confirmed more intensive selection at the beginning of the lactations, when the risk ratio increased (Table 2). The cows at the second stage of the first lactation showed 4.65 times lower risk of culling in comparison with the cows in the 100th day of lactation. The risk ratio subsequently moderately increased at the end of the first lactation. The trend of the risk of culling was similar across each lactation, and risk ratio tended to increase along lactations. It seems that the selection in the course of lactation is realized at the first stage of lactation.

These results are in agreement with those of van der Linde et al. (2006) and Chirinos et al. (2007) confirming an increase of the risk of culling across and along lactations; Ducrocq et al. (1988) stated an increasing trend of risk ratio from the second lactation. On the contrary, a decrease of risk ratio between lactations was recorded by Bonetti et al. (2009) and Raguz et al. (2011).

Roxström and Strandberg (2002) and Chirinos et al. (2007) found a consistent increase of the risk of culling throughout the lactation for all parities.

Effect of the milk production classes on the risk ratio. The effect of the milk production levels represents the impact of voluntary culling of cows. On the basis of our results, it is one of the most important factors influencing the length of productive life. This assignment has been confirmed also by Vukasinovic et al. (1977), Mészáros et al. (2008), Ducrocq (1994), and M'hamdi et al. (2010).

The cows with underaverage production were in higher risk of culling than cows producing more than +1 SD (Table 3). The risk ratio decreased with an increasing cows' production. Similar results have been reported also by Vukasinovic et al. (1997), Chirinos et al. (2007), and Raguz et al. (2011). Terawaki et al. (2006) and Bonetti et al. (2009) confirmed the highest (17-fold and ca. 4-fold, respectively) risk ratio for cows with the lowest milk production.

Table 2. Estimates of relative risk ratios for classes of parity × stage of lactation interaction

Lactation	Stage of lactation					
	up to 100 days	No. of uncensored records	101–200 days	No. of uncensored records	201 till lactation end	No. of uncensored records
1st	1	327 581	0.215	244 856	0.331	235 715
2nd	3.085	213 540	0.588	150 936	0.669	141 344
3rd	4.161	123 715	0.947	83 316	1.079	75 880
4th	5.047	62 745	1.278	39 760	1.475	35 093
5th	5.580	27 240	1.600	15 779	1.977	13 164
6th	6.005	8 734	2.045	3 558	2.109	2 174

Table 3. Estimates of relative risk ratios for milk production classes (expressed as standard deviation (SD) from within-herd-year average)

Class	Lower limit (SD)	Upper limit (SD)	Risk ratio	No. of uncensored records
1		< –1	1.618	226 625
2	–1	< 0	1.152	233 809
3	0	< +1	1	306 373
4	+1		0.968	109 395
5	non-standard and uncompleted lactations		2.738	86 526

Table 4. Estimates of relative risk ratios for classes of variation in herd size

Class	Lower limit (%)	Upper limit (%)	Risk ratio	No. of uncensored records
1		< –30	0.708	11 377
2	–30	< 0	1.250	245 168
3	0	0	1	340 621
4	0	< +30	1.161	330 002
5		> 30	1.042	141 560

Table 5. Estimates of relative risk ratios for classes of age at first calving

Class	Lower limit (days)	Upper limit (days)	Risk ratio	No. of uncensored records
1	600	690	0.910	7 698
2	691	780	0.939	80 091
3	781	870	1	113 845
4	871	960	1.066	67 136
5	961	1 200	1.158	58 811

Effect of the variation in herd size on the risk ratio. The variation in herd size was calculated as a percentage increase or decrease of the number of the cows in herd in comparison with previous year. This effect reached very small changes in log likelihood. Chirinos et al. (2007) and other authors found small effect of the herd size change on the length of productive life, too. The authors suggested that the time-dependent herd × year × season effect explains changes in the risk of culling regarding the extension or reduction in the herd size.

The herds of a stable size were set as a reference class (Table 4). The highest risk ratio was calculated for cows the herd size of which decreased from 0 to –30%. The lowest risk ratio was found in the herds exhibiting more than –30% size decrease (1.41 times lower risk of culling compared with cows in stable herds). This result was probably caused by the low number of uncensored data in comparison to other classes. In many cases the farmer is forced to lower the number of animals in his herd, in such cases the cows are voluntarily culled (censored data).

The risk of culling was slightly higher in size-increasing than in stable herds.

M'hamdi et al. (2010) and Raguz et al. (2011) confirmed a similar tendency, which was caused by higher selection intensity of cows. On the opposite, Ducrocq (2005), Mészáros et al. (2008), Bonetti et al. (2009) published a decrease of risk ratio in the herds with an increase of the cows number.

Effect of the age at the first calving on the risk ratio. The age at the first calving had a negligible but highly significant effect on the length of functional productive life. In comparison with other factors, risk ratio showed the considerably lowest variability, which was confirmed also by Páchová et al. (2005), Chirinos et al. (2007), and Raguz et al. (2011).

As the reference class we took the age at the first calving (781–870 days) (Table 5). The cows of the

Table 6. Genetic parameters and coefficient of heritability

Genetic parameters	
Sire variance	0.05
Hys variance	0.3
Heritability (original scale)	0.13

Hys = random time-dependent effect of herd × year × season interaction

Slovak Holstein breed calved between 600–690 days reached the lowest risk of culling (1.09 times lower in comparison with the reference class). On the basis of this result the increasing risk ratio in respect to increasing age at the first calving was confirmed.

There was a general agreement among authors of similar studies, that risk of culling is increasing with increasing age of cows (Syrstad, 1979; Vukasinovic, 1999; Chirinos et al., 2007, Bonetti et al., 2009; M'hamdi et al., 2010; Zavadilová and Štípková, 2013).

Genetic parameters and heritability. Genetic parameters were estimated from the genetic base of 1402 sires, having minimum 10 daughters in analysis. Table 6 shows the genetic parameters and coefficient of heritability.

Heritability was comparable with that published by Roxström et al. (2003), Caraviello et al. (2004), Back and Lidauer (2007), and Bonetti et al. (2009). Higher heritability was declared in Holstein population in Austria (0.17) and Germany (0.16) (http://www-interbull.slu.se/national_ges_info2/framesida-ges.htm).

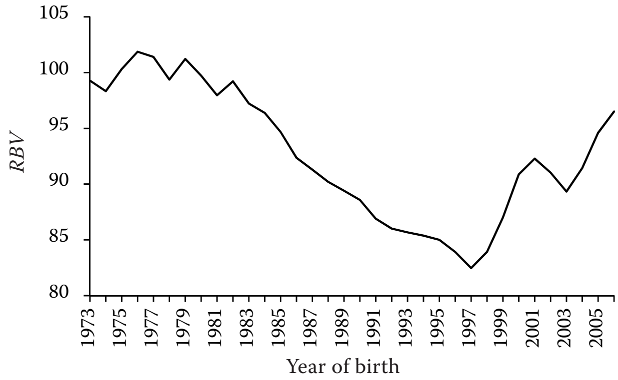

Figure 1. Genetic trend estimates of the functional productive life relative breeding values (running averages of four years)

Breeding values. Estimated breeding values of total bulls in the pedigree ranged from –0.78 to 0.8, which corresponded with the relative risk ratio between 0.46 and 2.23. The negative breeding values represent longer productive life of cows.

Table 7 shows breeding values of TOP 10 sires, which were expressed as relative breeding values with an average of 100 and genetic standard deviation of 12.

The genetic trend of *RBV* for functional productive life indicates an evolution in the breeding of the Slovak Holstein cows (Figure 1). The decreasing trend was felt in the eighties and the nineties. Probably it was caused by intensive selection focused only on milk production. The increase of *RBV* in the following period was involved by the import of the bull sperm from abroad, where these bulls were probably selected also for longevity.

Table 7. Relative breeding values (*RBV*) for functional productive life of TOP 10 sires of Slovak Holstein cattle

Sire	Country of origin	Linea	Register	No. of daughters	*RBV*	Reliability of *RBV*
Riostar	France	BES	007	248	170.4	0.89
Benni	Belgium	NIC	002	236	167.0	0.88
Walhowdon Marshall Harry ET	USA	BW	025	123	160.9	0.80
Hi-Pine Dutch Score ET	USA	TAG	004	1119	160.6	0.97
Canyon-Breeze Air-Time ET	USA	LU	025	165	159.9	0.84
Stanley ET	Germany	SOG	008	144	159.3	0.82
Call	Germany	CAL	008	584	159.1	0.95
Latinlover	the Netherlands	KOR	006	208	158.6	0.87
Cedric Red	the Netherlands	SOG	007	66	152.4	0.68
Brigeen Givenchy ET	USA	SOM	009	711	150.7	0.95

CONCLUSION

Survival analysis using Weibull hazard sire maternal-grandsire model was used to analyze the productive life data from Slovak Holstein cows. The factors with the highest influence on functional productive life – parity × stage of lactation interaction, herd × year × season, and milk production classes – had the greatest impact on the culling policy. The effects of the age at first calving and the herd size variation accomplished small effect on productive life.

On the basis of our results, the farmers in Slovakia perform selection on the basis of milk production at the beginning or at the end of lactation. Enrollment of the factor of milk production levels in the model might affect the decision of farmers in voluntary culling of cows.

The heritability on the original scale was low. This study presents the first estimation of breeding values for functional productive life of Holstein cattle in the Slovak Republic. Based on its results, following steps should imply the development of survival analysis for the genetic evaluation of Holstein cattle productive life in Slovakia.

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Corresponding Author

Ing. Eva Strapáková, Ph.D., Slovak University of Agriculture in Nitra, Faculty of Agrobiology and Food Resources, Department of Genetics and Breeding Biology, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic
Phone: +421 376 414 334, e-mail: Eva.Strapakova@uniag.sk