Factors affecting the functional length of productive life in Slovak Pinzgau cows

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ABSTRACT: A proportional hazard model was used to analyze the impact of the most important factors on the length of productive life in 44 796 Slovak Pinzgau cows. The calculations were carried out with Survival Kit 3.12. The milk production level within a herd was the most important factor. The relation between the milk production level and the culling risk was strongly non-linear. Cows with extremely low milk production (less than 1.5 standard deviations below average) had a 4.8 times higher culling risk than average cows. The culling risk for the highest yielding cows was about one half of the risk of average cows. In the first lactation the culling risk was highest at the beginning and decreased in the course of lactation whereas in subsequent lactations the culling risk was highest at the end of lactation. The risk decreased with parity. The effect of age at first calving did not have a large influence on the length of productive life, although a linear increase in culling risk was observed as the age at first calving increased. Cows from expanding herds were at lower risk to be culled compared to cows in herds of stable and decreasing size.

Keywords: cattle; functional traits; longevity; survival analysis; risk ratio

The length of productive life, usually measured as the time from first calving until death, describes the ability of a cow to avoid culling by the farmer. If the measure is adjusted for within-herd production deviation, it is called functional longevity, and this trait describes the cow's ability to avoid involuntary culling (Ducrocq et al., 1988). Egger-Danner (1993) introduced the relative milk production as a management index that compared phenotypic performances of cows within a herd for the production of milk, fat, and protein.

Longevity results from the good health and fertility status, which implies low costs of veterinary care and insemination (Essl, 1998). A lower proportion of involuntary culling allows the farmer to select more cows based on the level of their milk production. With the prolongation of the productive lifetime the proportion of cows being in the first, costly period of their life from birth to first calving decreases. Longer productive life affects overall profitability of milk production by reducing replacement costs and increasing the proportion of mature, high-producing cows in the herd (Vukasinovic et al., 2001). Marginal economic values for the length of productive life for Holstein and Czech Fleckvieh cows in the Czech Republic were calculated to be 74 and 58 € per year/cow, respectively (Wolfová et al., 2007). A similar economic value of approximately 66 € per year/cow was calculated for Slovak Pied cows in mountain areas (Krupa et al., 2006). The length of productive life has a large effect on the economic efficiency of the production system and its relative importance reaches about 25 to 30% of 305-day milk

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yield which is the most important trait (Wolfová et al., 2007).

Data on the length of productive life always contain incomplete records, because some cows are still alive at the time of data recording. These cows generate censored data. The proportional hazard model (Cox, 1972; Kalbfleisch and Prentice, 1980) is a suitable method to analyze censored records. The hazard is defined as the probability of being culled at time t, given that the animal is still alive just prior to t (Ducrocq, 1994). Proportional hazard models have been applied to different cattle production systems and breeds (Dürr et al., 1999; Vukasinovic et al., 2001; Fuerst and Egger-Danner, 2002; Roxström and Strandberg, 2002; Ojango et al., 2005; Páchová et al., 2005; Sewalem et al., 2005; Chirinos et al., 2007). In most of the investigations the Weibull model has been used (Ducrocq et al., 1988).

The aim of the present investigation is to apply the proportional hazard model to Slovak Pinzgau cattle for the first time using the Weibull model. The importance of the individual factors (milk production level, parity and stage of lactation, age at first calving and herd size change) acting on the functional length of productive life in this breed will be studied.

MATERIAL AND METHODS

A data set of 44 796 Slovak Pinzgau cows first calved between 1993 and 2007 was analyzed. Cows with age at first calving below 23 or above 50 months and cows with missing date of first calving were deleted. Similarly, cows not alive at the date of data collection (March 2007) with missing date of culling were not considered. Herds with less than 20 evaluated cows were omitted. The statistical overview of the evaluated dataset is presented in Table 1. The standard deviations were high except for the age at first calving which was restricted to be within the given bounds.

The records of cows alive at the time of data collection were treated as right censored. The records were also treated as right censored at the end of the tenth lactation, when the cow reached more than 10 lactations. Also cows removed from milk recording on behalf of the breeders' decision were considered as censored, while no further data about their production and longevity were available, but the true length of their productive life was assumed to be longer than the last entry in the milk recording. The data were analyzed by a proportional hazard model following the Weibull distribution:

$$\lambda(t) = \lambda_0(t) \times exp(\, hy_i + rp_j + pst_k + afc_l + hs_m)$$

where:

$\lambda(t)$ = the risk of culling at time t

$\lambda_0(t)$ = the baseline hazard function which is assumed to follow the Weibull distribution

hy_i = the time dependent effect of herd × year

rp_j = the time dependent effect of the relative milk production (see below)

pst_k = the time dependent effect of parity × stage of lactation

afc_l = the time independent effect of age at first calving

hs_m = the time dependent effect of annual herd size change

The relative milk production for each lactation was computed after their adjustment to the first lactation, as the milk production of a cow compared to the herd average in the given year. In the case of incomplete lactations (less than 240 days) they were recalculated using the Wood curve (Wood, 1967) before the adjustment. The resulting difference expressed in standard deviations was subdivided into nine classes. The lower and upper bounds for these classes are given in Table 2.

Each lactation was divided into four intervals to express the risk of culling during early, mid and later stages. These stages within each lactation were combined with the effect of parity to form the factor parity × stage of lactation (Table 3). The cows

Table 1. Statistical overview of the evaluated dataset including censored records

Variable	$\bar{x}$	SD	Minimum	Maximum	Median
Length of productive life (years)	3.32	2.31	0.02	13.31	2.97
Age at first calving (months)	35.18	5.51	23	50	34.82
Parity	3.19	2.06	1	10	3.00
Milk production at 1st lactation (kg)	2 524	1 119.26	20	8 911	2 507
Lifetime milk production (kg)	9 765	8 318.77	20	64 892	7 523

Table 2. Estimates of risk ratios for classes of the relative milk yield (difference from the mean milk production within herd and year expressed by standard deviations)

Class	Lower bound (SD)	Upper bound (SD)	Risk ratio
1		< –1.5	4.840
2	–1.5	< –1.0	2.506
3	–1.0	< –0.5	1.795
4	–0.5	< –0.2	1.300
5	–0.2	< +0.2	1.000
6	+0.2	< +0.5	0.849
7	+0.5	< +1.0	0.720
8	+1.0	+1.5	0.569
9	> +1.5		0.465

Table 3. Estimates of risk ratios for classes of the combined factor parity × stage of lactation

Lactation	Stage of lactation (bounds in days in milk)			
	1	2	3	4
	(to 60 day)	(61 to 150 day)	(151 to 240 day)	(above 240 day)
1	4.502	2.653	1.298	1.000
2	0.143	0.355	0.397	0.480
3	0.103	0.148	0.213	0.332
4	0.051	0.128	0.171	0.247
5	0.060	0.104	0.136	0.222
6	0.050	0.106	0.136	0.203
7	0.052	0.097	0.115	0.166
8	0.078	0.116	0.168	0.194
9	0.066	0.100	0.189	0.307
10	0.092	0.148	0.220	0.347

were grouped according to their age at first calving into 9 approximately three-month wide classes (Table 4).

The relative change in the herd size was computed to 1st January each year and expressed as percentage deviation from the herd size in the previous year. If there were less than 10 animals in the given year, no change was assumed. Five classes were formed as given in Table 5.

For basic data processing and initial text file creation SAS® 9.1 was used. The risk ratios were computed using Survival Kit 3.12 program package (Ducrocq and Sölkner, 1998).

RESULTS

All factors included in the model (herd × year, relative milk production, parity × stage of lactation, age at first calving and annual herd size change) were highly significant.

The risk ratios for classes of relative milk yield are shown in Table 2. The relative milk production expresses the milk performance relative to the performance of all cows in the same herd and year. A higher class number means higher milk performance. The results indicate a clear dependence of the risk ratio on the milk performance. Cows with lower than average production had a higher risk of culling compared to average-producing cows. While cows with slightly below-average production (class 4) had only a 1.3 times higher risk to be culled, the risk ratio for lower classes increased reaching the value of about 4.84 in class 1 with the lowest milk performance. On the other hand, the highest-yielding cows had a risk ratio of about 46% of average-yielding cows. That means, increasing the performance above average was of a relatively

Table 4. Estimates of risk ratios for classes of the age at first calving

Class	Lower bound (day)	Upper bound (day)	Risk ratio
1		792	0.941
2	793	884	0.987
3	885	975	0.984
4	976	1 067	1.000
5	1 068	1 158	1.039
6	1 159	1 250	1.133
7	1 251	1 341	1.114
8	1 342	1 433	1.185
9	1 434		1.176

Table 5. Estimates of risk ratios for classes of the relative change in the herd size (expressed as percentage deviation from the herd size in the previous year)

Class	Lower bound (%)	Upper bound (%)	Risk ratio
1		< –50	7.511
2	–50	< –20	1.804
3	–20	< +20	1.000
4	+20	< +50	0.373
5	+50		0.266

smaller effect on the risk ratio than decreasing milk performance.

The combined effect of lactation and stage of lactation on the risk ratio is presented in Table 3. The highest risk for culling was estimated for the first lactation. In this lactation, the risk ratio decreased with days in milk. The absolutely highest risk ratio was observed in stage 1 (until 60 days). The culling risk decreased from the first to the fourth or fifth lactation and remained then more or less equal, except for a slight increase at the end of the ninth and tenth lactation. Otherwise than in the first lactation, cows have the lowest risk of culling in the first stage and the highest risk of culling in the last stage of lactation from the second lactation onwards. The culling risk in all four stages of the first lactation is higher than in the remaining combinations of parity and stage of lactation.

The results for the factor age at first calving are given in Table 4. The risk ratios showed a considerably lower variability than for the factors considered above. They were in the range from 0.941 to 1.185 whereby their values increased with age at first calving. Though the effect of the factor age at first calving was statistically significant, it had only a moderate impact on the risk to be culled.

The risk ratios for the time dependent effect of relative annual herd size change are shown in Table 5. The risk ratio was set to 1.0 for cows from stable herds with no or only slight changes in the herd size and the other classes were compared to this class. The change in the herd size had a clear impact on the culling risk of cows. The risk increased in shrinking herds and decreased in expanding herds compared with herds stable in size.

DISCUSSION

The present investigation analyses the impact of different factors on the length of productive life using the methods of survival analysis based on the Slovak Pinzgau population. This breed is considered to be endangered because of decreasing numbers of young Pinzgau sires, their low utilization in insemination (Kadlečík et al., 2006) and the increase in the inbreeding coefficient (Kadlečík et al., 2004; Kasarda and Kadlečík, 2007). On the contrary, many bulls of other breeds (mainly Red Holstein) are used, which leads to a decrease in the purebred Pinzgau population in Slovakia.

In our model the time dependent effects of relative milk production, parity × stage of lactation, herd size change and the time independent effect of age at first calving were considered. Though the results will be specific for the considered breed and production system and for the model used, their comparison with literature values obtained on different breeds under different conditions will be worthwhile for deriving general tendencies.

The relative milk yield represents mainly the effect of voluntary culling. To take into account differences in milk production between herds, years and parities, the classes of the effect have to be formed on the herd-year-parity basis. The milk production level has been shown to be the most important factor or one of the most important factors influencing the length of productive life in many studies (Vukasinovic et al., 1997; Dürr et al., 1999; Vollema et al., 2000; Sewalem et al., 2005; Bielfeldt et al., 2006), which is in agreement with our results. In the literature, the number of classes formed for the milk production level ranged from 3 (Sewalem et al., 2005) to 9 (Ducrocq et al., 1988; Ducrocq, 1994). The number 5 or 6 is used in most of the papers.

Different procedures are used for the implementation of the milk production level in the model for the length of productive life. Several authors use only milk yield as factor (Vukasinovic et al., 1997; Roxström and Strandberg, 2002; Páchová et al., 2005), other authors consider separately milk yield, fat content and protein content (Fuerst and Egger-Danner, 2002; Egger-Danner et al., 2005; Sewalem et al., 2005; Chirinos et al., 2007). A further group of authors construct indices combining milk yield, milk fat and milk protein or only milk fat and protein yields (Ducrocq, 1994; Dürr et al., 1999; Vollema et al., 2000; Bielfeldt et al., 2006). The relative milk yield was also used in the present study as the milk production of cows compared to the herd average, after recalculation of incomplete lactation and adjustment to the first lactation. According to our opinion it should be reasonable to use the relative milk production for comparison of cows within the herd, while it is known to the farmers and this way would best reflect their behaviour in voluntary culling.

The asymmetric (non-linear) behaviour of the culling risk in dependence on the relative milk production when high risk ratios were observed for the classes with very low milk production and moderately low risk ratios were estimated for the highest yielding cows was confirmed by Fuerst and Egger-Danner (2002) and Chirinos et al. (2007). It seems that the nonlinear character of the relationship between risk ratio and milk production class is amplified when increasing the number of classes. Furthermore, the relationship between risk ratio and milk production will be influenced by the breed and production system (Sewalem et al., 2005) and by the way the relative value of milk production is expressed.

The selection of cows is very intensive at the beginning of the first lactation as documented by the highest risk of culling in stage 1 of lactation 1 (Table 3). The risk ratio decreases in the subsequent stages of the 1st lactation. This result is in agreement with the findings of Dürr et al. (1999), Vukasinovic et al. (2001), Fuerst and Egger-Danner (2002) and Egger-Danner et al. (2005), who also detected a similar pattern of the course of the risk ratio during the first lactation. As Dürr et al. (1999) stated, producers would always be tempted to get rid of low-producing cows in time for economic reasons. The sharp increase in the hazard observed at the beginning of the first lactation seemed to be related to most cases of voluntary culling (based on low production) tending to occur early in the first lactation.

Most authors (Dürr et al., 1999; Vukasinovic et al., 2001; Fuerst and Egger-Danner, 2002; Egger-Danner et al., 2005; Páchová et al., 2005) agree that from the second lactation onwards the hazard rate follows a different pattern than in the first lactation: the hazard is low at the beginning of the lactation immediately after calving, then increases with advancing lactation and reaches its maximum at the end of lactation, when most non-pregnant cows are culled. It seems that culling in the course of the lactation is restricted mainly to involuntary culling and the main selection is realized at the end of the lactation. The farmers possibly let even non-pregnant cows finish their lactations not to lose returns from milk.

In contradiction to the authors cited above, Roxström and Strandberg (2002) and Chirinos et al. (2007) found that the risk of being culled increased consistently throughout the lactation for all parities. According to Chirinos et al. (2007) the low culling risk at the start of the first lactation may be imposed by data editing, given that animals were required to have milk production information in order to obtain a measure of functional longevity and this information is available only when cows have at least the first two test day records. In contrast with other effects that do not depend on the time scale, the estimates of the combined effect of parity and stage within parity interact with the general shape of the baseline hazard function and cannot be separated from it, especially at the beginning of the time scale (Ducrocq et al., 1988). Therefore, these estimates must be interpreted with caution and their values will also depend on the model used.

There is a general agreement in the literature confirming our results that the age at first calving has only a small influence on the length of productive life, although a certain trend of increasing culling risk with higher age at first calving is observed (Dürr et al., 1999; Vukasinovic et al., 2001; Páchová et al., 2005; Sewalem et al., 2005; Bielfeldt et al., 2006). No significant effect of age at first calving on the length of productive life was reported by Ducrocq (1994) and Ojango et al. (2005).

In case the farmer is forced to lower the number of animals in his herd, those cows could be culled that otherwise would remain. Also if the herd expands, more cows will be left in the herd than in a stable situation. This change in the number of animals in the herd consequently causes a corresponding change in the risk of culling, as observed in this study. Our results for changing the herd size are comparable with those of Forabosco et al. (2006) in beef cattle. Vollema et al. (2000) reported similar results for decreasing the herd size, but for herds with increasing numbers our results indicated a sharper decrease in the culling risk. Mostly the change in the herd size caused smaller responses in the risk ratio than in our investigation. Dürr et al. (1999) arrived at a surprising conclusion that cows in herds from both extremes (accretion or reduction in the herd size of more than 25% from one year to another) were at a greater risk of being culled than were cows in herds with a stable number of cows. The authors assumed that culling rates were already very high in Quebec herds, leaving little space for producers to adjust the herd size by changing the culling intensity. Chirinos et al. (2007), who also found a small effect of the herd size change on the length of productive life, suggested that the time dependent herd-year-season effect might account for changes in the risk of culling due to increases or reductions in the herd size.

CONCLUSIONS

Proportional hazard models are an efficient means to identify factors acting on the length of productive life. The relative milk production level within herd, year and parity has the greatest impact on the culling policy. Cows with extremely low milk production have the culling risk 4.84 times higher than cows with average milk production. Change in the herd size is a second factor of great importance. In herds decreasing by more than 50% the culling risk is about 7.5 times higher than in stable herds. The selection pressure expressed as risk ratios is greatest at the beginning of the first lactation and at the end of subsequent lactations. Therefore parity and stage of lactation should be always used as a combined effect in the model because otherwise the different behaviour between the first and subsequent lactations cannot be correctly reflected by the model. Age at first calving is a factor of minor importance for the length of productive life.

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