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ANALYSIS OF FACTORS AFFECTING THE LENGTH OF PRODUCTIVE LIFE IN CROATIAN DAIRY COWS

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Abstract

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An analysis of factors affecting productive life of Croatian dairy cows was carried out using a proportional hazard model based on Weibull distribution, using Survival Kit 6.0. The data consisted of 62,877 Simmental and 43,653 Holstein cows collected from October 1, 1992 until December 11, 2009. Cows alive at the end of the study (20.1% Holstein, 19.4% Simmental) were considered as right censored. The probability of being culled was assigned as a product of the baseline hazard function and the function of explanatory variables. The factors that most affected the length of productive life were parity, year * season and milk production level within a herd, all time dependent variables. The risk decreased with parity. Animals in first parity were most exposed to risk of culling, that is about 21 times (Holstein) and about 14 times (Simmental) more than the animals in fourth parity, which was assigned as a reference class. The year * season effect showed linear increase of risk to be culled, with a peak year 2007. Relation between milk production level and the risk ratios indicated slightly non-linear trend. Very low producing animals (less than 1.5 standard deviations below average) were at 1.311 (Holstein) and 1.265 (Simmental) times higher risk to be culled than the average producing cows. At the same time, the Simmental cows from small herds (<5 cows) were at even higher risks of being culled according to their milk production. Results of the herd size effect indicated increase of culling risk in bigger herds under assumption of higher selection intensity. The effect of age at first calving, as well as effect of region had lowest influence on the length of productive life.

Key words: dairy cows, length of productive life, survival analysis, risk ratio
Abbreviations: LPL = length of productive life

Introduction

According to breeding strategies and animal welfare, longevity is one of the main research topics in different cattle production systems and breeds. It is considered as one of the most important profitability components in dairy cows production as well. Pogacar et al. (1998) represented it as a trait of high complexity defined as a function of animal's resistance and constitution.

Longevity is typically defined as the number of days from first calving until culling that actually

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represents cow's length of productive life (LPL) in a herd. It refers to cow's ability to stay in a herd as long as possible, that is to avoid voluntary as well as involuntary culling. Considering that involuntary culling is mainly determined by sterility, lameness, mastitis or other diseases, voluntary culling is mainly dependent on productivity (Ducrocq, 1994; Vollema et al., 2000). Hence, reducing the rate of involuntary culling, the production cost-effectiveness is higher; enabling higher flexibility by voluntary culling that principally corresponds to low production (Van Arendonk, 1986). The highest contribution of the longer productive life in dairy cows production becomes clear through decreasing the replacement costs (Vukasinovic et al., 1997; Boettcher et al., 1999). In addition, longer productive life also provides a herd structure composed of later lactations cows in higher production levels. According to Strandberg (1996) an increase in LPL from three to four lactations increases milk yield per lactation and profit per year by 11 to 13%.

The main problem that appears with direct longevity measures, such as LPL, is censoring. It refers to the proportion of partial or incompleted records in the database (Ducrocq, 1994). The true LPL can be measured only after culling of an animal. It means that longevity data of sire's daughters become more available with increasing of sire's age. At the end of the study period, some animals are still alive and only one part of their lifespan is known. These animals generate right censored data. Accuracy of the factors affecting longevity is highly dependable on the proportion of censored records. Vukasinovic et al. (1997) determined according to the results of their study that at least 60 to 70% of the data should be uncensored. Higher proportion would lead to biased results.

The most commonly used way to analyse longevity data is survival analysis. It showed like an appropriate method, because survival analysis fully utilizes the available information from uncensored as well as from censored records, and accounts the nonlinear characteristics of productive life data (Ducrocq, 1997; Vukasinovic et al., 1997; Durr et al., 1999; Essl, 1998; Caraviello et al., 2004; Ojango et al., 2005; Forabosco et al., 2006). One of the most frequently used models in the analysis of productive life is a proportional hazard model (Vukasinovic et al., 2001; Roxstrom and Strandberg, 2002; Sewalem et al., 2005; Chirinos et al., 2007), which is also known as a Cox regression (Cox, 1972; Prentice and Kalbfleisch, 1979). This model is based on a hazard rate, $\lambda(t)$, which defines, if applied to dairy cows, the probability of being culled at time t, given that a cow is still alive immediately prior to t. The hazard rate, $\lambda(t)$, is described as a product of a baseline hazard function, $\lambda_0(t)$, representing the aging process and a function of expository variables that presumably affect culling process. In most part of the studies the Weibull model was used (Ducrocq et al., 1988; Caraviello et al., 2004).

The main objective of this study was to apply the proportional hazard model on Croatian dairy cattle breeds for the first time using the Weibull model.

Materials and Methods

The data were obtained from the official milk recording scheme, provided by the Croatian Agricultural Agency. The dataset consisted of 62 877 Simmental and 43 653 Holstein cows with records on production traits collected from October 1, 1992 until December 11, 2009. All the cows had at least first parity registered and age at first calving between 20 and 40 months. The longevity measure, LPL, was computed as the number of days between the date of first calving and the date of culling or censoring. For the animals with missing culling date, the last known lactation end date was used. In case of missing information on culling, the cow was considered as culled if the number of days between the end of last lactation and the date of data collection exceeded 365 days. Otherwise, the record was considered as right censored. If the cow reached more than 7 lactations, it was considered

Table 1

Basic statistics of the analysed data for Holstein cows involving censored records

Variable	$\bar{x}$	SD	Minimum	Maximum	Median
Length of productive life, years	3.17	1.61	0.27	10.93	2.85
Parity	2.15	1.19	1	7	2.00
Age at first calving, months	27.13	3.26	20	40	26.6
Milk production at 1st lactation, kg	5 824	1 584	1 100	12 423	5 743
Lifetime milk production, kg	12 571	7 594	1 100	69 685	11 033

Table 2

Basic statistics of the analysed data for Simmental cows involving censored records

Variable	$\bar{x}$	SD	Minimum	Maximum	Median
Length of productive life, years	3.45	1.83	0.28	9.24	3.14
Parity	2.56	1.49	1	7	2.00
Age at first calving, months	27.03	3.43	20	40	26.4
Milk production at 1st lactation, kg	3 972	1 058	1 010	8 485	3 906
Lifetime milk production, kg	10 186	6 484	1 013	48 984	8 774

as censored at the end of 7th lactation. The basic statistics overview of the analysed data is shown in Tables 1 and 2.

The analysis was carried out using a proportional hazard model following the Weibull distribution:

$$\lambda(t) = \lambda_0(t) \exp (ys_i + rp_j + par_k + afc_l + reg_m + hs_n)$$

where:

$\lambda(t)$ = the hazard function of an individual depending on time *t* (days from first calving to culling or censoring)

$\lambda_0(t)$ = the baseline hazard function (related to the aging process) which is assumed to follow a Weibull distribution with scale parameter λ and shape parameter ρ

ys_i = the fixed time dependent effect of year x season

rp_j = the fixed time dependent effect of the relative milk production

par_k = the fixed time dependent effect of parity

afc_l = the fixed time independent effect of age at first calving

reg_m = the fixed time independent effect of region

hs_n = the fixed time independent effect of herd size

For estimation of the standard lactation milk yield Test interval method approved by ICAR (2003) was used. The relative milk production in lactations was calculated after their adjustment to the first lactation, as the milk production of a cow compared to the herd average in the given year. The resulting difference expressed in standard deviations was divided into 9 classes. The classes from 1 to 9 represented the animals from herds bigger than 5 cows. Three special classes were created: for the animals from small herds (<5 cows) as class 10, for the animals from small herds and short lactations

Table 3

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 1	Upper bound 2	Risk ratio (H)	Risk ratio (S)
1		< -1.5	1.311	1.265
2	-1.5	< -1.0	1.196	1.090
3	-1.0	< -0.5	1.080	1.043
4	-0.5	< -0.2	1.000	1.000
5	-0.2	< +0.2	0.995	0.898
6	0.2	< +0.5	0.931	0.894
7	0.5	< +1.0	0.913	0.858
8	1	< +1.5	0.895	0.828
9	1.5		0.890	0.902

[1,2] Lower and upper bounds are expressed in standard deviations

Table 4

Estimates of risk ratios for classes of the region

Class	Risk ratio (H)	Risk ratio (S)
Slavonia	0.933	0.946
North-West Croatia	1.000	1.000
Upland Croatia	0.940	0.919
Mediterranean Croatia	0.869	0.811

Table 5

Estimates of risk ratios for classes of the herd size

Class	Lower bound	Upper bound	Risk ratio (H)	Risk ratio (S)
1		<5	1.195	0.626
2	≥5	<20	1.000	1.000
3	≥20	< 80	1.120	1.113
4	≥80		1.136	1.506

(<210 days) as class 11 and for the animals from small herds and lactations >210 days as class 12.

To account for culling for low production, the effect of within herd production level was included, which resulted into estimation of the functional productive life. The lower and upper bounds for these classes are given in Table 3.

The cows were grouped according to the slightly different climatic conditions in four groups covering the four Croatian regions: Slavonia, North-West Croatia, Upland Croatia and Mediterranean Croatia (Table 4). The effect of the herd size was taken into account through 4 classes. The highest proportion of the cows was from small herds less than 5 animals. Other animals were divided into classes ≥5 and <20, ≥20 and < 80 and ≥80 as shown in Table 5. According to the age of first calving, cows were divided in 7 different classes. The year x season effect was taken into account through three seasons, where period from January to April presented season one, from May to September season two and from October to December season three. The initial text file was prepared with SAS 9.1. (2002-2003). The risk ratios for given effects were computed using Survival Kit 6.0 program package (Ducrocq et al., 2010).

Results

The overview of basics statistics for both breeds is presented in Tables 1 and 2. Simmental cows had longer LPL than Holstein as well as higher number of lactations during the productive life, while the mean age at first calving was similar in both breeds. As expected, milk production at 1st lactation as well as life milk production was higher in Holstein cows. All factors included in the model (year * season, region, herd size, relative milk yield, parity and age at first calving) were highly significant. The risk ratios for the relative milk yield including herds with >5 animals are shown in Table 3. The milk performance was expressed as the relative milk production, relative to the performance of all cows in the same herd and year. According to milk performance increase, a slight decrease of risk ratios is indicated by both breeds.

The cows with low production had higher risk to be culled than average producing cows. Due to the high proportion of the herds with less than 5 animals, omitting of these cows was not an option. From that reason, these animals were considered separately through 3 special milk yield classes (class 10, class 11 and class 12). The most obvious difference between two breeds was determined in class 10 (herd size < 5). In mentioned class, Holstein cows had the lowest risk ratio (0.762) which means these animals had a risk ratio of about 76.2% of average yielding cows in bigger herds (> 5 animals). Vice versa, the risk ratio rose up to 1.435 according to Simmental cows from this class, indicating 1.43 times higher risk of culling the animals from small herds. The effect of region showed same pattern for both breeds (Table 4.). The animals from Slavonia had slightly lower risk of culling compared with reference class of North-West Croatia. Also, the lower risks were found in two other regions with note of lowest risk of culling in Mediterranean region.

Table 6

Estimates of risk ratios for classes of the age at first calving in Holstein cows

Class	Lower bound	Upper bound	Risk ratio
1		≤709	0.927
2	>709	≤747	0.978
3	>747	≤798	1.000
4	>798	≤868	0.958
5	>868	≤949	0.970
6	>949	≤1005	1.006
7	>1005		1.025

Table 7

Estimates of risk ratios for classes of the age at first calving in Simmental cows

Class	Lower bound	Upper bound	Risk ratio
1		≤698	1.011
2	>698	≤739	1.023
3	>739	≤795	1.000
4	>795	≤870	0.980
5	>870	≤954	0.993
6	>954	≤1011	1.031
7	>1011		1.068

Table 8

Estimates of risk ratios for the parity

Parity	Risk ratio (H)	Risk ratio (S)
1	20.833	13.699
2	4.333	3.850
3	1.792	1.671
4	1.000	1.000
5	0.666	0.685
6	0.521	0.534
7	0.354	0.356

The results of estimated risk ratios for classes of the herd size are given in Table 5. The size of a herd with 5 to 20 animals was set as a reference class. Compared to this class, animals from bigger herds were at higher risk of culling, especially Simmental cows from biggest herds (≥ 80 animals). The difference between two breeds in risk ratio trend, compared to reference class, was found for small herds (< 5 animals), where Simmental cows were at only about 63% of reference class risk of culling. In Holstein cows, a slight increase of risk ratio was determined.

The results of age at first calving are presented in Tables 6 and 7. Comparing with other considered factors, risk ratios demonstrated considerably lowest variability. The values ranged from 0.927 to 1.025 in Simmental cows and 0.980 to 1.068 in Holstein cows showing a low impact on culling risk. The highest difference in risk ratios was found for the effect of parity (Table 8.). While the reference class was fourth parity, the animals from lower parities had higher risks of culling resulting with about 21 times higher risk in the first parity

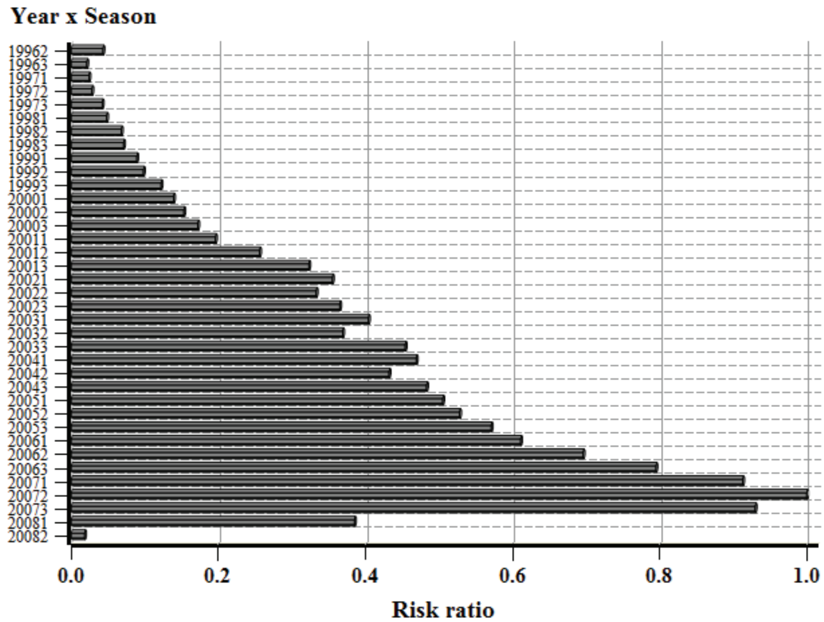

Fig. 1. Estimates of risk ratios for the year x season effect in Holstein cows

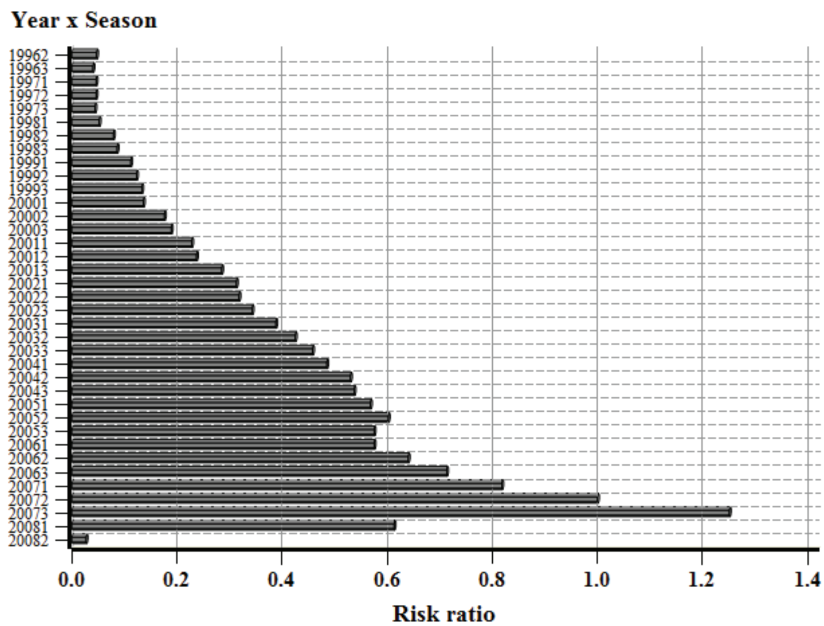

Fig. 2. Estimates of risk ratios for the year x season effect in Simmental cows

(Holstein breed) and about 14 times higher in Simmental breed. The animals from higher parities tend to be at lower risk ratios by both breeds.

Figures 1 and 2 represent the year*season effect, where the mean risk tends to increase substantially from one year to the next in both breeds.

Discussion

Survival analysis was used to describe the influence of different factors on the LPL in Croatian dairy cattle. The results for fixed effects were expressed as risk ratios, where values larger than one indicated higher culling risks. In our model six effects were considered including time-dependent (milk production within herd, year * season, parity) and time-independent effects (herd size, region, age at first calving).

The level of the milk production is being presented as one of the most important factors affecting the LPL by many authors (Vukasinovic et al., 1997; Smith et al., 2000; Vollema et al., 2000; Sewalem et al., 2005; Meszaros et al., 2008). Different authors considered this effect through different number of classes, ranging from 3 (Sewalem et al., 2005) to 9 (Ducrocq et al., 1988). According to our data structure, milk production within herd was taken into account through 9 classes representing only the animals from herds bigger than 5 cows. Because of the highest proportion of the herds with less than 5 animals, omitting of these cows was not an option. From that reason, these animals were considered separately through 3 special milk yield classes. Our results were completely in agreement with other studies according to the trend of risk ratios but with considerably lower values. Cows producing less than -1.5 standard deviations of the herd average were at about 1.3 times higher risk to be culled than the average producing cows which is very low comparing to other studies where higher risk ratios were found (Vukasinovic et al., 1997; Durr et al., 1999; Vollema et al., 2000; Chirinos et al., 2007; Meszaros et al., 2008). It could be due to the specific structure of Croatian data because in the last 20 years the system of the data collecting was changed for a few times, with stabilizing in last 10 years.

In attempt to show effect of region on the LPL, equable risk ratios were determined, with slight jump out of North-West region. Historically, it is the region with the most developed dairy cows farming in Croatia and such results were expected. Cows from the Mediterranean region were at lowest risk of culling which is also expected due to less intensive farming and smaller herd size in compare to other regions. Effect of region was also considered in few other studies (Smith et al., 2000, Chirinos et al., 2007) where Chirinos et al. (2007) obtained the same consistency of the results among the regions as in our case, concluding that the proposed model could serve as a basis for the development of the model used at the national level. In contrast, Smith et al. (2000) found different percentages of cows leaving the herds in different regions with providing the reasons of disposals.

The highest proportion of the cows was from small herds, that is herds with <5 animals. From this reason, the effect of the herd size change couldn't be taken into account as in numerous other studies (Durr et al., 1999; Vollema et al., 2000; Forabosco et al., 2006; Chirinos et al., 2007), only the effect of herd size was considered. The results were interesting within the meaning of opposite risk ratios comparing two breeds from small herds. Namely, while the risk of culling in Holstein cows slightly increased, Simmental cows where at lower risk to be culled.

Generally in the literature, the age at first calving is considered as an effect of very small influence on the LPL which is in agreement with our results. Ducrocq (1994) and Ojango et al. (2005) reported no significant effect of the age at first calving.

In contrast to results of some previous studies where lactation number and stage of lactation were estimated jointly (Ducrocq, 1994; Durr et al., 1999; Vukasinovic et al., 2001; Roxstrom and Strandberg, 2002; Meszaros, 2008), in our research only the effect of parity was taken into account because of the dataset specificity. In fact, there were no cows in earlier lactation stages but only cows over 150 days in lactation. Due to this reason, effect of the lactation stage couldn't be taken into account. The results showed very intensive selection intensity in first two lactations showed in table 8. Farmers would always tend to cull the low producing animals due two economic reasons, as expected. But the results should be interpreted with caution. The higher estimated culling risk in first two parities could be partly a consequence of above mentioned data structure that might have led to estimates that were biased upwards.

The year * season effect showed a similar increase in risk ratio by both breeds. This trend could be partially explained by more intensive selection in recent years, also due to the fewer number of observations in first few years of the research in addition to the data structure and censoring procedure. Similar results on this effect with similar trend were obtained by Vukasinovic et al. (1997).

Conclusions

Survival analysis using proportional hazard model was used to analyze data on LPL from Croatian Holstein and Simmental cows. The factors with highest impact on the LPL were parity, year *season and milk production within the herd. Cows in first lactation had a much higher risk of being culled than did cows in later lactations. The year * season factor showed a linear increase of risk ratios from one year to the next that could be partially explained by more intensive selection in recent years. Cows with higher milk production level within herd had about 30% higher risk ratio to be culled than the average producing cows. Also, the animals with lactations shorter than 210 days tend to have higher risk ratios according to their milk production level within herd, compared to average producing cows, either from small or bigger herds. The effects of the age at first calving and region showed like effects of minor importance for the LPL. Considerable uniformity of the risk ratios among four regions that represent slightly different climatic conditions could indicate a possibility of appliance of the used model at the national level.

Animals from bigger herds comprising both breeds were at relatively higher risks of culling than the animals from smaller herds, especially herds with less than 5 cows (Simmental). This factor could also be taken into account as a relative herd size change. The structure of the data didn't allow such consideration, because more than 70% of the animals were from herds with less than 5 animals, what may lead to biased results when considering herd size changes in very small herds. Based on our results and current understandings, following steps would imply the development of survival analysis for the genetic evaluation of longevity in Croatia.

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