Theses of Doctoral (PhD) Dissertation

Analysis of culling risk in Hungarian dairy cattle populations

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1. Introduction and aim of the thesis

The Holstein-Friesian is the dominant dairy breed in Hungary having 10,000-12,000 kg milk production during one lactation period. In Hungary, in addition to the Holstein-Friesian breed, the concentrated milk-producing breeds, such as the Jersey, the Ayrshire, the Swedish Red, and the Brown Swiss as well as the dual-purpose breed, the Hungarian Simmental cattle are found. In the last years, the milk production of the Hungarian Simmental cows had increased, with average lactation milk production exceeding 7,000 kg in 2020.

The selection for high-level milk production has resulted in changes in some valuable traits. The composition of milk has changed, the percentage of milk fat and the percentage of milk protein has decreased. The calving interval and the rate of inbreeding increased (BÉRI, 2013). The longevity or productive life decreased, the average number of lactations ranges from 2.1 to 2.2. A longer productive life increases profits and decreases the costs of replacement as well as the rate of voluntary culling (HU et al., 2021). On the other hand, cows have a maximum milk production in 4-6 lactations.

According to previous studies, the health status, reproduction, culling rate as well as longevity of dairy cows are greatly influenced by the conformation traits (SEWALEM et al., 2004; SAWA et al., 2013; CIELAVA et al., 2016). Therefore, the evaluation of linear and main type traits associated with longevity is an important research topic. A longer productive life can reduce the proportion of replacement, allowing higher selection pressure. Several research studies have confirmed the association of the conformation traits with longevity, but the effect of different combinations of conformation traits has not been studied yet.

Aim of the thesis

The aim of our research was to analyze the conformation traits of the dual-purpose Hungarian Simmental (HS) and the Hungarian Holstein-Friesian (HF) cattle using survival analysis. The survival analysis is one of the most commonly used mathematical methods in animal breeding and medical research to analyze production time and evaluate culling risk ratios of independent variables.

The main aim of our study was to evaluate the relationship between longevity and conformation traits as well as combinations of conformation traits. Previous studies have mainly focused on the Holstein-Friesian breed, with little literature available for dual-purpose breeds. In addition, several research studies have confirmed the association of the conformation traits with longevity, but only with one trait at a time. This approach could not estimate the combined effect of traits. In our research, combinations of the traits based on statistical analyses were considered. This approach might give information about the joint effects of linear type traits.

The aims of my thesis for both breeds:

- Evaluation of scores of linear and main type traits.
- Analysis of the relationship between animal (HS, HF), age at first calving (HS, HF), birth year (HS, HF), size of herd (HS), herd (HF), herd*calving year (HS), year of calving (HF) and longevity.
- Evaluation of between linear type traits and longevity.
- Determination of the combinations of linear type traits from the principal component analysis and cluster analysis.
- Analysis of the effect of combinations of linear type traits on longevity.
- Estimation of the impact of main type traits on longevity.
- Determination of the combinations of main type traits from the principal component analysis and cluster analysis.
- Evaluation of the effect of combinations of main type traits on longevity.
- Estimation of heritability of longevity.

2. Materials and methods

2. 1. Determination of longevity

Longevity was defined as the time from first calving to culling. The measurement variable was the number of calving for the Holstein-Friesian and the Hungarian Simmental cattle.

2. 2. Design of the database

Hungarian Simmental

The dataset was collected by the Association of Hungarian Simmental Breeders. The linear type traits database contained the results of 5129 Hungarian Simmental dual-purpose cows. The database consisted of 1461 censored data. The cows were born between 2002 and 2016. The main type traits were observed in 6867 Hungarian Simmental cattle. The cows were born between 1997 and 2015. At the time of analysis, 1689 cows were still in production (censored). The pedigree file used during survival analysis contained 26190 cattle.

Holstein-Friesian

The linear type trait dataset consisted of 17717 Holstein-Friesian cows, from 4 representative commercial herds. The data of cows alive at the time of data collection were censored. The database included 3950 censored data. The main type traits dataset was based on 8889 Holstein-Friesian cows. A total of 67 individuals were in production when the database was set up. The reason for the different numbers of data was the change in the judging score system, only those cows scored for all conformation traits were considered in the analysis. The cows were born between 2000-2017 and 2000-2012 of linear type trait and main type trait dataset. The pedigree file used during survival analysis contained 26122 cattle. The database was gathered by the Riska software.

2. 3. Analysis of the effect of linear type traits on longevity

Hungarian Simmental

The model contained the fixed effect of the age at first calving (≤25 months, 26 months, 27 months, 28 months, 29 months, 30 months, ≥31 months) the size of the herd (number of annual calving is under 20; the number of annual calving is between 20-50; the number of annual calving is over 50), the year of birth (2002–2016), and linear type traits and the random effect of the animal. The herd*calving year was a time-dependent covariate changing every year.

Scores for main and linear type traits are on a 1–9 scale covering the biological extremes of the population. The following linear type traits were examined:

1. Stature
2. Rump length
3. Rump width
4. Muscularity
5. Shoulder
6. Kidney
7. Rump angle
8. Rear legs set
9. Pasterns
10. Hoof height
11. Fore udder length
12. Rear udder length
13. Central ligament
14. Udder depth
15. Teat length
16. Teat thickness
17. Rear teat placement

The linear type traits were further joined into three groups:

Category 1: The scores: 1, 2, 3

Category 2: The scores: 4, 5, 6

Category 3: The scores: 7, 8, 9

<u>Holstein-Friesian</u>

The model contained the fixed effect of the age at first calving (≤22 months, 23 months, 24 months, 25 months, 26 months, 27 months, ≥28 months) the herd (1, 2, 3, 4), the year of birth (2000–2017), and linear type traits as well as the random effect of the animal. The year of calving was a time-dependent covariate changing every year.

Scores for main and linear type traits are on a 1–9 scale covering the biological extremes of the population, where intermediate animals receive 5. Linear type traits were judged once on first-parity cows within the interval of 30 days after first calving and before the end of lactation.

The following linear type traits were examined:

1. Stature
2. Chest width
3. Body depth
4. Angularity
5. Rump angle
6. Rump width
7. Rear leg rear view
8. Rear leg side view
9. Fore udder attachment
10. Rear udder height
11. Central ligament
12. Udder depth
13. Front teat placement
14. Teat length

The linear type traits were further joined to three groups:

Category 1: The scores: 1, 2, 3

Category 2: The scores: 4, 5, 6

Category 3: The scores: 7, 8, 9

2. 4. Analysis of the impact of combinations of linear type traits on longevity

<u>Hungarian Simmental</u>

The model contained the fixed effect of the age at first calving (≤25 months, 26 months, 27 months, 28 months, 29 months, 30 months, ≥31 months) the size of the herd (number of annual calving is under 20; the number of annual calving is between 20-50; the number of annual calving is over 50), the year of birth (2002–2016), and combinations of linear type traits as well as the random effect of the animal. The herd*calving year was a time-dependent covariate changing every year.

Based on the results of principal component analysis (a), cluster analysis (b), and experience of judges (c) following combination of linear type traits were examined:

1. Rump length-rump width (a, b, c)
2. Shoulder-kidney (a, b)
3. Fore udder length-rear udder length (a, c)
4. Central ligament-udder depth (c)
5. Udder depth-rear teat placement (a, b, c)
6. Teat length-teat thickness (a, b, c)

<u>Holstein-Friesian</u>

The model contained the fixed effect of the age at first calving (≤22 months, 23 months, 24 months, 25 months, 26 months, 27 months, ≥28 months) the herd (1, 2, 3, 4), the year of birth (2000–2017), and combinations of linear type traits as well as the random effect of the animal. The year of calving was a time-dependent covariate changing every year.

Based on the results of principal component analysis (a), cluster analysis (b), and experience of judges (c) following combination of linear type traits were examined:

1. Stature-rump width (a, b)
2. Chest width-body depth (a, b, c)
3. Rump angle-rump width (c)
4. Rear legs rear view-rear legs side view (a, b, c)
5. Rear legs rear view-rump angle (c)
6. Rear legs side view-rump width (c)
7. Angularity-rear udder height (b, c)
8. Fore udder attachment-udder depth (a, b, c)
9. Central ligament-front teat placement (a, c)

2. 5. Estimation of heritability of longevity

The heritability of Simmental and Holstein-Friesian cows' longevity was based on the animal model and was computed using the following formula:

$$h^2 = \frac{\sigma_g^2}{\frac{1}{p} + \sigma_g^2}$$

h^2 = heritability

σ_g^2 = genetic variance estimated using the Survival Kit

p = proportion of uncensored records (MÉSZÁROS et al., 2013b).

2. 6. Presentation of the software used for the analyses

Relationships among conformation traits as well as combinations of conformation traits and longevity were estimated using the Weibull model in the Survival Kit program (MÉSZÁROS et al., 2013a). The risk ratios showed the relative risk of culling compared with the reference class (where the risk ratio = 1).

Evaluation of heritability of longevity used Survival Kit program (MÉSZÁROS et al., 2013a).

3. Results

3. 1. Effect of linear type traits on longevity

Hungarian Simmental

Animal, year of birth, age at first calving, herd*year, rump width, central ligament, udder depth and teat thickness were significant effects on Simmental cows' longevity.

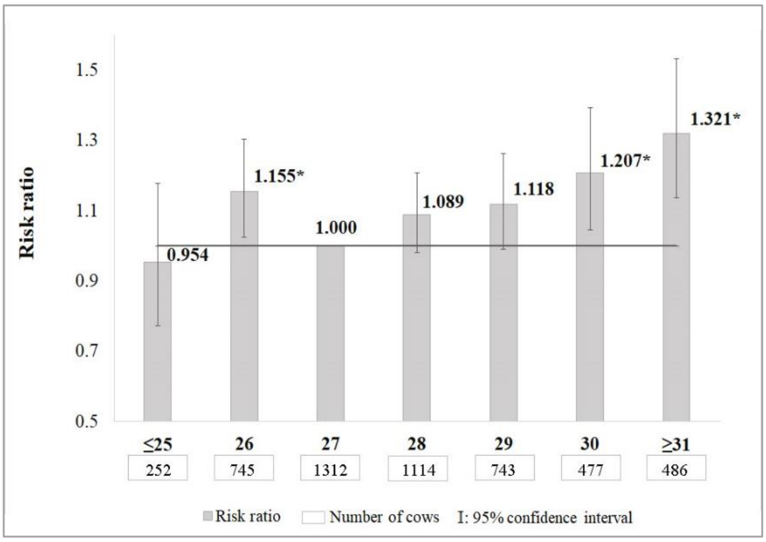

Figure 1: **Effect of age at first calving on relative culling risk**

*: Significant (p<0.05) difference from the reference group

Figure 1 presents the risk ratios of the effect of age at first calving on longevity. Compared to age at first calving at 27 months, first calving at 26 months, 30 as well as later than 31 months resulted in a higher relative risk. Increasing the age at first calving, the risk ratio increases. The highest risk of culling was estimated for cows first calved after 31 months. Most cows calved for the first time at 27 months.

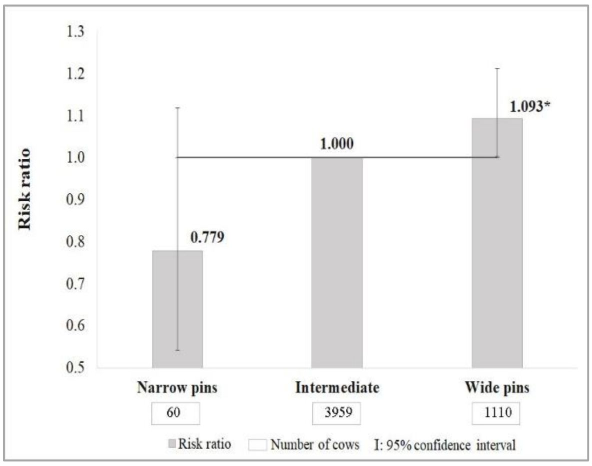

Figure 2: **Effect of rump width on relative culling risk**

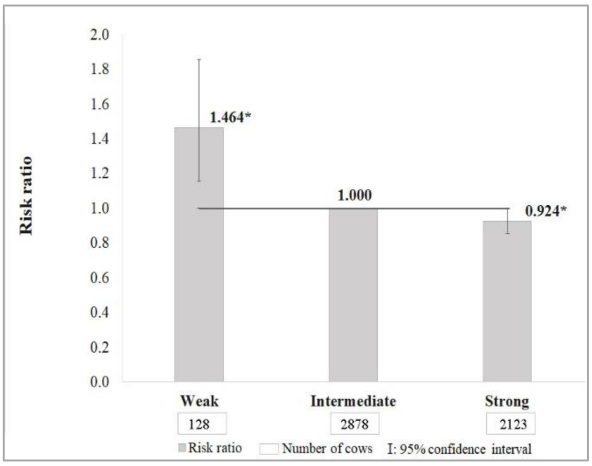

Figure 3: **Effect of central ligament on relative culling risk**

*: Significant (p<0.05) difference from the reference group

The relationship between the rump width and culling risk was shown in *Figure 2*. The highest risk of culling was estimated in cows having wide pins, with about 10% higher risk of culling compared with the reference class. Most cows had intermediate rump width.

Figure 3 shows the effect of the central ligament on the relative culling risk. The highest risk ratio was observed for the weak central ligament. Cows having weak central ligament had a nearly 50% higher risk of culling compared with the intermediate central ligament. The strong central ligament was the most favourable for longevity. Most cows had intermediate or strong central ligament.

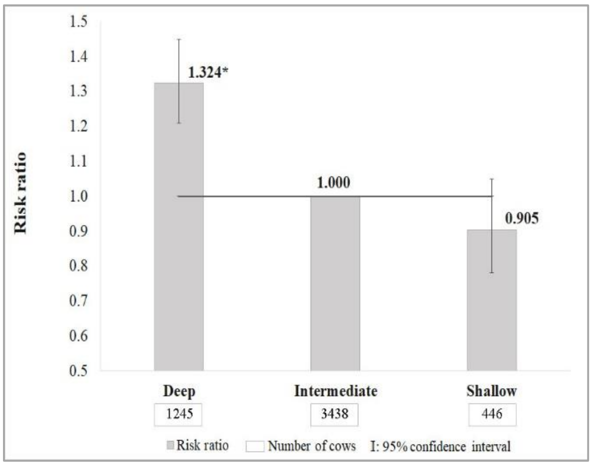

Figure 4: **Effect of udder depth on relative culling risk**

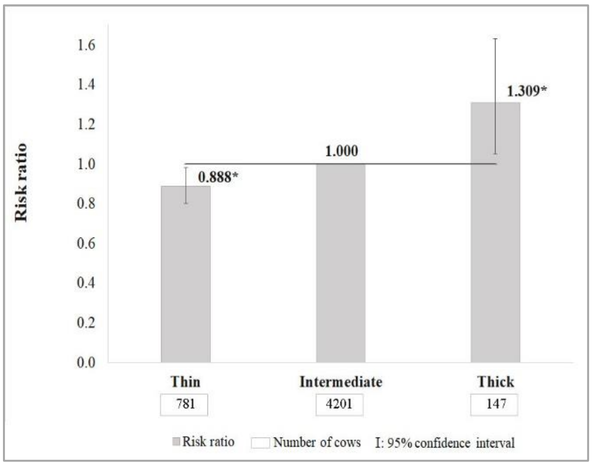

Figure 5: **Effect of teat thickness on relative culling risk**

*: Significant (p<0.05) difference from the reference group

The relationship between the udder depth and culling risk was shown in *Figure 4*. The highest risk ratio was estimated in cows having deep udder, with about 32% risk of culling compared with the intermediate udder depth. Most cows had intermediate udder depth, but more than 1000 cows had deep udder.

Cows having thick teats had a 30% higher risk of culling compared with the intermediate teat thickness. The lowest risk ratio was observed for tin teats. Most cows had intermediate teat thickness (*Figure 5*).

In the analyzed Hungarian Simmental population, the average longevity was 3.41 calvings. The genetic variance estimated by the Weibull model was 0.159, which resulted in heritability $h^2 = 0.10$ of longevity, taking into account the 28.5% censoring rate.

<u>Holstein-Friesian</u>

Animal, year of birth, year of calving, age at first calving, body depth, angularity, rump width, fore udder attachment, udder depth, and teat length had a significant effect on Holstein-Friesian cows' longevity. Surprisingly, rump angle, as well as feet and legs traits (rear leg rear view, rear leg side view) had not significant effect on a productive life.

The final model contained only significant effects (animal, year of birth, year of calving, age at first calving, body depth, angularity, rump width, fore udder attachment, udder depth, teat length), non-significant effects were removed from the model, and not used during further analysis.

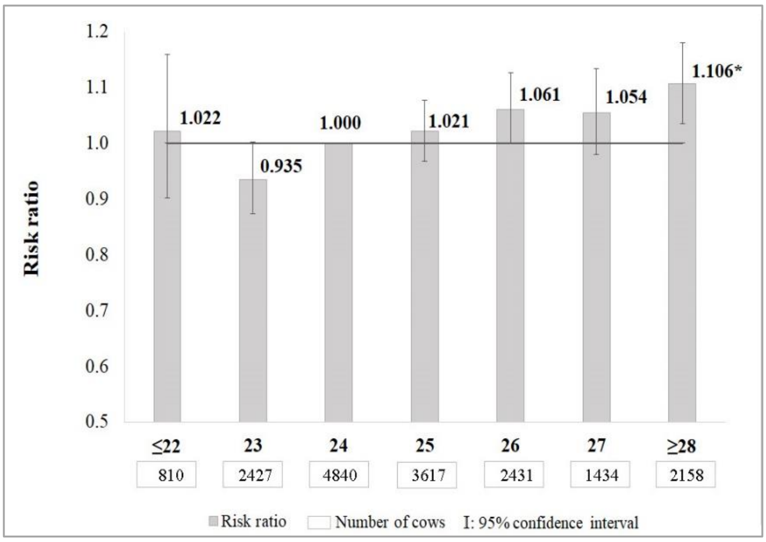

Figure 6: **Effect of age at first calving on the relative culling risk**

*: Significant (p<0.05) difference from the reference group

Figure 6 presents the risk ratios of the effect of age at first calving on longevity. 24 months of age at first calving was chosen as a reference class. Cows first calved at 28 and later than 28 months of age had a 10% higher risk of culling compared with the reference class. Increasing the age at first calving, the risk ratio increases. Most cows calved for the first time at 24 months.

Figures 7-12 show the relative culling risk of different linear traits.

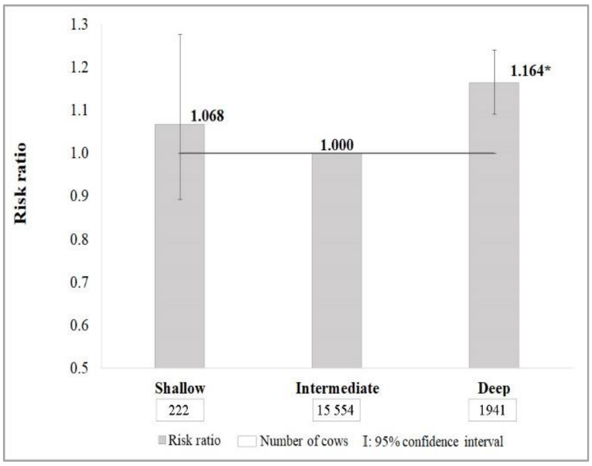

Figure 7: **Effect of body depth on relative culling risk**

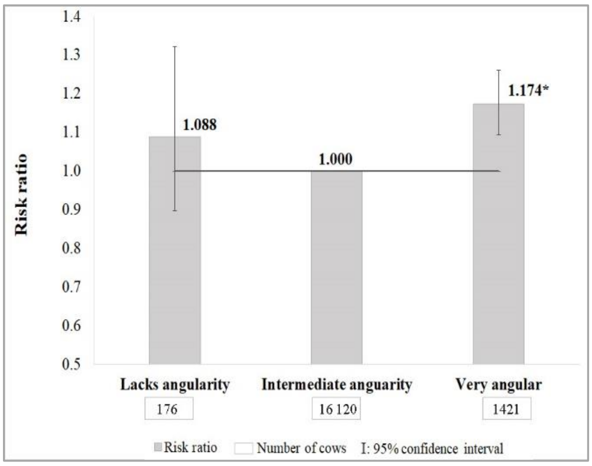

Figure 8: **Effect of angularity on relative culling risk**

*: Significant (p<0.05) difference from the reference group

The body depth is classified as the distance between the top of the spine and the bottom of the body (ICAR, 2018). Cows having deeper body depth had a 16% higher culling risk compared with the intermediate body depth (*Figure 7*).

Figure 8 presents the effect of angularity on longevity. Classification of angularity is by looking at the angle of the ribs (direction of the ribs) (ICAR, 2018). Cows having a higher score of angularity had a nearly 20% higher risk of culling compared with the reference class (category 2).

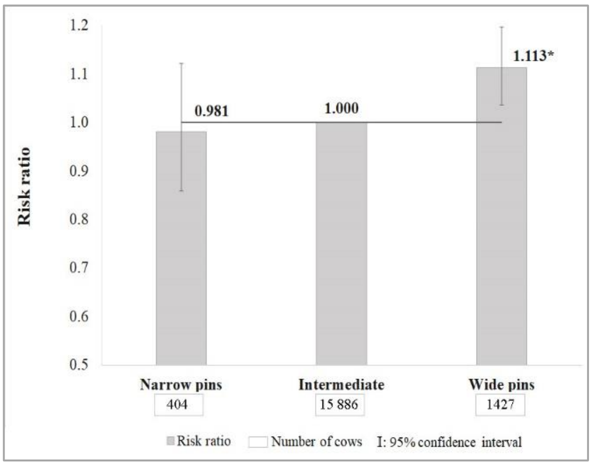

Figure 9: **Effect of rump width on relative culling risk**

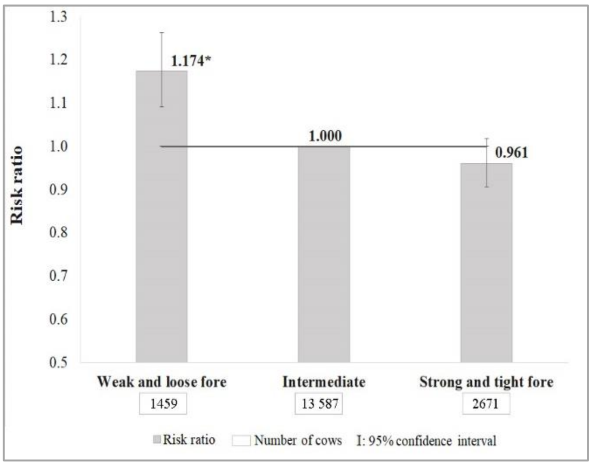

Figure 10: **Effect of fore udder attachment on relative culling risk**

*: Significant (p<0.05) difference from the reference group

Cows having wider pins had lower longevity than cows with intermediate rump width (*Figure 9*). These results were in agreement with the estimations for the Hungarian Simmental breed.

Figure 10 shows the effect of fore udder attachment on longevity. Fore udder attachment describes the strength of attachment of the fore udder to the abdominal wall (ICAR, 2018). Cows having weak and loose fore udder had a nearly 20% higher risk of culling than it was estimated for the reference group. The lowest risk ratio was observed for the strong and tight fore udder. The fore udder attachment might be in a relationship with mastitis.

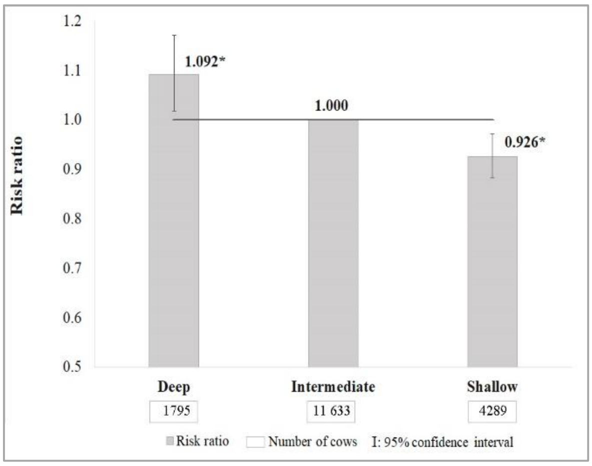

Figure 11: **Effect of udder depth on relative culling risk**

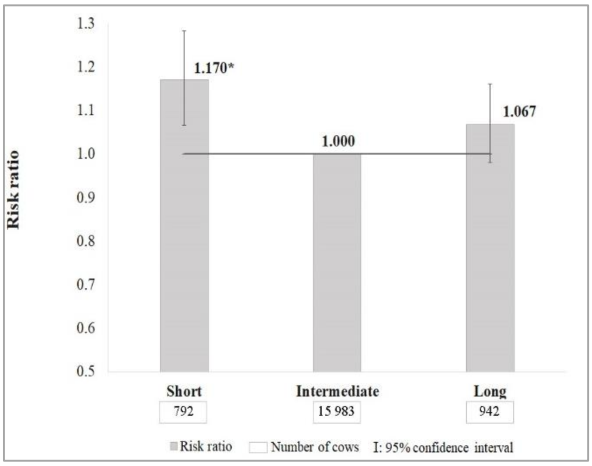

Figure 12: **Effect of teat length on relative culling risk**

*: Significant (p<0.05) difference from the reference group

Figure 11 shows the risk ratios of the effect of udder depth on longevity. Similar to the results presented for Hungarian Simmental, the relative risk decreased as the udder depth score increased. The highest risk of culling was found for the deep udder. The shallow udder was the most favourable on longevity. Most cows had intermediate and shallow udder depth.

The teat length is the distance between the root and the tip of the teat. Cows having shorter teats had a 15% higher risk of culling compared with the intermediate teat length (*Figure 12*). Cows with shorter teat length compared to intermediate teat length can be difficult to fit into intensive milking technology.

The analyzed Holstein-Friesian population's average longevity was 2.78 calving. The genetic variance estimated by the Weibull model was 0.155, which resulted in heritability h^2 = 0.11 of longevity, taking into account the 22.3% censoring rate.

3. 2. Effect of combinations of linear type traits on longevity

The combinations of linear type traits were based on principal component analysis and cluster analysis. This approach could estimate the interaction effect of traits.

<u>Hungarian Simmental</u>

The combination of central ligament and udder depth, as well as the combination of teat length and teat thickness were significant effects on longevity.

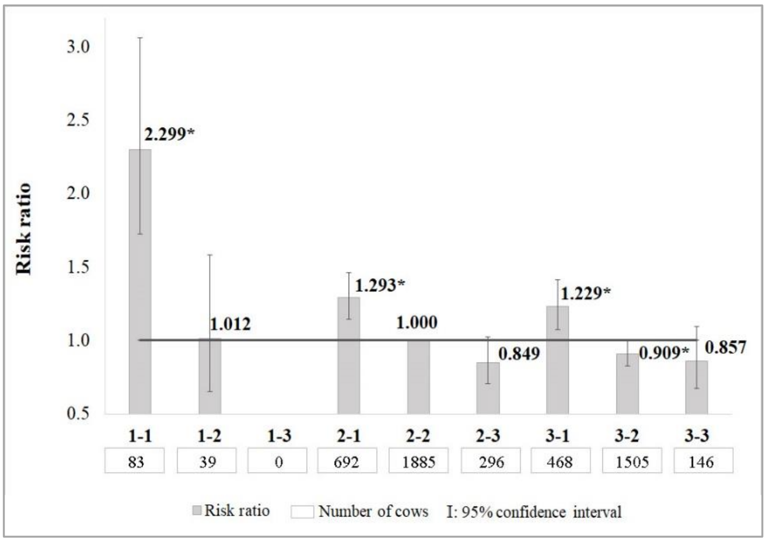

Figure 13: **Effect of combination of central ligament and udder depth on the culling risk**

1-1: weak central ligament-deep udder; **1-2**: weak-intermediate udder; **1-3**: weak-shallow udder; **2-1**: intermediate central ligament-deep udder; **2-2**: intermediate-intermediate udder; **2-3**: intermediate-shallow udder; **3-1**: strong central ligament-deep udder; **3-2**: strong-intermediate udder; **3-3**: strong-shallow udder

*: Significant (p<0.05) difference from the reference group

The relationship between the combination of central ligament and udder depth and culling risk was shown in *Figure 13*. The highest risk ratio was estimated for class 1-1. Cows having weak central ligament and deep udder had a 123% higher risk of culling than it was estimated for the reference group (intermediate central ligament with intermediate udder depth). The second highest risk ratio was observed in class 2-1 (intermediate central ligament with deep udder), the third in class 3-1 (strong central ligament-deep udder). The deep udder increased the risk ratio regardless of the score of the central ligament. The tendency of risk ratios was similar for weak central ligament (1-1, 1-2, 1-3), and intermediate central ligament (2-1, 2-2, 2-3), as well as strong central ligament (3-1, 3-2, 3-3) subclasses as risk ratio had decreased towards shallower udder depth. Most cows had intermediate central ligament with intermediate udder depth (2-2), as well as strong central ligament with intermediate udder depth (3-2). The number of cows having weak central ligament (1-1, 1-2, 1-3) was low.

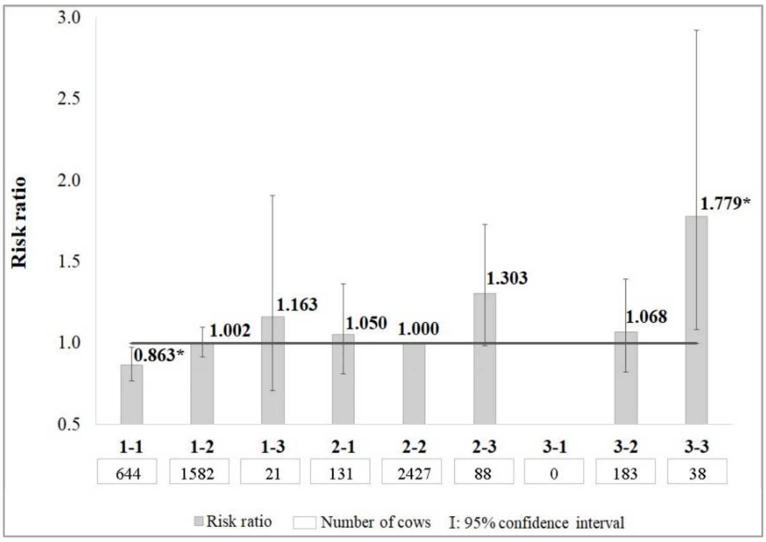

Figure 14: **Effect of combination of teat length and teat thickness on the culling risk**

1-1: short-thin teats; **1-2**: short-intermediate teats; **1-3**: short-thick teats; **2-1**: intermediate-thin teats; **2-2**: intermediate-intermediate teats; **2-3**: intermediate-thick teats; **3-1**: long-thick teats; **3-2**: long-intermediate teats; **3-3**: long-thick teats

*: Significant ($p<0.05$) difference from the reference group

Figure 14 shows the risk ratios of the effect of the combination of teat length and teat thickness on longevity. The highest risk ratio was estimated for class 3-3 (long and thick teats). The highest risk ratio was estimated for cows having long and thick teats, with about nearly 80% higher risk of culling compared with the intermediate length and intermediate thickness (class 2-2). The combinations 2-3 (intermediate and thick teats) and 1-3 (short and thick teats) had only tendencies to increase the risk of culling. The thick teats can tendentiously increase the risk ratio regardless of the score of teat length. Surprisingly, the lowest risk ratio was found in class 1-1 (short and thin teats). Most cows had intermediate teat length and intermediate teat thickness (class 2-2), as well as short and intermediate teat thickness (class 1-2). There were no observations for categories 3-1 (long and thin teats).

The genetic variance estimated by the Weibull model was 0.197, which resulted in heritability h^2=0.12 taking into account the 28.5 % censoring rate.

<u>Holstein-Friesian</u>

The combination of chest width and body depth, the combination of fore udder attachment and udder depth as well as the combination of angularity and rear udder height were significant effects on longevity.

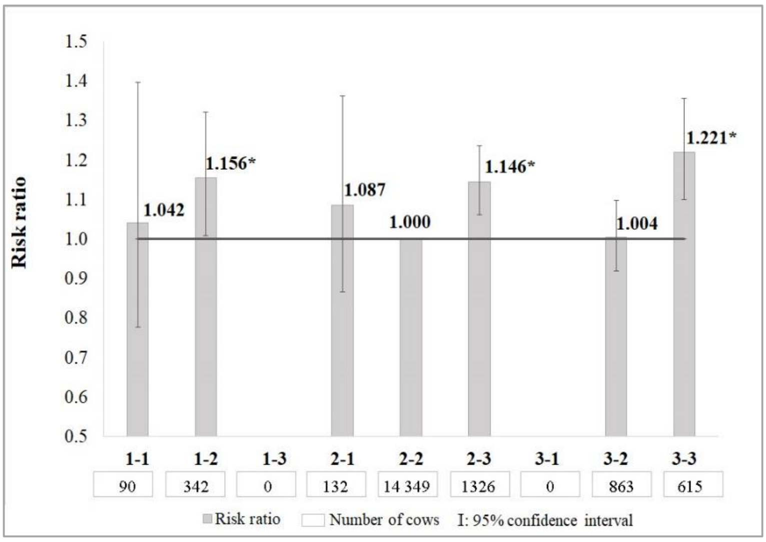

Figure 15: **Effect of combination of chest width and body depth on the culling risk**

1-1: narrow chest-shallow body depth; **1-2**: narrow chest-intermediate body depth; **1-3**: narrow chest-deep body; **2-1**: intermediate chest width-shallow body depth; **2-2**: intermediate chest width-intermediate body depth; **2-3**: intermediate chest width-deep body; **3-1**: wide chest-shallow body depth; **3-2**: wide chest-intermediate body depth; **3-3**: wide chest-deep body

*: Significant ($p<0.05$) difference from the reference group

Figure 15 shows the effect of the combination of chest width and body depth on the relative culling risk. The lowest risk ratio was observed for class 2-2 (intermediate chest width and intermediate body depth). In this case, the cows have optimal body weight, this combination has gentler on the joints as well as a more favourable effect on the foot structure. The stall floor made from concrete is part of the typical housing system in Hungarian farms, under such environmental conditions the intermediate chest width and body depth are advantageous. Cows having a wide chest and deep body (class: 3-3) had the highest culling risk compared to the reference group (class: 2-2). It was followed by cows with a narrow chest and intermediate body depth (class: 1-2) and the intermediate chest width and deep body (class: 2-3). The tendency of risk ratios was similar for narrow chest (1-1, 1-2) and wide chest (3-2, 3-3) subclasses, as risk ratios had increased along with body depth deepening, whereas for intermediate chest width subclasses the lowest culling ratio was estimated for intermediate body depth. There were no observations for categories 1-3 and 3-1. Overall, the risk ratio was higher in the case of the deeper body.

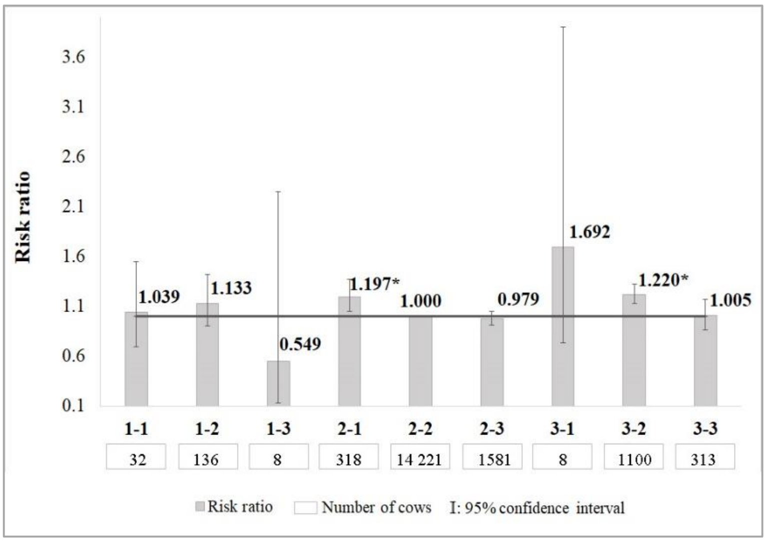

Figure 16: **Effect of combination of angularity and rear udder height on the culling risk**

1-1: lacks angularity-low rear udder height; **1-2**: lacks angularity-intermediate rear udder height; **1-3**: lacks angularity-high rear udder height; **2-1**: intermediate angularity-low rear udder height; **2-2**: intermediate angularity-intermediate rear udder height; **2-3**: intermediate angularity-high rear udder height; **3-1**: very angular-low rear udder height; **3-2**: very angular-intermediate rear udder height; **3-3**: very angular-high rear udder height
*: Significant ($p<0.05$) difference from the reference group

Figure 16 shows the risk ratios of the effect of the combination of angularity and rear udder height on longevity. The 3-2 (very angular with intermediate rear udder height) and 2-1 (intermediate angularity with low rear udder height) combinations had significant negative effects on longevity. Cows having higher scores of angularity with intermediate rear udder height (class 3-2) had a 22%, as well as the intermediate angularity with low rear udder height (2-1) had a 20% higher culling risk compared with the reference class. The risk ratio decreased along with the increased score in rear udder height, but the risk ratio increased along with the increased score of angularity.

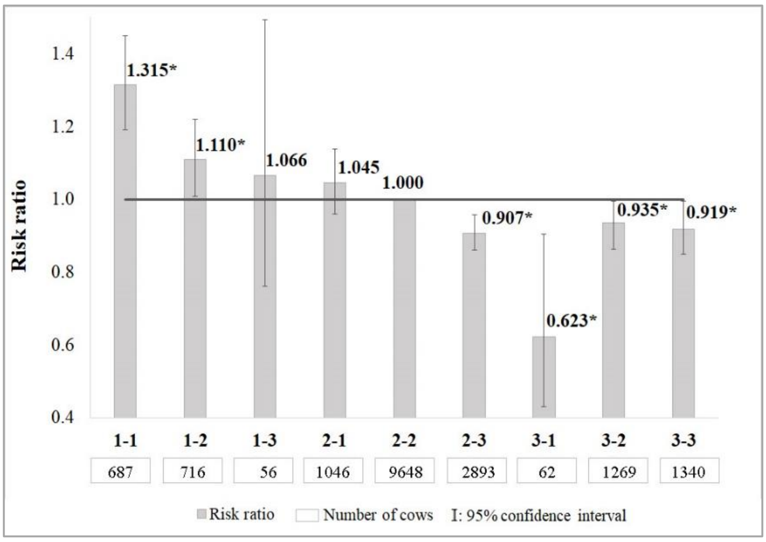

Figure 17: **Effect of combination of fore udder attachment and udder depth on the culling risk**

1-1: weak and loose fore udder-deep udder; **1-2**: weak and loose fore udder-intermediate udder depth; **1-3:** weak and loose fore udder-shallow udder depth; **2-1**: intermediate fore udder-deep udder; **2-2**: intermediate fore udder-intermediate udder depth; **2-3**: intermediate fore udder-shallow udder depth; **3-1**: strong and tight fore udder-deep udder; **3-2**: strong and tight fore udder-intermediate udder depth; **3-3**: strong and tight fore udder-shallow udder depth

*: Significant ($p<0.05$) difference from the reference group

The relationship between the combination of fore udder attachment and udder depth and culling risk was shown in *Figure 17*. The highest risk ratio was estimated for class 1-1. Cows having weak, loose and deep fore udder had a higher risk of culling than it was estimated for the reference group (class 2-2). The tendency of risk ratios was similar for weak and loose fore udder (1-1, 1-2, 1-3) and intermediate fore udder (2-1, 2-2, 2-3) subclasses as risk ratios had decreased towards shallower udder depth. Strong and tight fore udder subclasses were the most favourable (3-1, 3-2, 3-3).

The genetic variance estimated by the Weibull model was 0.169, which resulted the heritability h^2=0.12 taking into account the 22.3 % censoring rate.

4. New scientific results

The following scientific results can be established from my thesis:

1. The wider rump resulted in 9%, the weak central ligament 46%, the deep udder 32% as well as the thick teats 31% culling risk increase to the reference classes in the longevity of dual-purpose Hungarian Simmental cows. The risk of culling decreased with increasing scores of the mammary system, as well as the above-average musculature resulted in 17% culling risk increase compared to the reference class.

2. The combination of weak central ligament and deep udder resulted in 123% as well as the combination of long and thick teats 78% relative risk increase to the reference classes in the longevity of dual-purpose Hungarian Simmental cows. The highest risk ratio was estimated in cows having a lower score of mammary system with a lower score of feet and legs, with about 37% risk of culling compared with the reference class.

3. The deep body resulted in 16%, the higher score of angularity 17%, the wide rump width 11%, the weak and loose fore udder 17%, the deep udder 9% and the short teats 17% culling risk increase compared to the reference classes in the longevity of Hungarian Holstein-Friesian cows. The risk of culling increased with increasing scores of dairy form and body capacity, as well as the poor, fair mammary system and final score resulted in a 6% and 21% increase in culling risk compared to the reference group.

4. The combination of wide chest and deep body resulted in 22%, as well as the combination of the weak and loose fore udder and deep udder 32% relative risk increase to the reference classes in the longevity of Hungarian Holstein-Friesian cows. The highest risk ratio was estimated for „very good”, excellent dairy form with a poor, fair mammary system.

5. Important results of the thesis for practice

Based on the results of my thesis, the relationships among main and linear type traits and the longevity of dual-purpose Hungarian Simmental and Holstein-Friesian cows were determined.

1. The Hungarian Simmental dual-purpose cows having wider rump, weak central ligament, deep udder and thicker teats had shorter longevity. The deep body, the higher score of angularity, the wide rump, the weak and loose fore udder, the deep udder and the shorter teats were the most unfavourable for the Holstein-Friesian breed. The higher score of musculature, as well as the lower score of the mammary system increased the culling rate of Simmental cows. Among the main type traits, the very good, excellent dairy form and body capacity as well as the poor, fair mammary system and the final score had a negative impact on the longevity of Holstein-Friesian cows. Taking the results into account in breeding decisions and selection work can help increase the longevity of Holstein-Friesian and Simmental cows.

2. The evaluation of the relationship between combinations of conformation traits and the longevity approach could estimate the combined effect of traits. Hungarian Simmental cows having weak central ligament with deep udder as well as long and thick teats had shorter longevity. The combination of a wide chest and deep body and the weak and loose fore udder along with a deep udder reduced the longevity of Holstein-Friesian cows. The combination of the lower score of the mammary system and a lower score of feet and legs resulted in a negative impact on the longevity of Simmental cows. The combination of very good, excellent dairy form with poor, fair mammary system resulted in shorter longevity for Holstein-Friesian cows. These results can also be used in the system of conformation judging and can help to identify relationships between different linear and main type traits. Combinations can also be incorporated into breeding programs through the selection index.

3. Low heritability values of longevity were estimated for both breeds, indicating that the trait can be genetically improved by selection in addition to environmental factors.

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7. List of publications

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Candidate: Evelin Török
Doctoral School: Doctoral School of Animal Husbandry
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List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (3)

1. **Török, E.**, Vass, N., Béri, B., Könyves, L. P., Posta, J.: A hasznos élettartam alakulására ható tényezők elemzése holstein-fríz teheneknél.
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4. **Török, E.**, Füller, I., Vágó, B., Posta, J.: Evaluation of the relationship between main type traits and longevity in Hungarian Simmental cows.
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Hungarian conference proceedings (2)

7. **Török, E.**, Béri, B., Posta, J.: A termelésben töltött időt befolyásoló tényezők elemzése, különös tekintettel a lineáris küllemi tulajdonságokra a hazai tejtermelő állományokban.
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