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# Genetic Relationship between Type Traits, Number of Lactations Initiated, and Lifetime Milk Performance in Czech Fleckvieh Cattle

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**ABSTRACT**

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Genetic relationship was analyzed between type traits and longevity measures in dual-purpose cattle. Data from 91 486 Czech Fleckvieh cows first calved between 2003 and 2009 were used. Longevity was defined as the actual number of lactations initiated per cow and also as functional longevity, which incorporated an adjustment to account for variation in voluntary culling based upon milk production. Lifetime performance was defined as cumulative milk production through the 6$^{th}$ parity. All cows were scored for conformation traits during their first lactation. Genetic correlations between these traits and longevity measures were estimated by bivariate analysis using the DMU variance component program package. Type trait heritabilities ranged from 0.30 to 0.59, while heritabilities for longevity and functional longevity were 0.06 and 0.05, respectively. Heritability of lifetime performance was 0.08. Genetic correlations between type traits and longevity measures ranged from low to intermediate values. Genetic correlations of the measured body size traits to the real and functional longevity ranged from –0.06 to –0.29, for udder traits from –0.02 to 0.33, and for foot and leg traits from –0.03 to 0.17. Genetic correlations between the measured body size traits and lifetime performance ranged from –0.03 to –0.30, for udder traits from 0.05 to 0.47, for foot and leg traits from –0.07 to 0.15. Genetic correlations of composite trait scores for frame, muscularity, feet and legs, and udder with longevity traits ranged from –0.20 to 0.41 and for lifetime performance –0.14 to 0.51. The highest genetic correlations between a type trait and functional longevity were for composite udder score (0.25), feet and legs (0.26), and udder depth (0.33), suggesting that these traits could serve as indicators of functional longevity. We conclude that selection based upon easily and inexpensively measured type traits could improve functional longevity of cows as well as lifetime milk production.

**Keywords**: dairy cows; longevity; lifetime performance; conformation traits; genetic correlation

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Longevity is a significant trait in dairy cattle production. Especially important is functional longevity. In dairy and dual-purpose cattle breeds, lifespan affects not only the magnitude of milk production, but also farm profitability. With increased productive life, profitability rises in direct proportion to lactation milk yield. Longer productive life results in a higher proportion of cows that are in later, higher producing lactations (Vukasinovic et al. 1997). Additionally, reducing the proportion of culled cows reduces replacement heifer procurement cost (Sewalem et al. 2008).

In dairy cows, longevity is usually defined as the length of productive life, i.e. the number of days between first calving and eventual culling. Alternative longevity measures include age at culling, lifetime daily yield, and number of initiated lactations. Such traits may reflect economic efficiency as well as quantify the length of life.

Based upon work of Robertson (1966), Ducrocq (1987) proposed a distinction between actual and functional longevity. The former represents the actual length of life of the cow, independent of whether the animal left the herd due to involuntary culling, voluntary culling based upon milk production or other reasons. Alternatively, functional longevity represents the ability of a cow to avoid culling for involuntary reasons such as infertility or health problems. According to Robertson (1966), functional longevity can be approximated by statistically adjusting cow longevity for individual milk production relative to average production of the herd, thereby removing the effect of voluntary culling from breeding value estimations.

Longevity traits generally are reported to be lowly heritable, averaging about 0.10 (Vollema and Groen 1997; Essl 1998; Vukasinovic et al. 2001; Tsuruta et al. 2005). Therefore genetic improvement in longevity is difficult to achieve. A possible solution is to exploit the correlated response to selection on type traits, because several of them have shown intermediate genetic correlations to longevity traits (Vollema and Groen 1997; Vukasinovic et al. 2002; du Toit et al. 2012). Many type traits can be recorded during the first parity of the cow. Heritabilities for several such traits (ranging from 0.10 to 0.49 (Daliri et al. 2008; Campos et al. 2012, Zavadilova and Stipkova 2012)) have been higher than those generally reported for longevity traits. Suitable type-trait predictors of longevity in cattle include udder depth, teat position, rump length, and overall rating for udder. Cassandro et al. (1999) reported positive genetic correlations between functional longevity and udder depth and teat position of 0.43 and 0.21 respectively, while Zavadilova and Stipkova (2012) reported genetic correlations between functional longevity and height at sacrum of –0.26 and with rump length of 0.23 for Czech Holstein. The genetic correlation between longevity and rump length in Jersey cows was –0.19 (du Toit et al. 2012). Bouska et al. (2006) examined phenotypic relationships between linear type traits and longevity traits of Czech Fleckvieh cows, from which they concluded that increased survival time was linearly associated with increases in fore udder and rear udder, central ligament, and udder depth scores, making them potential indicators of cow longevity.

Lifetime performance is a trait that combines production and longevity (Klassen et al. 1992). It depends on production during each lactation, length of productive life, and calving interval. Health traits also are very important because they influence cost, production, and culling.

In a review article, Svitakova et al. (2014) reported that in recent years breeding objectives for cattle in the Czech Republic have assigned greater emphasis to functional traits such as reproductive performance, health, linear type traits, and longevity. Due to the requirements of breeders, our research is now focused on functional traits.

Prior to present analyses, Bouska et al. (2006) and Zavadilova et al. (2009a, b) reported on relationships between longevity and functional type traits in Fleckvieh cattle. While Bouska et al. (2006) and Zavadilova et al. (2009a) analyzed the phenotypic relationships between exterior traits and longevity, Zavadilova et al. (2009b) analyzed genetic relationships among them. All of the studies utilized records from the same Czech Fleckvieh population.

The aim of this research was to estimate the genetic relationships between longevity expressed as the number of initiated lactations and lifetime milk performance with type traits for Czech Fleckvieh cattle.

## MATERIAL AND METHODS

The data set consisted of records from 91 486 Czech Fleckvieh cows first calved between 2003 and 2009. All cows used in the analysis were scored for

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conformation between the 30th and the 210th day of their first lactation by classifiers of the Czech-Moravian Breeders' Corporation. Measured traits were height at sacrum, height at withers, rump length and width, body depth, and chest girth. The following traits (see Tables 1 and 2) were scored on a nine-point scale: height at sacrum, rump length, rump width, rump angle, body depth, rump muscularity, rear legs set, hock, pastern, heel, fore udder length, fore udder angle, rear udder length, rear udder attachment, central ligament, udder depth, front teat placement, teat position, teat length, and teat width. Frame, muscularity, feet and legs, and udder are composite traits for which the range of expression is between 50 and 100 points. When recording was terminated in 2015, all cows had been given the opportunity to begin the sixth lactation.

In this study, longevity was defined as the number of lactations initiated (NL), whereas functional longevity (NLF) was each cow's NL score adjusted for variation in her milk production. The number of lactations initiated was chosen as the descriptor of longevity because it is independent of the length of calving interval. Lifetime performance was defined as cumulative milk production through the 6th parity but only included milk yield from a normalized lactation, which is defined by the Czech-Moravian Breeders' Corporation for national dairy cattle performance control as one having at least 240 days in milk, no more than 305 days in milk, and total production of at least 1000 kg. This variable was transformed to log2 to achieve a normal distribution.

The model equation for linear type traits can be described as follows:

$$y_{ijklmn} = \mu + HDC_i + C_j + a_k + \beta_1 age_l + \beta_2 age_l^2 + \\ + \gamma_1 s_m + \gamma_2 s_m^2 + e_{ijklmn}$$

where:
dependent variables ($y_{ijklmn}$) are linear type trait scores, and fixed effects are $HDC_i$ (herd-date of classification – classifier, 10 114 levels) and $C_j$ (classifier, 2 levels). The model includes linear and quadratic regressions on age at first calving ($age_l$) and linear and quadratic regressions on days in milk at scoring $s_m$, where $\beta_1$, $\beta_2$, $\gamma_1$, $\gamma_2$ are regression coefficients. Random effects are animal ($a_k$) and the residual term ($e_{ijklmn}$).

The model equation for real and functional longevity and lifetime milk performance can be described as follows:

$$y_{ijklm} = \mu + HYS_i + a_k + \beta_1 age_l + \beta_2 age_l^2 + \lambda_1 mlk_j + \\ + \lambda_2 mlk_j^2 + e_{ijklm}$$

where:
dependent variables ($y_{ijklm}$) are number of lactations initiated and lifetime performance, and fixed effects are herd-year-season of the first calving ($HYS_i$, 12 243 levels) and linear and quadratic regressions on age at first calving ($age_l$) or on milk production in the first lactation ($mlk_j$) where $\beta_1$, $\beta_2$, $\lambda_1$, $\lambda_2$ are regression coefficients.

The above model was constructed for functional longevity but for real longevity and lifetime performance regression on milk production in the first lactation was excluded from the model.

Random effects are animal ($a_k$) and the residual term ($e_{ijklm}$). There were 334 322 animals in the pedigree file. Genetic correlations between longevity traits and type traits were estimated by bivariate analyses combining type trait and longevity trait using the variance component estimation program of the DMU package of Madsen and Jensen (2010).

Table 1. Description of scored traits

| Trait | Scale | | Ideal score |
|---|---|---|---|
| | 1st point | 9th point | |
| Height at sacrum | short | tall | 8 |
| Rump length | short | long | 9 |
| Rump width | narrow | wide | 9 |
| Rump angle | high pins | extreme slope | 5 |
| Body depth | shallow | deep | 9 |
| Rump muscularity | flat | very muscled | 9 |
| Rear legs set | straight | sickled | 5 |
| Hock | spongy | fine | 9 |
| Pastern | squashy | steep | 6 |
| Heel | short | tall | 7 |
| Fore udder length | short | long | 9 |
| Rear udder length | short | long | 9 |
| Rear udder attachment | very low | high | 9 |
| Central ligament | indistinct | deep and high | 9 |
| Udder depth | deep | shallow | 7 |
| Front teat placement | wide | narrow | 6 |
| Teat position | divergent | convergent | 5 |
| Teat length | short | long | 5 |
| Teat width | slim | thick | 5 |

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Table 2. Descriptive statistics of the analyzed data

| Trait | Number of cows | Mean | SD | CV (%) | Minimum | Maximum |
|---|---|---|---|---|---|---|
| Height at sacrum (cm) | 91 486 | 139.07 | 4.232 | 3.0 | 120 | 165 |
| Height at withers (cm) | 91 486 | 136.69 | 4.107 | 3.0 | 117 | 163 |
| Rump length (cm) | 91 486 | 53.50 | 2.228 | 4.2 | 43 | 65 |
| Rump width (cm) | 91 486 | 53.22 | 2.382 | 4.5 | 41 | 65 |
| Body depth (cm) | 91 486 | 79.55 | 4.021 | 5.1 | 52 | 97 |
| Chest girth (cm) | 91 486 | 196.79 | 8.663 | 4.4 | 160 | 232 |
| Height at sacrum (points) | 91 486 | 5.70 | 1.426 | 25.0 | 1 | 9 |
| Rump length (points) | 91 486 | 5.56 | 1.112 | 20.0 | 1 | 9 |
| Rump width (points) | 91 486 | 5.83 | 1.215 | 20.8 | 1 | 9 |
| Rump angle (points) | 91 486 | 5.46 | 1.031 | 18.9 | 1 | 9 |
| Body depth (points) | 91 486 | 5.94 | 1.051 | 17.7 | 1 | 9 |
| Rump muscularity (points) | 91 486 | 5.48 | 1.191 | 21.7 | 1 | 9 |
| Rear legs set (points) | 91 486 | 5.69 | 1.114 | 19.6 | 1 | 9 |
| Hock (points) | 91 486 | 5.78 | 1.208 | 20.9 | 1 | 9 |
| Pastern (points) | 91 486 | 4.85 | 1.176 | 24.1 | 1 | 9 |
| Heel (points) | 91 486 | 4.72 | 1.329 | 28.1 | 1 | 9 |
| Fore udder length (points) | 91 486 | 5.58 | 1.281 | 23.0 | 1 | 9 |
| Rear udder length (points) | 68 938 | 5.78 | 1.315 | 22.7 | 1 | 9 |
| Rear udder attachment (points) | 91 486 | 6.04 | 1.264 | 20.9 | 1 | 9 |
| Central ligament (points) | 91486 | 4.47 | 1.618 | 36.2 | 1 | 9 |
| Udder depth (points) | 91 486 | 6.08 | 1.123 | 18.5 | 1 | 9 |
| Front teat placement (points) | 91 486 | 5.16 | 1.082 | 21.0 | 1 | 9 |
| Teat position (points) | 81 570 | 4.62 | 1.316 | 28.5 | 1 | 9 |
| Teat length (points) | 91 486 | 4.53 | 1.079 | 23.8 | 1 | 9 |
| Teat width (points) | 91 486 | 5.21 | 1.203 | 23.1 | 1 | 9 |
| Frame (%) | 91 486 | 77.84 | 5.395 | 6.9 | 50 | 96 |
| Muscularity (%) | 91 486 | 76.88 | 6.134 | 8.0 | 50 | 94 |
| Feet and legs (%) | 91 486 | 75.60 | 9.328 | 12.3 | 10 | 99 |
| Udder (%) | 91 486 | 77.29 | 5.095 | 6.6 | 50 | 89 |
| Number of lactations initiated (*n*) | 91 486 | 3.28 | 1.745 | 53.2 | 1 | 13 |
| Number of lactations after editing[1] (*n*) | 91 486 | 3.21 | 1.586 | 49.5 | 1 | 6 |
| Age at 1st calving (points) | 91 486 | 853 | 80.25 | 9.40 | 654 | 1 247 |
| Milk production in 1st parity (kg) | 83 518 | 5 998 | 1 320.66 | 22.02 | 1 198 | 13 024 |
| Lifetime milk production (kg) | 88 559 | 19 685 | 12 304 | 62.50 | 1 401 | 55 994 |
| Lifetime milk production logaritmized | 88 559 | 13.92 | 1.089 | 7.74 | 10.45 | 15.74 |

SD = standard deviation, CV = coefficient of variation
[1]all parities over 6 are scored as 6

## RESULTS AND DISCUSSION

***Heritabilities***. Heritability estimates are shown in Table 3. As expected from published results, the highest heritabilities were found for height at sacrum (0.58), height at withers (0.59), and frame (0.43), while the lowest were for foot and leg traits (0.03–0.17). Udder and teat traits, rump traits, and others exhibited low to intermediate heritabilities (0.10–0.25). Body depth in cm had slightly higher heritability (0.27) than body depth scored objectively (0.20).

For Czech Holstein cows, Nemcova et al. (2011) reported similar but higher heritabilities for ud-

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der depth (0.32) and teat length (0.34) than those in the present study. Compared with our results, Nemcova et al. (2011) reported a lower heritability for height at withers of 0.40. In Czech Fleckvieh, Zavadilova et al. (2009b) found similar or lower values of heritabilities than those in this analysis: height at withers 0.39, udder depth 0.22, teat length 0.26. They reported a very large difference between heritability for body depth in cm and in scored points, 0.63 and 0.23, respectively. This difference was higher than that observed in our study. The dataset used by Zavadilova et al. (2009b) included Czech Fleckvieh cows first calved from 1994 to 2003. It is unlikely, however, that in the 10 years separating the two examined populations, there could have been substantial changes in heritability for type traits in the population.

Heritability was low for longevity expressed as number of lactations initiated. For observed longevity and functional longevity (adjusted for milk

Table 3. Heritabilities ($h_2$) for type traits and longevity measures; genetic correlations of type traits to longevity measures

| Trait | $h_2$ ± SE | NL ± SE | NLF ± SE | LifeMilk ± SE |
|---|---|---|---|---|
| Height at sacrum (cm) | 0.58 ± 0.014 | –0.14 ± 0.046** | –0.16 ± 0.049** | –0.04 ± –0.041 |
| Height at withers (cm) | 0.59 ± 0.013 | –0.12 ± 0.031** | –0.16 ± 0.049** | –0.07 ± 0.041* |
| Rump length (cm) | 0.26 ± 0.012 | –0.29 ± 0.049** | –0.16 ± 0.053** | –0.26 ± 0.044** |
| Rump width (cm) | 0.25 ± 0.011 | –0.26 ± 0.049** | –0.18 ± 0.054** | –0.30 ± 0.044** |
| Body depth (cm) | 0.27 ± 0.012 | –0.29 ± 0.049** | –0.19 ± 0.054** | –0.10 ± 0.045* |
| Chest girth (cm) | 0.28 ± 0.011 | –0.11 ± 0.049** | –0.06 ± 0.053** | –0.12 ± 0.044** |
| Height at sacrum (points) | 0.56 ± 0.013 | –0.14 ± 0.044** | –0.14 ± 0.048** | –0.04 ± 0.040 |
| Rump length (points) | 0.25 ± 0.012 | –0.24 ± 0.049** | –0.19 ± 0.055** | –0.27 ± 0.045** |
| Rump width (points) | 0.23 ± 0.011 | –0.25 ± 0.049** | –0.17 ± 0.055** | –0.30 ± 0.044** |
| Rump angle (points) | 0.20 ± 0.010 | 0.02 ± 0.052 | –0.03 ± 0.057 | 0.03 ± 0.048 |
| Body depth (points) | 0.20 ± 0.010 | –0.18 ± 0.052** | –0.19 ± 0.053** | –0.10 ± 0.046** |
| Rump muscularity (points) | 0.29 ± 0.012 | 0.01 ± 0.049 | 0.16 ± 0.052** | –0.19 ± 0.043** |
| Rear leg set (points) | 0.14 ± 0.006 | –0.10 ± 0.056 | –0.09 ± 0.062 | –0.07 ± 0.051 |
| Hock (points) | 0.17 ± 0.010 | 0.17 ± 0.052** | 0.14 ± 0.058** | 0.15 ± 0.048** |
| Pastern (points) | 0.09 ± 0.007 | 0.06 ± 0.062 | 0.09 ± 0.068 | 0.01 ± 0.057 |
| Heel (points) | 0.03 ± 0.004 | –0.03 ± 0.079 | –0.03 ± 0.088 | –0.05 ± 0.073 |
| Fore udder length (points) | 0.17 ± 0.010 | 0.26 ± 0.065** | 0.09 ± 0.059 | 0.36 ± 0.044** |
| Rear udder length (points) | 0.24 ± 0.013 | 0.23 ± 0.052** | –0.02 ± 0.060** | 0.48 ± 0.042** |
| Rear udder attachment (points) | 0.22 ± 0.011 | 0.28 ± 0.049** | 0.08 ± 0.057 | 0.47 ± 0.040** |
| Central ligament (points) | 0.10 ± 0.007 | 0.14 ± 0.058* | 0.09 ± 0.063 | 0.24 ± 0.052** |
| Udder depth (points) | 0.25 ± 0.012 | 0.21 ± 0.049** | 0.33 ± 0.023** | 0.05 ± 0.046 |
| Teat position (points) | 0.16 ± 0.009 | 0.14 ± 0.053** | 0.12 ± 0.059* | 0.13 ± 0.048** |
| Front teat placement (points) | 0.23 ± 0.052 | 0.06 ± 0.056 | 0.06 ± 0.056 | 0.05 ± 0.048 |
| Teat length (points) | 0.23 ± 0.059 | –0.08 ± 0.051 | –0.07 ± 0.056 | –0.09 ± 0.046* |
| Teat width (points) | 0.21 ± 0.010 | –0.16 ± 0.051** | –0.19 ± 0.055** | –0.12 ± 0.047** |
| Frame (%) | 0.43 ± 0.014 | –0.20 ± 0.046** | –0.18 ± 0.051** | –0.14 ± 0.043** |
| Muscularity (%) | 0.29 ± 0.012 | 0.05 ± 0.048 | 0.19 ± 0.052** | –0.18 ± 0.044** |
| Feet and legs (%) | 0.06 ± 0.006 | 0.24 ± 0.066** | 0.26 ± 0.071** | 0.09 ± 0.062 |
| Udder (%) | 0.19 ± 0.010 | 0.41 ± 0.047** | 0.25 ± 0.057** | 0.51 ± 0.039** |
| NL (*n*) | 0.06 ± 0.006 | | | 0.89 ± 0.013** |
| NLF (*n*) | 0.05 ± 0.005 | | | 0.87 ± 0.026** |
| LifeMilk | 0.08 ± 0.007 | | | |

NL = real longevity as number of lactations initiated, NLF = functional longevity as number of lactations initiated, LifeMilk = logaritmized lifetime milk performance, SE = standard error

*$P$ < 0.05, **$P$ < 0.01

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yield), estimates were 0.06 and 0.05, respectively. Heritability of lifetime performance was 0.08.

Similar estimates were published by Zavadilova and Stipkova (2012): 0.04–0.05 for number of lactations initiated (real and/or functional longevity) in Holstein. Pertinent heritability estimates in the literature include Zavadilova et al. (2009b) 0.05 for length of productive life (functional longevity) in Czech Fleckvieh; Daliri et al. (2008) 0.3 to 0.4 for herd life of Holsteins; Klassen et al. (1992) 0.05 for number of lactations in Holsteins. Our heritability estimates are at the low end of published estimates (Imbayarwo-Chikosi et al. 2015). For length of productive life (functional longevity), the highest heritability estimates generally have been from analyses in which proportional hazard models were used. For example, Caraviello et al. (2004) reported heritabilities in Jersey cows of 0.15 to 0.20 on the original scale, and Egger-Danner et al. (2005) reported 0.12 for Pinzgau. For Polish Simmental cattle, Morek-Kopec and Zarnecki (2017) reported the effective heritability 0.25 and equivalent heritability 0.09, when Weibull model was employed. Conversely, very low heritabilities generally are found when random regression models are employed. Examples include 0.002–0.01 by Van Pelt et al. (2015) in Dutch dairy cattle, and 0.01–0.07 by Veerkamp et al. (2001) in Holstein. For lifetime milk production in Holsteins, Klassen et al. (1992) reported a heritability of 0.10.

***Genetic correlations***. Genetic correlations between each type trait with real and functional longevity and lifetime milk performance are shown in Table 3. Genetic correlations between both longevity traits and the measured body size traits ranged from –0.06 to –0.29, while for lifetime performance, these correlations ranged between –0.04 and –0.30. For measured rump length, rump width, and body depth, the genetic correlations with real longevity were higher than those with functional longevity: from –0.26 to –0.29 vs from –0.16 to –0.19, respectively. The largest genetic correlations with lifetime milk were for rump length (–0.26) and rump width (–0.30). These negative correlations may be interpreted to mean that smaller and narrower cows, in comparison with larger and wider cows, are genetically predisposed to longer life and higher lifetime milk production. Body size traits scored in points (height at sacrum, rump length, rump width and body depth) showed similar patterns of genetic correlations with longevity and lifetime performance as for those of measured traits. An exception was body depth, for which genetic correlation of the measured trait with real longevity was higher than those for other body size traits, and for the scored body depth the correlations with both real and functional longevity were practically the same. This suggests that body depth in cm and body depth scored in points differ slightly in the information they convey. Zavadilova et al. (2009b) reported different tendencies for genetic correlations between functional and real longevity with both measured and scored body depth. For measured depth traits, the genetic correlations with real and functional longevity were almost the same (–0.12, –0.14). For scored body depth traits, the genetic correlation with real longevity was –0.16, while for functional longevity the genetic correlation with body depth was higher (–0.23) than the former. For Czech Fleckvieh cattle, Zavadilova et al. (2009b) reported predominantly negative genetic correlations of both longevity traits with body size type traits. For Brazilian Holsteins, Kern et al. (2015) reported genetic correlations between the number of lactations initiated and body size type traits ranging from –0.19 to –0.30. In their study du Toit et al. (2012) reported a similar value of –0.19 for genetic correlations between body depth and number of lactations in Jerseys. Higher genetic correlations between longevity and body depth than in the present study were –0.23 for Czech Holstein by Zavadilova and Stipkova (2012), –0.26 for Holstein by Kern et al. (2015), and 0.28 for Austrian Fleckvieh (Fuerst et al. 2013). For Aosta Red Pied, Mazza et al. (2016) found medium negative genetic correlations between test-day milk, fat and protein yield, and muscularity conformation score in dual-purpose cattle, values of –0.42, –0.37, –0.34, respectively.

Important differences between longevity traits (NL, NLF) and lifetime milk performance were found for rump muscularity. While NL was not genetically correlated with rump muscularity (0.01), NLF had a positive genetic correlation to rump muscularity (0.16); while lifetime yield performance had a negative genetic relationship (–0.19) with rump muscularity. A possible explanation is that lifetime performance depends on genetic merit for milk production, which seems to be compromised by higher muscularity. Equivalently, more muscular cows tend to have lower milk yield but better health and longer life. Because real longev-

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ity depends on milk performance and health, the resulting genetic correlation between muscularity and real longevity is zero.

Genetic correlations between udder type traits and both longevity traits were intermediate. For most udder traits, genetic correlations with real longevity were higher than those with functional longevity, while the genetic correlations of udder traits with lifetime milk production were higher than those with real as well as functional longevity. The only exception was for udder depth, which was correlated by 0.21, 0.33, and 0.05 with real longevity, functional longevity, and lifetime performance, respectively. From this we deduce that a large and well-attached udder is a prerequisite for high milk production. Conversely, cows with deep udders have a genetic predisposition to involuntary culling, probably due to udder health problems. However, the genetic connection between udder depth and lifetime milk production is near zero. We conclude that sires and dams with high breeding values are to be preferred to ensure offspring with well-attached, moderately deep udders.

High genetic correlations between functional longevity and udder depth were –0.36 for Swiss Simmental (Vukasinovic et al. 2002) and –0.28 for Czech Fleckvieh (Zavadilova et al. 2009b). Lower genetic correlations between functional longevity and udder depth were 0.16 for Jersey (du Toit et al. 2012) and 0.17 for Holstein (Kern et al. 2015). Also for Holstein cattle, Setati et al. (2004) found positive genetic correlations between udder traits and functional longevity expressed as number of lactations initiated to be much higher than those reported in our study (rear udder height 0.22, fore udder attachment 0.41, udder depth 0.31). For Aosta Red Pied dual-purpose cattle, Mazza et al. (2016) reported low negative genetic correlations between test-day milk yield and udder conformation factor (udder depth, teat placement, teat length) of –0.28, –0.22, –0.24, respectively. In contrast, these authors found positive genetic correlations between test-day milk, fat and protein yield with a morphological factor representing udder size traits (fore and rear udder attachment, udder width) of 0.68, 0.59, 0.66, respectively.

Zavadilova et al. (2009b) reported a near zero genetic correlation (–0.02) between udder depth and real longevity, compared with 0.21 in the current study. In Zavadilova et al. (2009b), fore udder length, rear udder attachment, and central ligament showed positive genetic correlations with real longevity and negative genetic correlations with functional longevity. For Czech Fleckvieh, Bouska et al. (2006) proposed fore udder, rear udder, central ligament, and udder depth as potential indicators of cow longevity.

Genetic correlations of teat traits to longevity were low to intermediate, and there were no important differences in those genetic correlations between functional and real longevity and lifetime production. Among traits, teat width had the largest genetic correlation with longevity, –0.16 and –0.19 for functional vs real, respectively, and –0.12 for lifetime performance. Slimmer teats were associated with a higher number of initiated lactations and higher lifetime production. Genetic correlations between front teat placement and teat position with longevity traits suggested that narrower and more convergent teats were associated with an increased number of lactations initiated. Zavadilova et al. (2009b) reported similar results for teat placement and teat length and width, but their estimates were higher than those in the present study. For Jersey cattle, du Toit et al. (2012) also reported higher genetic correlations for teat placement (0.28) and teat length (–0.34) than those in our study. In Holsteins, Kern et al. (2015) reported lower estimates than in our study for genetic correlations of functional longevity to teat placement (0.02) and teat length (0.11).

In our study differences between genetic correlations of foot and legs traits with real and functional longevity were minimal. The hock trait showed the highest genetic correlation to both real and functional longevity, (0.19 and 0.14, respectively), and to lifetime production (0.15). We conclude that dry and fine hock is weakly genetically correlated with longer cow life and higher milk production. For Czech Fleckvieh, Zavadilova et al. (2009b) reported genetic correlations between hock and these longevity traits of 0.24 and 0.17. Similar results were reported by Zavadilova and Stipkova (2012) in Czech Holsteins – genetic correlations between hock quality and real longevity 0.19 and for functional longevity 0.19 when longevity was expressed as production life in days, but only 0.05 for real and functional longevity when longevity was expressed in number of lactations initiated. In contrast to our results for pastern, Zavadilova et al. (2009b) reported a negative genetic correlation (–0.10) with real longevity and a positive genetic correlation (0.12) with functional longevity.

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Genetic correlations of composite traits (frame, muscularity, feet and legs, udder) to longevity traits and to lifetime milk production were intermediate to low. All correlations had positive values except those between muscularity and lifetime milk production and frame and real longevity, functional longevity, and lifetime milk production. Negative genetic correlations of frame to the longevity traits were consistent with results for body size traits. Higher breeding values for composite traits, excluding body frame, were associated with genetic merit for a higher number of lactations initiated. Lifetime milk production was positively correlated only with the composite udder trait 0.51.

Negative genetic correlations in Czech Fleckvieh between longevity and frame suggest that genetically smaller cows have a genetic predisposition for longer life. Negative genetic correlations between functional longevity expressed as number of lactations initiated and stature were published by Zavadilova and Stipkova 2012 (–0.20) and by Kern et al. 2015 (–0.30) in Holstein.

Genetic correlations between feet and leg score and longevity traits suggest that cows with higher scores have a genetic disposition for a greater number of lactations initiated. Earlier, Zavadilova et al. (2009b) in Czech Fleckvieh reported lower genetic correlations than in the current study between real and functional longevity and feet and legs (–0.01, 0.09). For Austrian Fleckvieh, Fuerst et al. (2013) reported a substantial genetic correlation (0.36) between functional longevity and feet and legs, similar to the results of Pfeiffer et al. (2014) of 0.39.

Our estimate of the genetic correlation between muscularity and functional longevity was 0.19, whereas the genetic correlation to real longevity was very low. Thus, cows that scored higher for muscularity also had enhanced probability of initiating a higher number of lactations, independent of milk production. In contrast to our study, Zavadilova et al. (2009b) reported a genetic correlation between muscularity and real longevity of –0.23 and of 0.03 between muscularity and functional longevity. They hypothesized that muscularity showed a negative relationship with real longevity due to milk production, i.e. cows with excellent muscularity showed lower milk production due to antagonism between the traits. Fuerst et al. (2013) reported a genetic correlation of muscularity with functional longevity of 0.15, while Pfeiffer et al. (2014) reported a negative genetic correlation between those traits of –0.08.

Udder evaluated as a composite trait had the highest genetic correlation with real longevity of any of the composite traits, a value of 0.41. We assume that the high milk yield of high udder score cows is responsible for the positive genetic correlation of udder score and real longevity. For functional longevity, the genetic correlation with udder as a composite trait was 0.25. We propose that lower genetic correlations with functional longevity than with real longevity probably are caused by statistical corrections for variation in milk production. In the definition of functional longevity, culling is triggered only by health or age but not by low milk production. Zavadilova et al. (2009b) similarly reported a higher genetic correlation between udder and real longevity in days (0.28) than between udder and functional longevity (–0.02). For Czech Fleckvieh, Bouska et al. (2006) reported an increasing survival time of cows to be associated with a steady increase in udder trait scores. For Austrian Fleckvieh, Fuerst et al. (2013) reported a genetic correlation between longevity and udder score of 0.39. Pfeiffer et al. (2014) reported a value of 0.40 for the same genetic parameter.

Three related studies preceded our analysis, all utilizing data from Czech Fleckvieh cattle: Bouska et al. (2006), Zavadilova et al. (2009a), and Zavadilova et al. (2009b). Each examined the relationship between traits measured on the live animal and its subsequent longevity in the herd. While Bouska et al. (2006) and Zavadilova (2009a) analyzed phenotypic relationships between exterior traits and longevity, Zavadilova (2009b) analyzed genetic relationships between them.

The differences in correlations between the current study and analyses performed by Zavadilova et al. (2009b) could be explained by different definitions of the longevity traits. Zavadilova et al. (2009b) defined longevity as the number of days between first calving and culling, i.e. length of productive life.

Zavadilova and Stipkova (2012) analyzed genetic relationships between exterior traits and longevity in Holstein cattle when longevity was defined as the number of days of productive life or number of lactations initiated. Their results indicate that the length of productive life and number of lactations are different traits according to longevity because

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length of productive life includes the length of calving interval. For Holstein cows, Zavadilova and Stipkova (2012) and Kern et al. (2015), however, found minimal differences in genetic correlations when assuming different methods of defining longevity. Therefore we assume that differences in the estimates of genetic correlations by Zavadilova et al. (2009b) and those in the current study are caused more by a diverse definition of longevity traits or augmentation of dataset than by genetic changes of the cattle population over time.

## CONCLUSION

We conclude that various measured and subjectively scored type traits in Czech Fleckvieh are genetically correlated with longevity expressed as the number of initiated lactations (real or functional) and with lifetime milk performance. These genetic relationships vary from low to intermediate, the highest relationship is manifested especially in udder and body size traits including feet and leg score and muscularity as a composite trait.

The genetic correlations between exterior traits and longevity measures showed the differing importance of type traits in the selection process. It is obvious that selection on lifetime milk performance influences positively all udder traits except udder depth while leading to reduced muscularity as a correlated response. We also conclude that number of lactations initiated is a reasonable equivalent to longevity measured in days and has the advantage of being independent of the length of the calving interval. Lifetime performance includes the production, reproduction, health and economic considerations and indicates the genetic potential and quality of herd management and therefore proves to be a composite performance indicator for dairy cows in some aspect better then functional longevity. There were few important differences between genetic correlations of type traits with real versus functional longevity. Due to their positive genetic correlations with functional longevity, udder depth and two composite traits: udder and feet and legs, are recommended as potential indicators of that desired trait. In addition, selection for fore and rear udder length and high rear udder attachment may contribute to greater longevity of Czech Fleckvieh cattle.

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