Genetic correlations between longevity and conformation traits in the Czech Holstein population

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ABSTRACT: Genetic correlations between longevity and conformation traits were estimated using data on Czech Holstein cows first calved in the years 1993–2008. Longevity traits considered were length of productive life and number of lactations initiated and their functional equivalents (i.e. the longevity traits corrected for milk production). Conformation traits were twenty one linear descriptive type traits, six composite traits and height at sacrum measured in cm. A possible nonlinear relationship between conformation and longevity traits was also investigated. The heritabilities ranged from 0.05 to 0.43 for conformation traits and from 0.03 to 0.05 for longevity traits. Low to moderate genetic relationships between conformation and longevity traits were found. The genetic correlations were higher for functional longevity than for direct longevity traits. Negative genetic correlations with all longevity traits were found for height at the sacrum, stature, dairy form, body conformation, and capacity. Final score showed weak genetic correlation with all analyzed longevity traits. Positive genetic correlations occurred between feet and legs and direct longevity and functional longevity (0.19, 0.14) and between udder and direct longevity (0.10). Body condition score and angularity showed strong genetic correlations with functional longevity (body condition score 0.30, angularity –0.31). Foot and leg traits showed weak genetic correlations with longevity traits except rear legs set (side view) (–0.24) and hock quality (0.19). The udder traits showed inconsistent and rather weak genetic correlations with longevity traits, with the exception of a stronger genetic correlation between rear udder width and functional longevity (–0.22) and between central ligament and number of lactations (–0.18, –0.19). The teat traits showed always negative genetic correlations with longevity traits. The strongest correlations were found for rear teat position (–0.28) and the weakest for teat length (–0.03). Some conformation traits showed markedly stronger genetic correlations with functional longevity than with direct longevity (rear udder width and rear udder height, dairy form, body condition score, angularity, rear legs set (side view), rear legs rear view). A quadratic relationship between conformation and longevity traits did exist. Even if the linear relationship generally prevailed, the quadratic relationship should be taken into account.

Keywords: cows; Holstein breed; longevity; conformation traits; genetic correlation; nonlinearity

Longevity is a trait of high importance in breeding programs. Especially functional longevity, i.e. the cow's ability to delay involuntary culling, is an economically important trait. Introducing longevity traits in selection indices or increasing the accuracy of young bulls' genetic evaluation for longevity (Vukasinovic et al., 2002) demands knowledge on genetic correlations between longevity traits and other traits that are generally evaluated in dairy cattle. In particular, focus should be placed on the relationship with potentially early predictors, e.g. conformation traits.

Conformation continues to be an important component of breeding and selection decisions

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for dairy cattle populations. Culling decisions are often, either directly or indirectly, primarily influenced by conformation. Conformation traits can be measured during the first lactation and have reasonably strong genetic correlations with longevity, ranging from 0.15 to 0.40 (Short and Lawlor, 1992). Conformation traits describing udder, feet and legs, and overall type have moderate to high heritabilities making selection more efficient. Consequently, most research studies have attempted to indentify conformation traits that can be used as predictors of longevity. Many studies (Rogers et al., 1989; Burke and Funk, 1993; Vollema and Groen, 1997; Cruickshank et al., 2002; Vacek et al., 2006) have examined the relationships among longevity and conformations traits. Conformation traits usually showed stronger correlation to functional longevity that represents the ability of a cow to delay involuntary culling than to direct herd life. Among the conformation traits, the udder traits or foot and leg traits seem to be the most important ones, but the published genetic correlations depend considerably on the analyzed cattle populations (Larroque and Ducrocq, 1999) and changed when the population changed with time (Vollema and Groen, 1997). The genetic parameters should be re-estimated over time when they are intended to be implemented in breeding programs.

The relationship of longevity to conformations traits is not always linear. For some conformation traits, the highest of the lowest score presents the desirable optimum. Some conformation traits might have an optimum value with regard to longevity. Several researchers (Foster et al., 1989; Burke and Funk, 1993; Dekkers et al., 1994) found significant quadratic regression coefficients when using conformation traits to explain longevity.

The objective of this study was to investigate the genetic relationship between longevity and conformation traits and to test non-linearity of the relationship.

MATERIAL AND METHODS

The data originated from 57 803 Holstein cows first calved from 2003 to 2008. All cows used in the analysis were scored for conformation between the 30th and the 210th day of their first lactation. The data were obtained from the Holstein Cattle Breeders' Association of the Czech Republic. Cows were required to have valid sire identification and age at the first calving had to be between 500 and 1200 days of age. The following linear type traits were used: fore udder attachment, rear udder height, udder depth, rear udder width, central ligament, teat length, front teat placement, rear teat position, stature, angularity, chest width, body depth, rump angle, rump width, rear legs (rear view), rear legs set (side view), foot angle, bone quality, body condition score (BCS) and locomotion. The traits were scored on a nine-point scale. Height at sacrum was measured in cm. Final score, dairy form, body capacity, body composition, udder and feet and legs were composite traits evaluated in the interval between 50 and 100 points. All of the composite traits except for final score were computed as functions of scores of the appropriate sets of linear type traits. Final score was calculated from the other composite traits (Holstein Cattle Breeders' Association of the Czech Republic, 2010). All traits were recorded on all cows, with the exceptions of locomotion (49 759 records), rear udder width (46 258 records), BCS (25 752 records), hock quality (11 545), dairy form (57 761), capacity (57 761) and height at sacrum (50 729 records). The descriptions and basic statistical characteristics of the analyzed traits are presented in Table 1a and 1b.

Longevity expressed as the number of days between the first calving and culling, i.e. as length of productive life (LPL), averaged 712 days with a minimum of 27 days and a maximum of 2034 days; when longevity was given in number of lactations initiated (NL), the average was 2.1 parities with a minimum of 1 and a maximum of 5. Both longevity traits (LPL and NL) were corrected for milk production including the effect of first lactation milk yield in the model employed for the genetic parameters estimation. After this correction, longevity traits included in the analysis were considered to be functional, which was indicated by suffix F (length of productive life as functional longevity, LPLF, number of lactations initiated as functional longevity, NLF). All cows in the study were culled. The percentages of culled cows in different parities are presented in Figure 1. The highest number of cows was culled in the second lactation. That is different from the common culling policy in the Czech Republic, where most cows are culled in the first lactation. This could be explained by the fact that the analyzed dataset included only cows scored for conformation. The number of cows culled in the first lactation was lower by the number of cows culled before conformation scoring.

Table 1a. Means and standard deviations of linear type traits and their description

Traits	*n*	Mean	SD	*CV* (%)	Type traits score	
					1	9
Stature	57 803	5.9	1.32	22.28	short	tall
Body condition score	25 752	4.8	1.34	27.71	thin	fat
Angularity	57 803	5.5	1.23	22.23	lacks angularity, coarse	very angular
Body depth	57 803	5.8	1.42	24.41	shallow	deep
Chest width	57 803	5.8	1.39	24.06	narrow	wide
Rump width	57 803	5.9	1.37	23.42	narrow	wide
Rump angle	57 803	4.9	1.28	26.16	high pins	extreme slope
Rear legs set (side view)	57 803	5.3	1.36	25.90	straight	sickle
Rear legs (rear view)	57 803	5.2	1.63	31.32	extreme toe out	parallel feet
Hock quality	11 545	5.4	1.62	29.93	swollen	dry
Foot angle	57 803	4.9	1.23	25.06	very low angle	very steep
Bone quality	57 803	5.8	1.47	25.47	coarse	flat
Locomotion	49 759	5.1	1.54	30.41	severe abduction and short stride	no abduction and long stride
Central ligament	57 803	5.6	1.66	29.86	weak	strong
Fore udder attachment	57 803	5.2	1.61	31.11	weak and loose	extremely strong and tight
Rear udder width	46 258	5.3	1.56	29.73	narrow	wide
Rear udder height	57 803	5.5	1.57	28.56	very low	high
Udder depth	57 803	5.7	1.54	26.98	below hock	shallow
Rear teat position	57 803	5.6	1.52	27.30	outside the quarter	inside the quarter
Front teat placement	57 803	4.9	1.28	26.21	outside the quarter	inside the quarter
Teat length	57 803	4.7	1.16	24.34	short	long

n = number of records, SD = standard deviation, *CV* = coefficient of variance

Table 1b. Means and standard deviations of height at the sacrum, composite traits, length of productive life, and number of lactations initiated

Traits	*n*	Mean	SD	*CV* (%)
Height at sacrum (cm)	50 729	144.0	3.93	2.73
Dairy form	57 761	80.0	3.88	4.85
Body capacity	57 761	81.2	4.03	4.96
Body conformation	57 803	80.5	4.27	5.31
Udder	57 803	78.3	4.87	6.21
Final score	57 803	79.2	3.04	3.84
Feet & legs	57 803	79.0	4.74	6.01
LPL	57 803	712.2	378.31	53.12
NL	57 803	2.1	1.00	47.42

n = number of records, SD = standard deviation, *CV* = coefficient of variance, LPL = length of productive life, NL = number of lactations initiated

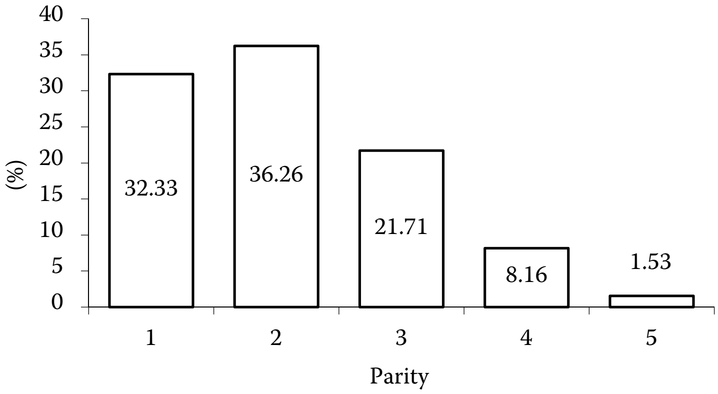

Figure 1. Percentage of cows culled in different parities

Genetic correlations between longevity traits and conformation traits were estimated in bivariate runs using restricted maximum likelihood (REML) and optimization by a quasi Newton algorithm with analytical gradients (Neumaier and Groeneveld, 1998) as implemented in VCE 6.0 program (Groeneveld et al., 2008).

The following model was used to estimate the genetic parameters:

$$Y_{ijklmno} = \text{herd}_i + \text{year season}_j + \text{age}_k + \text{classif}_l + \text{last}_m + \text{animal}_n + \text{MILK}_o + e_{ijklmno}$$

where:

$Y_{ijklmno}$ = observation of longevity or conformation trait

herd_i = fixed effect of herd i (749 herds)

year season_j = combined fixed effect of year (2003–2008) and season (January to March, April to June, July to September, October to December) of the first calving j (22 classes)

age_k = fixed effect of age at the first calving k (<690; 691–750; 751–850; 851–970; >971 days) (5 classes)

classif_l = fixed effect of classifier l (8 classes), only for conformation traits

last_m = fixed effect of season of the last calving m, only for longevity traits (January to March, April to June, July to September, October to December) (4 classes)

animal_n = random effect of animal n connected with pedigree including 146 440 animals

MILK_o = fixed effect of the first lactation milk yield expressed as deviation from within herd-year-first parity average (between the herd-year average and +0.5 standard deviation (SD); between +0.5 SD and +1 SD; over +1 SD; between the herd-year average and –0.5 SD; between 0.5 SD and –1 SD; below –1 SD; production below 1000 kg of milk per lactation and/or length of lactation below 240 days; 7 classes), only for functional longevity traits (LPLF and NLF)

$e_{ijklmno}$ = random residual effect

Each bivariate analysis included the equation for the longevity trait and that for the conformation trait. Because longevity was defined in two ways – as direct, that is uncorrected for milk production (LPL, NL), and as functional or corrected for milk production (LPLF, NLF), two sets of analyses were created for LPL and NL. Each of them included all the conformation traits analyzed. Therefore, there are four sets of results, estimated genetic correlations between longevity and conformation traits, presented in this study. The estimated heritabilities for conformation traits are presented and discussed only once, from bivariate analyses between conformation traits and LPL. The results for heritability of conformation traits from the other sets of analyses were almost the same.

To check linear and quadratic relationships between conformation and longevity trait, the estimates of breeding values for sires with more than ten daughters in the analyzed dataset were used. The solutions for sires from bivariate analysis were used for the estimation of the regression coefficients. Both the linear and the quadratic regression coefficients of each breeding value for a conformation trait on each breeding value for a longevity trait were calculated separately using the REG procedure of SAS (2002).

RESULTS

Heritability

Heritability estimates are only presented and discussed from the set of bivariate analyses between conformation traits and LPL. The estimates of heritability from bivariate analyses between conformation traits and the other longevity traits were almost the same, differences between heritability estimates from separate analyses were negligible.

Table 2. Estimated heritabilities[1] and genetic correlations[2] between longevity traits and conformations traits

Trait	h	Genetic correlations to longevity traits			
		LPL	LPLF	NL	NLF
Final score	0.21	–0.01	0.02	–0.10	–0.13
Dairy form	0.28	–0.10	–0.26	–0.23	–0.30
Body conformation	0.20	–0.21	–0.20	–0.15	–0.14
Feet and legs	0.12	0.19	0.14	0.09	0.01
Udder	0.18	0.10	0.03	–0.02	–0.04
Capacity	0.20	–0.26	–0.27	–0.21	–0.21
Height at sacrum	0.43	–0.18	–0.26	–0.16	–0.19
Stature	0.41	–0.18	–0.27	–0.18	–0.20
Body condition score	0.30	0.14	0.30	0.22	0.29
Angularity	0.22	–0.06	–0.25	–0.22	–0.31
Body depth	0.21	–0.22	–0.23	–0.21	–0.26
Chest width	0.15	–0.15	–0.08	–0.08	–0.04
Rump width	0.35	–0.21	–0.27	–0.14	–0.15
Rump angle	0.31	0.19	0.15	0.21	0.20
Rear legs set (side view)	0.14	–0.17	–0.22	–0.11	–0.24
Rear legs (rear view)	0.09	–0.01	–0.07	0.00	–0.10
Hock quality	0.20	0.19	0.19	0.05	0.05
Foot angle	0.10	0.10	0.06	0.01	–0.10
Bone quality	0.24	0.08	0.01	–0.02	–0.11
Locomotion	0.05	0.06	0.10	0.07	0.09
Central ligament	0.18	–0.09	–0.11	–0.18	–0.19
Fore udder attachment	0.21	0.04	0.10	0.04	0.06
Rear udder width	0.13	0.06	–0.22	–0.03	–0.16
Rear udder height	0.20	0.06	–0.10	–0.04	–0.13
Udder depth	0.28	0.08	0.11	0.04	0.04
Rear teat position	0.26	–0.21	–0.21	–0.28	–0.24
Front teat placement	0.24	–0.12	–0.13	–0.14	–0.13
Teat length	0.27	–0.05	–0.07	–0.03	–0.04

LPL = length of productive life, NL = number of lactations initiated, LPLF = length of productive life as the functional longevity, NLF = number of lactations initiated as the functional longevity

[1]standard error of heritability (*h*) estimates ranges from 0.0039 to 0.0107

[2]standard error of genetic correlations estimates ranges from 0.0065 to 0.1058

The estimated heritability for longevity traits ranged from 0.03 to 0.05. A comparison of the results for longevity uncorrected for milk production (LPL) and that corrected for milk production (LPLF) revealed that the heritability was 0.03. The heritability for NL (0.05) was slightly higher than that for its functional equivalent (NLF) (0.04). The standard errors of the estimates ranged from 0.0038 to 0.0288.

The estimated heritabilities for conformation traits are presented in Table 2. Among linear type traits, the highest heritability was found for height at the sacrum (0.43), the lowest one for locomotion (0.05). The heritabilities for traits related to body stature, body size and body depth ranged from 0.14 to 0.42. The heritability for rump traits was 0.31 for rump angle and 0.35 for rump width. For foot and leg traits, the heritability estimates were between 0.09 and 0.20. For bone quality, the estimated heritability was 0.24. The range of estimated heritability was from 0.14 to 0.28 for udder traits and from 0.24 to 0.27 for teat traits. The heritability for BCS was 0.30. Among composite traits, the highest estimated heritability occurred for dairy form (0.28) and the lowest one was found for feet and legs (0.12).

Genetic correlations between longevity and conformation traits

Table 2 summarizes the estimated genetic correlations between longevity and conformation traits. The height at the sacrum showed negative correlations with all longevity traits, although these correlations were stronger with functional (–0.26, –0.19) than with uncorrected (–0.18, –0.16) longevity traits. The difference between direct and functional longevity was more expressive for LPL than for NL. Almost the same results were found for stature. These results indicate that, from the genetic point of view, tall cows tended to have poorer longevity, especially poorer functional longevity. The stronger correlations with functional LPL than with functional NL can be explained by the fact that LPL takes into account the number of days.

Longevity and composite traits. Among composite traits, negative genetic correlations with all longevity traits occurred for dairy form, capacity, and body composition. In contrast to capacity and body composition, dairy form showed stronger correlations with functional longevity traits than with direct longevity traits and also stronger correlations with NL than with LPL. Generally, cows with higher breeding value for dairy form, capacity, and body composition have lower breeding value for longevity. The composite trait feet and legs showed slight positive genetic correlations with both types of longevity traits. These correlations were stronger with direct longevity than with functional longevity traits, but considerably weaker with NL than with LPL. The composite trait udder shows inconsistent and rather weak genetic correlations with longevity. It had slight positive genetic correlations with LPL but negative ones with NL. Similarly, final score showed weak genetic correlations with LPL and slightly higher negative correlations with NL. Summing up the results for composite traits, all genetic correlations with a value of 0.10 and higher were negative except the genetic correlation between feet and legs with LPL and LPLF (0.19; 0.14) and udder with LPL (0.10). Only these two composite traits (feet and legs and udder) are positively connected with longevity expressed as length of productive life.

Longevity and linear type traits. Among linear type traits, BCS showed positive genetic correlations with LPL as well as with NL. These correlations were stronger with functional longevity traits. On the contrary, angularity showed negative genetic correlation with longevity traits. Similarly to BCS, these correlations were stronger with functional longevity. Except for the genetic correlation with LPL, the absolute values of genetic correlations of BCS and angularity with longevity traits were comparable. BCS and angularity showed reciprocity in the relationship to longevity. BCS had positive and angularity had negative genetic correlations to longevity.

Body depth and chest width showed negative genetic correlations with longevity. Correlations with body depth were substantially higher than with chest width. Cows genetically deep and wide had a lower breeding value for longevity. Also rump width showed negative correlations with both longevity traits which were stronger with LPL than with NL. The rump angle was positively correlated with longevity, the genetic correlation with functional LPL was slightly lower with milk uncorrected LPL. Genetically, sloped rump seems to be connected with a long lifetime.

Foot and leg trait showed weak genetic correlations with longevity traits except for rear legs set (side view) and hock quality. Rear legs set (side view) showed negative genetic correlations with LPL as well as with NL which were stronger with functional longevity traits. Hock quality was positively correlated with LPL but only slightly with NL. Genetic correlations stronger for functional longevity traits occurred also for rear legs (rear view). Foot angle and bone quality showed stronger genetic correlation with NLF than with NL. According to the results for rear legs set (side view), sickled legs seem to be more detrimental for longevity than strait legs.

The udder traits showed inconsistent and rather weak genetic correlations with longevity traits, with the exception of a stronger genetic correlation between rear udder width and LPLF (–0.22) and the negative genetic correlations between central ligament and NL traits. The cows with a breeding value for a wide udder tend to have a lower breeding value for longevity in days. The teat traits showed always negative genetic correlations with longevity traits. The strongest correlations were found for rear teat position and the weakest ones for teat length. We can expect that rear teat genetically more outside the quarter advantages cows according to longevity.

Length of productive life and number of lactations initiated. On the average, the genetic correlations between conformation traits and LPL were slightly higher than those with NL, especially for functional longevity LPLF and NLF, but the differences were small. On the contrary, the range of the estimated genetic correlations was slightly broader for NL (–0.28 to 0.22) than for LPL (–0.26 to 0.19). The range of genetic correlations for functional longevity was –0.31 to 0.29 for NLF and –0.27 to 0.30 for LPLF.

It can be speculated that high producing cows are preferred in spite of their poorer fertility that causes a prolongation of the calving interval and hence a prolongation of LPL.

On the account of that, the genetic correlation between rear udder width or rear udder height and LPL is positive. Because NL does not depend on calving interval the correlations to NL as well as to NLF are both negative, but still the correlations between both conformation traits are stronger with functional NL than with direct NL. This shows that voluntary culling increases not only the length of productive life but also the number of lactations and that not all high producing cows have poor fertility and long calving intervals.

These results indicate that the length of productive life and number of lactations are different traits according to longevity. LPL includes the length of calving interval. Demands on the length of calving interval are in contrast to the length of productive life. A long calving interval is connected with poorer fertility of cows, but could cause a longer LPL in the same time. By contrast, the number of lactations does not depend on the calving interval. Similarly, Tsuruta et al. (2005) referred to an antagonistic relationship between productive life restricted to 305 days per lactation and days open. They estimated strong negative genetic correlation between these two traits.

Functional longevity vs. direct longevity. Genetic correlations between the conformation traits and functional longevity were stronger on the average than those with uncorrected longevity traits. The strongest genetic correlations were found between body condition score and LPLF (0.30) and between angularity and NLF (–0.31). Some conformation traits showed markedly stronger genetic correlations with functional longevity than with direct longevity. For the length of productive life, rear udder width and rear udder height, dairy form, BCS, angularity, and/or height at sacrum and stature had much stronger correlations with functional longevity than with direct longevity.

Functional longevity traits are a measurement of involuntary culling, as are the conformation traits. It is a question why the correction for milk production caused an increase of the genetic correlations between the above-mentioned conformation traits and longevity.

Dairy form, BCS, angularity, height at sacrum and stature, and rear legs set (side view) kept the same negative or positive direction for direct as well as for functional longevity traits. That means that estimated genetic correlation is caused first of all by the conformation of the body.

Rear udder width and rear udder height showed strong negative direction of genetic correlations with functional longevity, but weak with direct longevity traits. Generally, the negative genetic correlations between rear udder width and rear udder height and functional longevity indicated that cows genetically predisposed to wider udders and/or higher attached udders incline to lower longevity. For direct longevity traits, the relationship between the above-mentioned traits and longevity is changed because of voluntary culling according to milk production.

The genetic correlations between rear legs set (side view), rear legs (rear view), foot angle and bone quality NLF were strong and negative, particularly for foot angle and bone quality; they were different from those with the other longevity traits. According to the low absolute values of the estimated correlations and according to the fluctuations between positive and negative values, we consider the genetic correlations between longevity traits and rear legs rear view, foot angle and bone quality to be uninformative and insignificant. On the contrary, rear legs set (side view) showed consistently stronger negative genetic correlations with both functional longevity traits indicating a clear relationship between conformation of legs and longevity.

Functional longevity could be treated as an indicator of cow's health and measures her ability to delay involuntary culling. Based on genetic correlations to functional longevity, some conformation traits could be identified as its early predictors. Among composite traits, dairy form, capacity and body conformation showed genetic correlations to functional traits over 0.20 except for body conformation and NLF (–0.14). But in this case, these traits can be treated as negative indicators of functional longevity because of the negative genetic correlations to both functional longevity traits. Similarly, stature, height at sacrum, body depth and rump width had relatively strong but negative genetic correlations to functional longevity. These results indicate that genetically high or deep cows and/or high dairy character cows are handicapped with respect to functional longevity. These findings are in accord with the results for angularity and body condition score that showed also a quite high genetic correlation to functional longevity. On the basis of the positive genetic correlations between BCS and LPLF or NLF, BCS may be considered to be a positive indicator for functional longevity. Rump angle, rear legs set (side view), hock quality, rear udder width and rear teat position also showed high genetic correlations to functional longevity traits. These traits could be designated as indicators of functional longevity. We can suppose that the population of Czech Holstein cattle is sufficiently unified in conformation traits, therefore conformation traits show a low variability and it is difficult to use them as indicators of other traits.

Nonlinear relationship. Linear and quadratic regression coefficients of breeding values for each conformation trait on breeding values for each longevity trait were calculated separately using the REG procedure of SAS (2002) to check linear and quadratic relationships between the conformation and longevity traits. Table 3 indicates which conformation traits had significant ($P < 0.05$) linear and/or quadratic regression coefficients with longevity traits. A significant nonlinear relationship with longevity was found for feet and legs, capacity, BCS, angularity, chest width, rear legs (rear view), hock quality, and front teat placement. For number of lactations, dairy form and body conformation showed a significant nonlinear relationship. Only feet and legs, chest width, rear legs (rear view) and hock quality had a significant quadratic relationship with NL and/or NLF when the linear relationship was not significant. Insignificant regression

Table 3. Significance ($P < 0.05$) of linear and quadratic regression coefficients of sire breeding values of longevity on the breeding values of conformation traits

Trait	LPL	LPLF	NL	NLF
Final score	*L*	–	*L*	*L*
Dairy form	*L*	*L*	*L Q*	*L Q*
Body conformation	*L*	*L*	*L Q*	*L Q*
Feet and legs	*L Q*	*L Q*	*Q*	*L Q*
Udder	*L*	–	*L*	*L*
Capacity	*L*	*L Q*	*L Q*	*L Q*
Height at sacrum	*L*	*L*	*L*	*L*
Stature	*L*	*L*	*L*	*L*
Body condition score	*L Q*	*L Q*	*L Q*	*L Q*
Angularity	*L*	*L Q*	*L*	*L Q*
Body depth	*L*	*L*	*L*	*L*
Chest width	*L*	*L Q*	*L Q*	*Q*
Rump width	*L*	*L*	*L*	*L*
Rump angle	*L*	*L*	*L*	*L*
Rear legs set (side view)	*L*	*L*	*L*	*L*
Rear legs (rear view)	*L Q*	*L*	*Q*	*L*
Hock quality	*L Q*	*L Q*	*Q*	*Q*
Foot angle	*L*	*L*	*L*	*L*
Bone quality	*L*	*L*	–	*L*
Locomotion	–	*L*	–	*L*
Central ligament	*L*	*L*	*L*	*L*
Fore udder attachment	–	*L*	–	*L*
Rear udder width	*L*	*L*	–	*L*
Rear udder height	*L*	*L*	–	*L*
Udder depth	*L*	*L*	–	–
Rear teat position	*L*	*L*	*L*	*L*
Front teat placement	*L Q*	*L Q*	*L Q*	*L Q*
Teat length	–	*L*	–	–

LPL = length of productive life, NL = number of lactations initiated, LPLF = length of productive life as the functional longevity, NLF = number of lactations initiated as the functional longevity, *L* = linear regression coefficient, *Q* = quadratic regression coefficient coefficients were found for conformation traits that were slightly correlated with longevity (final score, udder, bone quality, locomotion, fore udder attachment, rear udder width, rear udder height, udder depth and teat length). It is not true that conversely the low genetic correlations are connected with insignificant regression coefficients.

DISCUSSION

Heritability of longevity

Compared with literature estimates, the heritabilities of longevity traits estimated in this study are low, but still on the lower bound of the range of published results. Heritability estimates for longevity from linear models were reported to range from 0.06 to 0.12 (Vollema and Groen, 1997; Cruikshank et al., 2002; Setati et al., 2004; Tsuruta et al., 2005). If the survival analysis is used, the estimated heritabilities are mostly higher. For Czech Holstein cattle, Páchová et al. (2005) reported a low heritability of functional longevity (0.04). However, mostly higher estimates were published for the Holstein breed: 0.15 by Schneider et al. (1999), 0.18 by Buenger et al. (2001) and Vukasinovic et al. (2001), and 0.14 by Sewalem et al. (2005).

Heritability of conformation traits

Comparing with the results of the previous study for Czech Holstein (Němcová et al., 2011), the heritabilities were similar. Schaeffer et al. (1985), Short et al. (1991), Setati et al.(2004), and Pérez-Cabal et al. (2006) reported similar estimates of heritabilities for the Holstein breed.

Genetic correlations between conformation and longevity

The genetic correlations between conformation and longevity traits estimated in this study are comparable with literature estimates, maybe they are slightly lower. In the literature, the strongest genetic correlations based on Holstein cattle data were usually not higher than 0.5 (Tsuruta et al., 2005). Similarly to our results, Rogers et al. (1989) found genetic correlations between conformation and longevity traits up to 0.36. By contrast, Vollema and Groen (1997) reported genetic correlations in the range from 0.70 to 0.93 between subjective score for udder or in the range from 0.66 to 0.84 between front teat placement and longevity traits.

For udder depth, Vollema and Groen (1997) reported strong genetic correlations between udder traits, especially udder depth, and functional longevity. But they found only a weak genetic correlation between udder depth and functional longevity in the upgraded population. These results were explained by the fact that the udder depth in the population of Dutch Friesian cows decreased due to upgrading by the Holstein breed. Similar differences could be found between this study and former results on the Czech Fleckvieh breed (Zavadilová et al., 2009). In our study, the genetic correlations between udder depth and longevity ranged from 0.04 to 0.11 and did not differ between direct and functional longevity. However in Fleckvieh, the genetic correlations between udder depth and functional longevity were much stronger (0.28) than to direct longevity (–0.02) (Zavadilová et al., 2009).

For Slovak Simmental cattle, Strapák et al. (2010) reported that udder depth had the most important effect on the length of productive life. These results indicate genetic differences in udder depth between Czech Holstein and Czech Fleckvieh cows. In the Czech Holstein population, udder depth has a substantially lower effect on longevity than in Czech Fleckvieh. This could be explained by differences between the breeding programs of dual purpose and dairy cattle breeds. For the Czech Holstein breed, Vacek et al. (2006) reported Pearson correlation coefficients between length of production life adjusted for milk yield and the composite characteristics udder (0.16), feet and legs (0.13) and rear udder height (0.08), which is more in accord with our results for LPL than for LPLF. Rogers et al. (1989) reported low genetic correlations between udder traits and survival, however, a positive and relative high correlation (0.20) was found between central attachment and survival. After adjustment for milk, they reported a strong positive genetic correlation for udder depth (0.24). They preferred foot angle as indicator of hoof health to rear legs set (side view).

In the contrary to our results, Setati et al. (2004) found strong positive genetic correlations between functional longevity expressed as number of lactations initiated and udder traits (rear udder height 0.22, fore udder attachment 0.41, udder depth 0.31). They reported positive genetic correlations to teat position and teat length (0.41, 0.48) and to angularity (0.36). These different results indicate basic genetic differences between those two populations of Holstein cattle. Tsuruta et al. (2005) found positive intermediate to high genetic correlations between direct longevity and udder depth, fore udder attachment, rear udder height and central ligament. In accordance with our findings, they reported negative genetic correlations between longevity and rear legs set (side view) and positive genetic correlations between longevity and foot angle. But they found positive genetic correlations also to rear legs (rear view). The positive genetic correlation between longevity and final score reported by Tsuruta et al. (2005) markedly exceeded our estimation. Our results correspond with their study for dairy form and partly for BCS. From negative correlations between longevity and dairy form they deduce that angular cows are forced to convert body reserves into energy and put themselves at higher risk being culled. Negative genetic correlations between dairy form and BCS (–0.66) was reported by Tsuruta et al. (2005) and by Němcová (2010, personal communication) (–0.81). This has shown that there is a close connection between these two traits. Tsuruta et al. (2005) hypothesize that dairy form could be used as a predictor of a cow's ability to convert body fat into energy, while the BCS measures a current state. Zavadilová et al. (2011) reported the opposite relationship to longevity for BCS and longevity. Angular cows tended to have poorer longevity, whereas less angular cows seemed to be favoured with respect to survival. On the contrary, survival declined with reduced BCS.

The low genetic correlation between longevity traits and final score may be due to an inadequate construction of composite traits with regard to the choice of traits and the weighing of individual traits. On the basis of our results we would recommend to redefine the final score index that is used in the Czech Republic.

Nonlinearity

Many other researchers (Foster et al., 1989; Klassen et al., 1992; Burke and Funk, 1993) have found significant quadratic regression coefficients when conformation traits are used to explain longevity, but Rogers et al. (1989) found only significant linear coefficients. Dekkers et al. (1994) found both significant quadratic and cubic regression coefficients. Brotherstone and Hill (1991) found significant quadratic regression coefficients when survival was regressed on conformation scores phenotypically. Vacek et al. (2006) reported non-linear relationships for udder depth and rear legs set. Cows with moderate deep udder showed the longest LPLF, similarly the cows with regular rear legs set (score 3). Cows with sickled legs had the significantly lowest longevity.

CONCLUSION

The results of the present study indicate the existence of weak to intermediate genetic relationships between conformation traits and longevity expressed as the length of productive life or number of lactations initiated, whether direct or functional. Conformation traits have stronger correlations with functional longevity traits than with direct longevity traits.

Functional longevity could be considered as an indicator of cow's health and as a measure of her ability to delay involuntary culling. Based on genetic correlations to functional longevity, some conformation traits could be identified as early predictors of functional longevity: dairy form, capacity, body conformation score, rear legs set (side view) and hock quality, and/or rump angle. Rear legs set (side view) showed consistently a stronger negative genetic correlation with both functional longevity traits. It showed a quite clear relationship between the conformation of legs and longevity. The positive genetic correlations between BCS and LPLF or NLF indicate that BCS may be a positive indicator of functional longevity. The estimated correlations may be time-dependent and should be verified in defined intervals. The results can be applied in future research and breeding value estimation of longevity traits in Czech Holstein cattle. Quadratic relationships between conformation and longevity traits were found. Even if the linear relationship generally prevailed, the quadratic relationship may be of importance when using conformation traits in the selection for longevity.

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