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Genetic analysis of lactation persistency in the Polish Holstein-Friesian cows*

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The objectives of this study were to analyze the genetic properties of three measures of lactation persistency in Polish Holstein-Friesian cows, and possibly to choose one measure which could be used for estimation of breeding value for lactation persistency in the Polish dairy cattle population. Data included 117,327 first three lactations of 110,141 cows calved in 1995-2009. The lactation curve model of Ali and Schaeffer was fitted to test-day milk yields. The first definition of persistency ($P_{2:1}$) was milk yield in the second 100 days in milk (DIM) divided by yield in the first 100 DIM. The second definition ($P_{3:1}$) was milk yield in the third 100 DIM divided by yield in the first 100 DIM, and the third definition (P_d) was milk yield at 280 DIM divided by milk yield at 60 DIM. The multiple-trait REML method was applied for (co)variance component estimation.
Heritabilities for three measures of persistency were very low, and ranged from 0.01 to 0.08. Genetic correlations were highest between $P_{3:1}$ and P_d (0.96-0.99), and lowest between $P_{2:1}$ and P_d (0.66-0.81), in the first three lactations. The correlations between 305-d milk yield and $P_{3:1}$ or P_d in each of the first three lactations, and $P_{2:1}$ in the second lactation, were negative and moderate. The phenotypic correlations between 305-d milk yield and persistency measures were low in the first three lactations. The phenotypic correlation between milk yield and P_d in each lactation was almost the same (0.14-0.15); the correlation between milk yield and $P_{3:1}$ (0.11-0.17) or $P_{2:1}$ (0.08-0.13) showed little variation in the first three lactations. All three compared measures of persistency were low-heritable and practically uncorrelated with total milk yield of 305-d lactations, so any of them could be used in the breeding program. However, the P_d measure could be recommended for use in practice because it is easy to calculate and interpret.

KEYWORDS: dairy cattle / lactation curve / lactation persistency / variance components

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Milk yield together with protein and fat yields are the main sources of income for dairy farmers, whereas lactation persistency have a great influence on the health, reproduction and feed costs of dairy cows [Gengler 1996]. A cow with higher lactation persistency suffers less stress from high peak yield and is exposed to fewer health and fertility problems. Avoidance of metabolic stress within the first trimester of lactation is known to improve reproductive performance and thus also reduce the costs of reproduction, although the reduction may vary considerably under different management policies and production levels [Swalve and Gengler 1999]. Persistency of lactation is defined in different ways but usually as the ability of a cow to maintain milk yield at a high level after the peak yield, or as the ability to maintain a more or less constant yield during the lactation [Gengler 1996]. High lactation persistency is associated with a slow rate of decline in production, whereas low persistency is associated with a rapid rate of decline [Swalve and Gengler 1999]. Given the same lactational production, persistent lactations are characterized by flatter lactation curves with lower peak yield reached at a later day in milk [Dekkers *et al*. 1998].

Measuring lactation persistency by one single term is difficult, and many different measures can be found in the literature [Johansson and Hansson 1940, Sölkner and Fuchs 1987, Swalve 1994, Jamrozik *et al*. 1998, Swalve and Gengler 1999, Muir *et al*. 2004]. Generally, persistency measures can be classified into three groups: measures expressed as ratios of partial or total yields, measures derived from variation of test-day (TD) yields during the lactation, and measures based on the shape of fitted lactation curve models [Gengler 1996]. Random regression TD models have been applied to construct measures of persistency belonging to the latter group. Because a cow with the flatter lactation curve is called more persistent than a cow with the same total milk yield but with a curve rapidly decreasing after the peak, a persistency measure based on the shape of the lactation curve after the peak seems a natural way of describing persistency [Jamrozik *et al*. 1998].

Genetic parameters for persistency have been the subject of many papers [Sölkner and Fuchs 1987, Swalve 1994, Jamrozik *et al*. 1998; Strabel and Jamrozik 2006a, 2006b, Weller *et al*. 2006, Khorshidie *et al*. 2012]. Heritability and the genetic correlations among various persistency measures as well as their correlations with milk yield vary considerably depending upon how the persistency measure is defined [Swalve and Gengler 1999]. In the literature, heritability ranges between 0.05 and 0.30 [Swalve and Gengler 1999] whereas genetic correlations were from -0.04 to 0.65 [Gengler 1996, Strabel and Jamrozik 2006a]. According to Gengler [1996] it is easier to interpret persistency if its definition is related to the flatness of the lactation curve. He also recommended the use of such a measure which is genetically independent of 305-d milk yield; however, Muir *et al.* [2004] concluded that a small positive genetic correlation between persistency and milk yield indicated that selection for increased milk yield would slightly improve persistency.

Breeding values for persistency of lactation have been calculated in some cattle populations, and dairy producers have access to these proofs and can use them in herd management [Canadian Dairy Network 2004]. The objectives of this study were to analyze the genetic properties of three measures of lactation persistency in Polish Holstein-Friesian cows, and possibly to choose one measure which could be used for estimation of breeding value for lactation persistency in the Polish dairy cattle population.

Material and methods

Data were 1,221,407 test-day (TD) milk yields from 117,327 first three lactations of 110,141 Polish Holstein-Friesian cows in 1,638 herds (Tab. 1). Cows were daughters of 10,286 sires. Data came from SYMLEK, the Polish national recording system, and were made available by the Polish Federation of Cattle Breeders and Dairy Farmers.

Cows calved from 1995 to 2009 at age 18-48, 29-65 and 41-75 months for the first, second and third time, respectively. The following restrictions were imposed: 1-10 TD records per lactation per cow, TD yields between 5 and 305 days in milk (DIM) and daily milk yields not exceeding 85 kg. According to the age at calving, the data were divided into five (18-24, 25-26, 27-28, 29-30, 31-48 months), four (29-38, 39-41, 42-44, 45-65 months) and three (41-51, 52-55, 56-75 months) groups within first, second and third lactations, respectively. Two seasons of calving were created (October-March and April-September).

A multiple-trait prediction (MTP) method was applied for fitting lactation curves and estimating partial and 305-d lactation yields from individual TD milk yields [Schaeffer and Jamrozik 1996]. In the MTP method, information about standard lactation curves and (co)variances among the parameters of lactation curve were incorporated. A standard lactation curve is a curve fitted for a group of cows being in the same lactation and calving at similar ages and in the same season of a year. The parameters of standard lactation curves were estimated within 24 subclasses of lactation by age at calving by season of calving. Both standard and individual lactation curves were modelled using Ali and Schaeffer's [1987] function:

$$y = b_0 + b_1 \cdot \left(\frac{t}{305}\right) + b_2 \cdot \left(\frac{t}{305}\right)^2 + b_3 \cdot \ln\left(\frac{305}{t}\right) + b_4 \cdot \ln^2\left(\frac{305}{t}\right)$$

where t is DIM, b_0, b_1, b_2, b_3 and b_4 are parameters to be estimated, and y is milk yield at DIM t. To estimate the matrix containing (co)variances among the lactation curve parameters only cows with first TD before 50 DIM and a minimum of 9 TD records in lactation were used.

Three different measures of persistency were calculated [Johansson and Hansson 1940; Canadian Dairy Network 2004]: $P_{2:1}$ – milk yield in the second 100 DIM divided by yield in the first 100 DIM, $P_{3:1}$ – milk yield in the third 100 DIM divided by yield in the first 100 DIM, P_d – milk yield at 280 DIM divided by milk yield at 60 DIM. All three measures were expressed as percentages.

For each lactation of a cow the milk yields for the first, second and third 100 DIM, the yields on 60 and 280 DIM, as well as the 305-d lactation yields were calculated using parameters of Ali and Schaeffer lactation curve fitted by MTP method. For example, the total 305-d milk yield in first lactation of a cow was calculated by adding up daily yields of that cow predicted for each day of the first lactation between 5 and 305 DIM. Partial yields were calculated likewise.

(Co)variance components for three measures of persistency ($P_{2:1}$, $P_{3:1}$, P_d) and 305-d milk yield were estimated separately for first, second and third lactations using the multiple-trait REML method [Misztal 2008]. The linear model included fixed effects of herd-year-season (HYS) and age class as well as random animal effect. For analysis, 10% of herds with more than 5 cows in herd-year-season subclasses in each of first three lactations were randomly chosen. There were 82,474, 73,326 and 65,229 animals included in the analysis and 2,992, 3,154 and 3,184 HYS subclasses created in the first, second and third lactations, respectively. Cows in successive lactations were assigned to one of five, four or three age at calving subclasses, respectively.

Results and discussion

The notion of persistency is very intuitive and general. From a mathematical point of view there is no clear consensus on how best to model persistency, although many different measures have been proposed [Gengler 1996]. The measures used in this study are based on ratios of partial yields ($P_{2:1}$ or $P_{3:1}$) or on the shape of the lactation curve after the peak (P_d). High values of all three measures stand for good persistency, and small values stand for poor persistency.

Means and standard deviations for $P_{2:1}$, $P_{3:1}$ and P_d, and for 305-d milk yields are presented in Table 1. Generally, first lactations are more persistent than later lactations. This is consistent with the results of other studies indicating that persistency decreases with increasing milk production [Sölkner and Fuchs 1987, Swalve 1994]. Average lactation persistency of second and third parities was nearly the same, but with smaller standard deviation in the second lactation. Means and standard deviations for 305-d milk yield in the second and third lactations are also similar (Tab. 1).

According to our results and as indicated by many authors, in more persistent lactations the peak yields were lower and reached later during lactation [Sölkner and Fuchs 1987, Jamrozik *et a*l. 1998, Tekerli *et al*. 2000; Muir *et al*. 2004]. Sölkner and Fuchs [1987] noted that the most likely physiological reason for this is that the mammary gland of the cow is not fully developed at the beginning of the first lactation. Tekerli *et al.* [2000] confirmed that the milk secretory tissue needs a longer time to reach its peak activity in primiparous cows than in multiparous cows. Jamrozik *et al*. [1998] also showed that persistency differs between lactations, and suggested that there are differences between early- and late-maturing breeds. Sölkner and Fuchs [1987] concluded that increased lactation persistency may have economic benefits resulting from improved health or reduced incidence of diseases. Dekkers

Table 1. Data description and genetic parameters for three persistency measures ($P_{2:1}$, $P_{3:1}$, P_d) by parity

Trait	Item[1]	Lactation 1	Lactation 2	Lactation 3
No. of test-day records		477,453	398,432	345,522
No. of lactations		45,542	38,723	33,062
305-d milk yield (kg)	mean	6,466	7,233	7,401
	SD	1,904	2,318	2,301
Persistency (%)[2]				
$P_{2:1}$	mean	90.68	83.36	82.79
	SD	21.82	14.39	23.29
	h^2	0.03	0.05	0.01
$P_{2:1}$ – 305-d milk	R_g	0.30	-0.06	0.38
	R_p	0.08	0.13	0.08
$P_{3:1}$	mean	77.36	65.56	63.52
	SD	23.88	17.11	23.05
	h^2	0.05	0.08	0.02
$P_{3:1}$ – 305-d milk	R_g	-0.05	-0.44	-0.13
	R_p	0.11	0.17	0.12
P_d	mean	72.92	60.88	58.29
	SD	19.88	18.74	19.22
	h^2	0.07	0.08	0.04
P_d – 305-d milk	R_g	-0.28	-0.55	-0.30
	R_p	0.14	0.15	0.15
$P_{2:1}$ – $P_{3:1}$	$corr_g$	0.91	0.89	0.80
	$corr_p$	0.90	0.78	0.89
$P_{2:1}$ – P_d	$corr_g$	0.77	0.81	0.66
	$corr_p$	0.43	0.56	0.42
$P_{3:1}$ – P_d	$corr_g$	0.96	0.99	0.98
	$corr_p$	0.73	0.95	0.75

[1]SD – standard deviation; h^2 – heritability (SD from 0.006 to 0.012); R_g/R_p – genetic (SD from 0.021 to 0.089) / phenotypic (SD from 0.012 to 0.022) correlation between persistency measure and 305-d milk yield; $corr_g$ / $corr_p$ – genetic (SD from 0.001 to 0.045) / phenotypic (SD from 0.003 to 0.020) correlation between two persistency measures.
[2]$P_{2:1}$ – milk yield in the second 100 DIM divided by yield in the first 100 DIM; $P_{3:1}$ – milk yield in the third 100 DIM divided by yield in the first 100 DIM; P_d – milk yield expected at 280 DIM divided by milk yield expected at 60 DIM.

et al. [1998] described the positive effects of high persistency on health costs and reproductive performance. For cows with more persistent lactations the physiological stress connected with high milk production would be lower and as a consequence it would be cheaper to feed such cows because a greater fraction of feed energy could be provided by roughage, not by more expensive concentrates [Dekkers *et al.* 1998, Tekerli *et al.* 2000].

Heritability estimates for persistency vary according to the definition of persistency and the population studied and are in the range of 0.05-0.30 [Sölkner and Fuchs 1987, Gengler *et al*. 1995, Weller *et al*. 2006, Khorshidie *et al*. 2012]. Heritabilities estimated in this study for three measures of persistency in the first three lactations were very low (Tab. 1). This means that little genetic progress could be achieved through selection. Persistency in the second lactation was slightly more heritable than in the first one (0.05-0.08), whereas the lowest heritability for persistency was observed in the third lactation (0.01-0.04). Strabel and Jamrozik [2006a] compared a few persistency measures in the Polish Holstein-Friesian population and estimated slightly higher heritability for P_d in the first three parities (0.07-0.14). Swalve [1994] presented heritability of 0.11 for $P_{3:1}$ in the first lactation. Gengler *et al*. [1995] found higher heritabilities for $P_{2:1}$ (0.12) and $P_{3:1}$ (0.11) in the first lactation. Higher heritabilities were also obtained by Sölkner and Fuchs [1987]: for $P_{2:1}$ it ranged from 0.12 to 0.14 and for $P_{3:1}$ between 0.19 and 0.21 in the first three lactations. Sölkner and Fuchs [1987] showed that for each persistency measure the heritabilities were rather constant in the first three lactations but differing in value depending on the measure. Additionally they found that longer measures (including data from the whole lactation) and measures based on variation had the highest heritabilities [Sölkner and Fuchs 1987]. We also observed that heritabilities of persistency were almost the same in the first three lactations. However, Jamrozik *et al.* [1998] reported increased heritability from the first to later lactations but without apparent differences between the second and third lactations, and they explained that different lactations were characterized by genetically different persistency. Strabel and Jamrozik [2006ab] concluded that heritabilities of persistency increased steadily with lactation number. Khorshidie *et al.* [2012] noticed that a persistency measure with higher heritability is more suitable for inclusion in a selection goal.

An important characteristic of the persistency measure is its correlation with 305-d milk yield. Many authors have asserted that a good measure of persistency should be independent of lactation milk yield [Gengler 1996, Jamrozik *et al*. 1998, Swalve and Gengler 1999] or corrected for milk yield. In this study the genetic correlation between 305-d milk yield and the three measures of persistency ranged between -0.55 and 0.38 (Tab. 1). When lactation persistency measures required partial yields from the last 100 days of lactation ($P_{3:1}$ or P_d), negative genetic correlations between persistency and 305-d milk yield were found in each of first three lactations. The 305-d yields of milk in the second lactation were negatively and relatively highly correlated with two measures of persistency, $P_{3:1}$ (-0.44) and P_d (-0.55), whereas a negative but close to zero correlation was observed for $P_{2:1}$ (-0.06). Low correlations between 305-d milk yield and persistency suggest that independent selection for both traits is possible.

Phenotypic correlations between 305-d milk yield and three different measures of persistency were low (Tab. 1). The smallest correlations were found for the $P_{2:1}$ (0.08-0.13) in each of the first three lactations. The correlation between total milk yield and P_d was the same in each lactation (0.14-0.15), whereas those between milk yield and

$P_{2:1}$ or $P_{3:1}$ varied slightly in the first three lactations. Gengler *et al*. [1995] estimated the phenotypic correlation between $P_{2:1}$ and 305-d milk yield at 0.24, which was higher than the estimates obtained in the present study (0.08-0.13), and a correlation between milk yield and $P_{3:1}$ of 0.18, similar to our results (0.11-0.17). According to Sölkner and Fuchs's [1987] genetic correlations between milk yield and $P_{2:1}$ or $P_{3:1}$ (about 0.5) were higher than presented in this paper. Similar values of correlations were presented by Swalve [1994] for $P_{3:1}$ (0.51-0.56) and Gengler *et al*. [1995] for $P_{2:1}$ (0.65) and $P_{3:1}$ (0.51). In the Polish Holstein-Friesian population the genetic correlations between milk yield and different measures of persistency reported by Strabel and Jamrozik [2006a] ranged from -0.04 to 0.25. Jamrozik *et al*. [1998] and Khorshidie *et al*. [2012] confirmed weak genetic relationships between milk production and persistency measures, and speculated that animals with the same milk production might have different lactation persistency. Rekaya *et al*. [2001] concluded that moderate genetic correlations between persistency in the first three lactations suggested that genetic evaluation of persistency in the second and third lactations would be imprecise if only first lactation data were used.

To determine whether these three measures of persistency gave similar rankings of animals, the correlations between different measures were calculated and presented in Table 1. All genetic correlations between three measures of persistency were higher than 0.66. A very high genetic relationship was found between $P_{3:1}$ and P_d (0.96-0.99) across lactations, indicating that both measures could be considered as genetically the same trait. The correlations were slightly lower between $P_{2:1}$ and $P_{3:1}$ (0.80-0.91) and much lower between $P_{2:1}$ and P_d (0.66-0.81). The phenotypic correlations among three persistency measures were positive and moderate to high (Tab. 1). The correlations were higher between $P_{3:1}$ and $P_{2:1}$ or $P_{3:1}$ and P_d (0.73-0.95), and smaller between $P_{2:1}$ and P_d (0.42-0.56). Gengler *et al*. [1995] obtained a much lower phenotypic correlation between $P_{2:1}$ and $P_{3:1}$ in the first lactation (0.67) and a slightly lower genetic correlation between those two persistency measures (0.84), whereas Sölkner and Fuchs [1987] showed the same genetic relationship between $P_{2:1}$ and $P_{3:1}$ (0.89). The latter observed that genetic correlations between various measures of persistency were always higher for measures including the same parts of lactation. Gengler *et al*. [1995] found high phenotypic correlations between measures that used the same formula but for different periods of lactation, for example $P_{2:1}$ and $P_{3:1}$. This is in agreement with our results: both the phenotypic and genetic correlations between persistency that met the above condition (i.e. $P_{2:1}$ and $P_{3:1}$) were high (0.78-0.91).

Lactation persistency is an economically very important trait in dairy cattle. Better persistency reduces possible health and reproduction problems as well as costs of feeding. It is planning to continue research on this topic in the Polish population. Perhaps other persistency measures or different lactation curve models should be examined. Especially, that some researchers have maintained that persistency measures based on the ratio between milk yields at different stages of lactation fail to define this trait clearly, and as an alternative they proposed to use some parameters of the lactation curve model that have a biological interpretation [Rekaya *et al*. 2001, Muir *et al*. 2004].

Our results show that it is hard to designate the one best persistency measure among the three measures examined in the present study. Each of them meets some conditions expected for well-defined lactation persistency. All three measures were independent of 305-d milk production, although $P_{2:1}$ behaved slightly better than $P_{3:1}$ or P_d. The P_d measure had the highest heritability, but generally all three measures were low-heritable traits, so little genetic improvement could be possible through selection. On the other hand, the negative genetic correlation found between P_d and 305-d milk yield showed that cows with a high genetic level for persistency would tend to have a lower genetic level for milk production, but only to a small extent. Given the above, all three measures of persistency ($P_{3:1}$, $P_{2:1}$, P_d) could be used for genetic evaluation of Polish Holstein-Friesians. However, the P_d measure is recommended for use in breeding practice because of the ease of its calculation and interpretation.

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