Annals of Warsaw University of Life Sciences – SGGW
Animal Science No 54 (1), 2015: 27–36
(Ann. Warsaw Univ. of Life Sci. – SGGW, Anim. Sci. 54 (1), 2015)

Relation between the shape and course of lactation curve and production traits of Polish Holstein-Friesian and Montbeliarde cows

MARCIN GOŁĘBIEWSKI, TOMASZ PIOTROWSKI, PIOTR BRZOZOWSKI, HENRYK GRODZKI, TOMASZ PRZYSUCHA, JAN SLÓSARZ, MAŁGORZATA KUNOWSKA-SLÓSARZ, TERESA NAŁĘCZ-TARWACKA, AGATA WÓJCIK
Department of Animal Breeding and Production, Warsaw University of Life Sciences – SGGW

Abstract: *Relation between the shape and course of lactation curve and production traits of Polish Holstein-Friesian and Montbeliarde cows.* The aim of the study was to examine the relation between shape and course of lactation curve and production traits of Polish Holstein-Friesian (PHF) and Montbeliarde (MO) cows kept under various production systems. The production parameters were based on cows records developed by Polish Federation of Cattle Breeders and Producers and involved 1374 lactations. For estimation of lactation curve parameters Wood's model was applied. The influence of breed, lactation number and type of the farm on Wood's parameters were analyzed. The relations between shape and curse of the lactation curve on daily production and milk chemical composition were investigated. Analysis revealed that standard shape of the lactation curve was the most often observed, the significantly higher frequency was observed in MO than PHF cows. Cows with standard lactation curve characterized by the highest production and the best milk quality. The significant influence of breed, lactation number and farm type on Wood's parameters were stated. Cow with less dynamic changes in milk production during lactation characterized by significantly better production parameters.

Key words: lactation persistency, lactation curve shape, production traits, dairy cow, Montbeliarde breed, Polish Holstein-Friesian breed

INTRODUCTION

The lactation persistence of dairy cows, measured by the level and rate of daily milk production decreasing after the peak of lactation, plays a important role in economics of milk production (Togashi and Lin 2009). The slower milk decline during the lactation the beneficial economic effect. The difficulties of comparing the lactation persistence of cows in various studies are mainly due to different ways of defining this parameter (Gengler 1996, Swalve and Gengler 1999). The lactation persistence can be presented in three ways: as a uniform rate of lactation (Gengler and Misztal 1996), on the basis of milk records (Gengler and Misztal 1996, Grossman et al. 1999) and by setting the parameters of mathematical models of lactation curves (Rowlands et al. 1982, Goodal and Sprevak 1984, Leon-Velarde et al. 1995). According to Grossman et al. (1999), the first two ways of defining the lactation persistence are vague, hence the great interest of researchers in finding mathematical model describing lactation curve that precisely describe the distribution of the daily milk records of lactating cows. Mostly, for these purposes, in scientific literature gamma function of lactation curves developed by Wood was applied (1967, 1976).

Cows with flat lactation curve characterized by higher feed efficiency, better withstand high milk production at the peak of lactation (Muir et al. 2004, Weller et al. 2006), are more resistant to diseases (Jakobsen et al. 2002, Harder et al. 2006), characterized by better fertility (Bar-Anan and Ron 1985, De Vries 2006), thus tend to generate higher revenue (Dekkers et al. 1998). Despite the great importance of lactation perseverance, this feature is often not taken into account in the merit indexes. The reason for this may be the lack of adequate data to estimate its economic weight and the difficulty in assessing the influence of the effect of lactation persistence on other functional traits. Recently, with the growing interest in methods that use data on test day records, the more popular have become the procedures for lactation persistence (lactation curve) assessment in animal breeding programs (Schaeffer and Dekkers 1994, Jamrozik et al. 1997).

The aim of this study was to determine the relationship between the shape and course of the lactation curve and the and production traits of Polish Holstein-Friesian and Montbeliarde cows kept under various production systems.

MATERIAL AND METHODS

The material consisted cows of Polish Holstein-Friesian of Black and White variety (PHF) and Montbeliarde (MO) from six dairy farms located different regions of Poland. All farms were divided into two groups with regard to herd size, production system and the intensity of production. Data were recorded by the Polish Association of Cattle Breeders and Milk Producers (PFHBiPM), and each of the stocks covered by the milk performance was controlled by AT4. Herds differed size and intensity of production, and all of them were two races held at the same time (the exception was only one herd of cows term montbeliarde). In total, the study analyzed 1374 lactations (967 PHF and 407 MO).

For statistical analysis, the data from the daily performance reports, consisted:

1. Basic identification data of each studied cow, i.e.: tag number, breed, herd number, birth data and culling data;
2. Performance information of studied cows, i.e.: milk production, fat, protein, lactose, urea and dry matter concentration, somatic cell count. In addition to standard production traits, the FCM (fat corrected milk) and ECM (energy corrected milk) were calculated according to the formulas:

$$FCM = 0.4\ M \times 15\ F$$

$$ECM = 0.25 \times M + 12.2 \times F + 7.7 \times P$$

where:
M – milk (kg);
F – fat (kg);
P – protein (kg).

3. Analysis of lactation curve shape was based on Wood's model parameters:

$$Yn = an^{b}e^{-cn}$$

where:
Yn – average daily yield in the n-th week;

a – parameter describing general production ability related to peak lactation;
b – parameter related to the ascending part of the curve between calving and peak of lactation;
c – parameter related to the descending part of the curve following lactation peak;
n – week of the lactation (Wood 1967). Wood function parameters were calculated according to Gauss-Newton method (Hartley 1961).

Since a non-linear form of regression does not guarantee convergence, Wood's function was transformed to its logarithm form: $\ln Yn = \ln(a) + b \ln(n) - cn$.

Wood's model can fit analyzed traits curves in four different shapes (Wood 1976, Macciotta et al. 2005), mainly depending on the value of parameters *b* and *c*, as a is always positive and influences average level of production (Table 1). Type C1 represents the shape of the typical curve of daily milk yield while C2 and C3 correspond to continuously increasing and decreasing curves, respectively. The type C4 refers to the shape of reversed standard curve, with a descending initial phase and ascending phase after reaching the minimum (Gołębiewski 2010).

TABLE 1. Possible curve shapes of Wood's model (Gołębiewski 2010)

Curve shape	Parameters of Wood's model		Curve description
	b	*c*	
C1	$b > 0$	$c < 0$	standard lactation curve
C2	$b > 0$	$c > 0$	continuously ascending curve
C3	$b < 0$	$c < 0$	continuously descending curve
C4	$b < 0$	$c > 0$	inverted to standard curve

Goodness of fit was estimated by the adjusted determination coefficient (R2) (Olori et al. 1999, Macciotta et al. 2005).

Scripts were written in Visual Basic using Solver in MS Excel and run in order to calculate parameters of Wood's model.

For the statistical analysis PAWS Statistics 19 (2010), software package was applied. To compare the distribution of lactation curves types of the of cows of both breeds Chi^2 test was used.

The analysis of variation (ANOVA) of SPSS software package was used to evaluate breed (MO and PHF), production intensity (1 – intensive and 2 – less intensive), lactation number (first, second, third, fourth and more) on coefficients of Wood's model according to model 1, which is:

$$Y = \mu + A_i + B_j + C_k + (A_i \times B_j) + \\ + (A_i \times C_k) + e_{ijkl}$$

where:
μ – mean;
A_i – breed (1 – MO; 2 – PHF);
B_j – lactation number (1 – first, 2 – second, 3 – third, 4 – fourth and more);
C_k – production intensity (1 – larger herds, intensive production system; 2 – smaller herds, moderate production intensity);
$A_i \times B_j$ – interaction between breed and lactation;
$A_i \times C_k$ – interaction between breed and production intensity;
e_{ijkl} – random error.

During the statistical analysis of the production parameters of studied cows also influence of the shape of the lactation curve on the analyzed traits was performed according to model 2, which is:

$$Y = \mu + Eh + eh$$

where:

μ – mean;

Eh – lactation curve shape (1-C1; 2-C3; 3-C4);

e_{ijkl} – random error.

Due to the incidental occurrence C2 curve was omitted in further analysis.

To evaluate impact of the production parameters on dynamics of parameters *b* and *c* of Wood function model 3 were applied in a form:

$$Y = \mu + Fg + Gt + e_{ijkl}$$

where:

μ – mean;

Fg – parameter *b* (1) ≤ 0; (2) 0–0.5; (3) > 0.51);

Gt – parameter *c* (1) ≤ –0.25; (2) –0.249–0.3; (3) > 0;

e_{ijkl} – random error.

In order to determine the direction and strength of the relationship between parameters *b* and *c* of the Wood model and the production traits Pearson correlations were calculated.

RESULTS AND DISCUSSION

Distributions of the different types of lactation curves of the MO and PHF breeds are shown in Table 2. There was a significant ($P \leq 0.05$) differences between both breeds in report to lactation curves distributions. The most frequently observed type of lactation curve was standard lactation curve (1), which occurred in 73.9% cows. Similar results obtained Olori et al. (1999). Marcciotta et al. (2005), reported 80 and 17% frequencies of types C1 and C4, respectively. The standard shape of the lactation curve, illustrating the daily changes in milk yield, was observed more frequently in MO than PHF cows (of more than 7 percentage points). Other types of curves occurred less frequently: type 3 (16.8%) and type 4 (9.2%). Significant differences between breeds were reported only during statistical analysis of type 3 of lactation curve. The PHF cows were characterized by a 6.4 percentage point higher frequency of the type 3 of lactation curve.

The effect of breed on the development of Wood's model parameters was studied (Table 3). Statistically significant differences between the breeds were observed for the all analyzed parameters. PHF cows were characterized by a 3.269 kg higher ($P \leq 0.01$) daily milk production (the parameter *a*). Similar results observed Gołębiewski (2010). However, MO cows had faster dynamic of production to the lactation peak and more rapid decline after reaching maximum capacity (respectively parameters *b* and *c* of Wood's model). The differences between the breeds were 0.105, 0.025 respectively for parameters *b* and *c* with comparable level of the determination coefficient (R^2). Olori et al. (1999) observed great proportion of lactation curves with $R^2 \geq 0.75$.

Table 4 presents the effect of the intensity of production on the parameters of Wood's model. It was noted ($P \leq 0.01$) higher values of the parameter *a* (3.614)

TABLE 2. Distribution of the lactation curve types in Polish Holstein-Friesian and Montbeliarde cows

Curve shape	Breed				Total	
	PHF	%	MO	%	PHF and MO	%
1	694	68.4	321	31.6	1015	73.9
2	1	100.0	0	0.0	1	0.1
3	181	78.4	50	21.6	231	16.8
4	91	71.7	36	28.3	127	9.2
Total	967	–	407	–	1374	100.0

$Chi^2 \leq 0.05$; 1 – standard; 2 – ascending; 3 – descending; 4 – inverted.

TABLE 3. Influence of the breed of cow on Wood's model parameters

Parameter	Breed						Total		
	PHF			MO					
	N	Mean	SE	N	Mean	SE	N	Mean	SE
a	967	31.943**	0.326	407	28.674**	0.522	1374	30.975	0.280
b	967	0.228**	0.014	407	0.333**	0.023	1374	0.259	0.012
c	967	–0.121**	0.004	407	–0.146**	0.007	1374	–0.129	0.003
R^2	967	0.718*	0.007	407	0.693*	0.012	1374	0.711	0.006

a – parameter describing general production ability related to peak lactation; *b* – parameter related to the ascending part of the curve between calving and peak of lactation; *c* – parameter related to the descending part of the curve following lactation peak; R^2 – determination coefficient;
* significance at $P \leq 0.05$; ** significance at $P \leq 0.01$.

TABLE 4. Influence of the production intensity on Wood's model parameters

Parameter	Production intensity						Total		
	1			2					
	N	Mean	SE	N	Mean	SE	N	Mean	SE
a	233	33.976**	0.728	1141	30.362**	0.299	1374	30.975	0.280
b	233	0.317*	0.036	1141	0.247*	0.012	1374	0.259	0.012
c	233	–0.159**	0.010	1141	–0.122**	0.003	1374	–0.129	0.003
R^2	233	0.726	0.013	1141	0.708	0.007	1374	0.711	0.006

1 – intensive production; 2 – less intensive production; *a* – parameter describing general production ability related to peak lactation; *b* – parameter related to the ascending part of the curve between calving and peak of lactation; *c* – parameter related to the descending part of the curve following lactation peak; R^2 – determination coefficient;
* significance at $P \leq 0.05$; ** significance at $P \leq 0.01$.

defining the overall productivity for type 1 of farm, which is characterized by a higher intensity of production, nutrition and free-stall production system. Cows kept in this system were also characterized by a faster growth of curve ($P \leq 0.05$) in the initial phase of lactation and the ($P \leq 0.01$) more rapid decrease (0.037) in its final stage, than cows kept in farms with lower production intensity,

TABLE 5. Influence of the lactation number on Wood's model parameters

Parameter	Lactation												Total (n = 1374)		
	1 (n = 704)			2 (n = 356)			3 (n = 281)			4 and more n = 33					
	N	Mean	Se	N	Mean	Se	N	Mean	Se	N	Mean	Se	N	Mean	Se
a	704	25.872*	0.29	356	36.106*	0.527	281	36.378*	0.611	33	38.472*	1.811	1374	30.975	0.295
b	704	0.275	0.015	356	0.217	0.023	281	0.287	0.029	33	0.15	0.1	1374	0.259	0.012
c	704	−0.111*	0.004	356	−0.142*	0.007	281	−0.155*	0.009	33	−0.133	0.028	1374	−0.129	0.003
R^2	704	0.656*	0.009	356	0.774*	0.01	281	0.768*	0.011	33	0.707	0.034	1374	0.711	0.006

a – parameter describing general production ability related to peak lactation; *b* – parameter related to the ascending part of the curve between calving and peak of lactation; *c* – parameter related to the descending part of the curve following lactation peak;
R^2 – determination coefficient; 1, 2, 3, 4 and more – lactation numbers;
* significance at $P \leq 0.01$.

traditional feeding and tie-stall system. The determination coefficient (R^2) did not differ significantly in both types of farms. Also Gołębiewski (2010), confirmed that cows kept under intensive production system characterized by higher milk production.

When analyzing the effect of the lactation number on Wood's model parameters (Table 5) study revealed that the value of the parameter *a* for the cows in first lactation were lower ($P \leq 0.01$) from lactating cows at second, third, fourth and further lactations (by 10.234, 10.506, 12.600 respectively). It was also found lower value of the parameter *c* of primiparous *versus* cows at second and third lactation (0.031 and 0.44 at $P \leq \leq 0.01$ respectively), what was probably caused by better lactation persistency of younger cows. Similarly, the R^2 value was lower at first than at second and third lactation (0.118 and 0.112 respectively). There were no significant differences in the values of the parameter *b* between different lactations numbers.

There was no relation between lactation curve and performance parameters in standard lactation. The best production parameters, such as: milk, FCM, ECM, fat, protein, lactose and dry matter, were characterized by a cow with lactation curve opposite to the standard curve (type 4) however the values were very similar to those obtained by the cows standard (type 1) lactation curve. Cows with a standard lactation curve characterized by the highest concentration of chemical components of milk, excluding protein content which reached the highest value at cows with a decreasing lactation curve (type 3).

Different results were observed during the analysis of the relationship between the shape of the lactation curve, and the performance parameters based on the daily records (Table 6). Significant differences in daily milk yield were reported between cows characterized by curves of types 1 and 4 (1.691), and types 3 and 4 (1.548). Cows with a standard curve (type 1) had the highest daily production. The number of somatic cells ($P \leq 0.01$) differ between cows characterized by a different course of lactation curve, and was the lowest for type 1 (611.070), and the difference between types 1 and 3 and types 1 and 4 were 127.56 and 139.39 respectively. Lactation curve type had an influence ($P \leq 0.05$) on the percentage of protein in milk. The highest protein content were reported in milk produced by cow characterized by standard lactation curve (3.484) and the lowest in milk of cows with type 4 of lactation curve (3.378). There was no relation between of lactation curve shape and concentration of fat, lactose, dry matter and urea in milk.

Table 7 presents the relationship between the dynamics of lactation curve changes, and the performance parameters based on test day records. There was a significantly higher daily yield of cows with a moderate increase in the initial phase of lactation (parameter b) compared with the cows characterized by rapid increase of the milk production before the lactation peak. Cows with moderate value of parameter *b* (2) also characterized by a higher content of fat, protein, lactose and dry matter in milk than cows from the first group ($P \leq 0.01$), as well as lower somatic cells count in milk ($P \leq 0.01$), and the highest urea levels compared with cows of fast (1) and slow (3) growth rate of the lactation curve. Cows characterized by the smallest value of parameter *b* characterized by the ($P \leq 0.01$) the highest percentage of protein content (3.558) and the lowest level of urea in milk (230.62) compared to the cows of the other groups (1.2).

Analyzing the lactation curve declining rate at the final phase of lactation (parameter *c*) the dominance of cows with moderate decrease rate (2) on other

TABLE 6. Relation between lactation curve shape and production traits of cows based on test day records

Trait	Curve shape								
	1			3			4		
	N	Mean	SE	N	Mean	SE	N	Mean	SE
Milk (kg)	1015	23.069*	0.169	231	22.926*	0.350	127	21.378*	0.493
Fat (%)	989	3.904	0.042	229	3.922	0.088	126	3.727	0.132
Protein (%)	1015	3.484**	0.016	231	3.433**	0.033	127	3.378**	0.043
Lactose (%)	1015	4.938	0.008	231	4.952	0.014	127	4.976	0.014
Dry matter (%)	1015	13.322	0.023	231	13.307	0.045	127	13.268	0.066
Somatic cell count (K/ml)	1015	611.070*	25.964	231	738.630*	58.593	127	750.460**	74.114
Urea (mg/l)	1015	232.360	2.067	231	246.210	4.409	127	240.730	6.495

* significance at $P \leq 0.01$; ** significance at $P \leq 0.05$.

TABLE 7. Influence of the dynamics of lactation curve changes on milk production

Trait				Milk (kg)	Fat (%)	Protein (%)	Lactose (%)	Dry matter (%)	Somatic cell count (K/ml)	Urea (mg/l)
Parameter	*b*	1	N	360	357	360	360	360	360	360
			Mean	22.367**	3.852	3.414*	4.961	13.292	739.68*	244.34*
			SE	0.286	0.073	0.026	0.01	0.037	45.788	3.64
		2	N	661	649	661	661	661	661	661
			Mean	23.262**	3.941	3.443*	4.94	13.304	583.79*	248.8*
			SE	0.209	0.051	0.019	0.009	0.028	28.179	2.614
		3	N	353	339	353	353	353	353	353
			Mean	22.72	3.833	3.558*	4.935	13.357	663.21	230.62*
			SE	0.286	0.077	0.026	0.013	0.04	52.754	3.308
	c	1	N	509	492	509	509	509	509	509
			Mean	22.554**	3.878	3.558*	4.933	13.389*	706.8**	229.75*
			SE	0.239	0.063	0.022	0.011	0.033	44.446	2.829
		2	N	737	726	737	737	737	737	737
			Mean	23.38*	3.927	3.417*	4.946	13.271*	584.94**	252.27*
			SE	0.196	0.048	0.018	0.008	0.026	25.905	2.434
		3	N	128	127	128	128	128	128	128
			Mean	21.383**	3.729	3.375*	4.977	13.266	745.52**	241.88
			SE	0.489	0.131	0.043	0.013	0.065	73.699	6.544

b, *c* – parameters of Wood's model;
1, 2, 3 – dynamics of lactation curve changes;
* significance at $P \leq 0.01$; ** significance at $P \leq 0.05$.

groups (1 and 3) for the majority of production parameters was observed. These cows produced more milk ($P \leq 0.01$) from cows with high (1) and small (3) values of parameter *c*. Milk obtained from these cows was characterized by a high content of fat, had significantly lower levels of somatic cells count as well ($P \leq 0.01$) as the highest level of urea than animals from other groups. Cows with the fast declining rate (1) of lactation curve at the end of lactation were characterized higher milk production ($P \leq 0.05$), the highest concentration of protein in milk (3.558) and dry matter (13.389) than cows of group 3 ($P \leq 0.01$).

There was no significant correlation between the Wood's model parameters and production traits in standard lactation. However a significant ($P \leq 0.01$) correlations were reported between the parameter *b* and the percentage of protein (0.105) in milk based on daily test records (Table 8). Moreover, negative correlation was observed between the level of urea in the milk of the parameter *b* (–0.067). The parameter *c* ($P \leq 0.01$) was negatively correlated with the percentage of protein content (–0.182) and dry matter (–0.098) in milk. There was also a negative correlation ($P \leq 0.05$) between the parameter *c* and the number

TABELA 8. Correlations between Wood's model parameters and milk production traits (mean values)

Parameter	b	c
Milk (kg)	–0.005	0.022
Fat (%)	–0.017	–0.001
Protein (%)	0.105**	–0.182**
Lactose (%)	–0.014	0.043
Dry matter (%)	0.037	–0.098**
Somatic cell count (K/ml)	0.003	–0.058*
Urea (mg/l)	–0.067*	0.0143**

* significance at $P \leq 0.05$; ** significance at $P \leq 0.01$.

of somatic cells count (–0.058). Study reveled that correlation between the urea content and parameter *c* of Wood's model remained at 0.0143.

CONCLUSION

Irrespectively to cow's breed, the most frequently type of lactation curve was standard lactation curve. However, the abnormal shape of lactation curves were more frequent in MO than PHF cows. Moreover, study reviled that, only standard lactation curved guaranteed the highest daily milk production.

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Streszczenie: *Zależność między kształtem oraz przebiegiem krzywej laktacji a cechami produkcyjnymi krów rasy polskiej holsztyńsko-fryzyjskiej i montbeliarde.* Celem pracy było określenie zależności między kształtem i przebiegiem krzywych laktacji a kształtowaniem się parametrów produkcyjnych w stadach krów rasy PHF i MO w różnych systemach utrzymania. Wskaźniki produkcyjne analizowanych stad opracowano na podstawie wyników oceny użytkowości mlecznej, które obejmowały 1374 laktacje. Do obliczenia parametrów krzywej laktacji wykorzystano model Wooda. Analizowano wpływ rasy, laktacji oraz typu gospodarstwa na kształtowanie się parametrów modelu Wooda. Badano również zależność między kształtem i przebiegiem krzywej a produkcją i składem chemicznym mleka w próbnych udojach. W przeprowadzonych badaniach stwierdzono, że najczęściej występującym typem krzywej była krzywa standardowa, która wykazała większą częstotliwość krów rasy MO niż PHF. Standardowy przebieg krzywej laktacji gwarantował największą produkcję i jakość mleka badanych krów. Stwierdzono istotny wpływ rasy, laktacji oraz typu gospodarstwa na kształtowanie się parametrów modelu Wooda. Krowy charakteryzujące się mniej dynamicznym przebiegiem laktacji charakteryzowały się istotnie lepszą produkcyjnością laktacyjną.

MS received May 2015

Authors' address:
Marcin Gołębiewski
Zakład Hodowli Bydła
Katedra Szczegółowej Hodowli Zwierząt
Wydział Nauk o Zwierzętach SGGW
02-786 Warszawa, Ciszewskiego 8, Poland
e-mail: marcin_golebiewski@sggw.pl