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CHARACTERISTICS OF LACTATION CURVE AND REPRODUCTION IN DAIRY CATTLE

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Abstract

The purpose of the research was to assess changes in the lactation activity of cows and their impact on the level of reproduction, as well as to study their fluctuations with respect to genetic and environmental factors. A sample of 807 cows of various ages was formed for the study. The cows were kept on a commercial farm in Kharkiv region, Ukraine. Data from DairyPlan C21 software were used in the study. It was revealed that the parameters of the Wood lactation curve model were significantly influenced by the calving season, days open, and cow's origin; lactation persistency of cows was more influenced by environmental factors (parity, calving season, days open) than by the sire. In order to improve the level of reproduction in dairy herds, it is advisable to take into account the lactation persistency of cows, since it has negative relationship with days open ($r = -0.074$). To improve lactation persistency it is necessary to use for insemination of cows semen of sires with high breeding values for this trait.

Keywords: reproduction, parameters of lactation curve, lactation persistency, dairy cattle

INTRODUCTION

Sustainable milk production affects farm profitability and depends on the reproduction rate and duration of cow use (Dallago *et al.,* 2021). An increase in the milk production of cows led to a deterioration in the level of reproduction and other functional traits of animals (Haile-Mariam and Pryce, 2019), which is due to the presence of genetic antagonism between these groups of traits (Berry *et al.,* 2014). For example, in the population of Holstein cows in the USA, milk yield increased from 5,912 kg in 1957 to 12,934 kg in 2020, thus, on average, milk yield increased by 111.5 kg per year. The average annual genetic progress in milk yield was 72.6 kg (CDCB 2022).

Herewith, until 2008, there was a steady decrease in the genetic value of animals for reproduction traits. Only after reproduction traits were included in the Lifetime Net Merit Index ($NM) they began to gradually improve (Cole *et al.*, 2021).

The consequence of reproductive problems is a lack of replacement heifers. In practice, estrus synchronization schemes (Carvalho *et al.,* 2018) and electronic sensors for its detection (Mayo *et al.,* 2019), as well as improved breeding programs (Chegini *et al.,* 2019a), crossbreeding (Rinell and Heringstad, 2018; Borshch *et al.,* 2021a) and sexed semen are widely used (Pahmeyer and Britz, 2020).

The level of reproduction is influenced by many factors (Muller *et al.,* 2014), including the level of milk production of cows (Rearte *et al.,* 2018).

On farms in Australia (Workie *et al.*, 2021), Spain (Armengol and Fraile, 2018), England (Brickell and Wathes, 2011), and Estonia (Rilanto *et al.*, 2020), one of the main reasons for the culling of cows from the herds are problems with reproduction.

When studying milk performance, it is important to take into account not only its general level (milk yield), but also the peculiarities of lactation activity of cows. For this purpose mathematical models are widely used. Among the parametric mathematical models of the lactation curve, the Wood model (Wood, 1967; Bouallegue and M'hamdi, 2020) is the most common, as it allows describing the main characteristics of lactation activity: milk yield at the beginning of lactation, the increase in milk yield up to reaching the peak of lactation and the subsequent decline of milk yield.

In the investigation of Elahi Torshizi (2016), low heritability (from 0.015 to 0.024) was established for the parameters of the Wood model. Similar estimates of heritability were obtained by Radjabalizadeh *et al.* (2022). This is due to the fact that the lactation activity of cows is influenced by many environmental factors, primarily the feeding system (Różańska-Zawieja *et al.,* 2021). Marumo *et al.* (2022) proved the influence of temperature fluctuations indoors and outdoors on the lactation activity of cows.

According to Hossein-Zadeh (2019), cows that produced twins had different values of Wood's model parameters compared to single-calf cows.

Li *et al.* (2022) conducted a large-scale study (8,595,413 lactations of cows from all regions of the USA) of the influence of environmental factors (milking frequency, parity, year and month of calving, region of the country) on parameters of the Wood lactation curve model. They found that parity most likely affects the scaling parameter (a), the post-peak lactation decline parameter (c) and milk yield for 305 days, while the month of calving most affects the pre-peak lactation raise parameter (b).

In the conditions of milking parlors with automatic systems of cow production recording, methods of estimation of lactation curves can be a tool in managing the reproduction process (Ben Abdelkrim *et al.,* 2021). In dairy farming, it is becoming relevant to use data from milking parlors to assess the impact of various factors on economically important traits and to make breeding and management decisions (Neethirajan and Kemp, 2021).

An important characteristic of the lactation activity of cows is lactation persistency, which is defined as the ability of a cow to maintain a high milk yield after reaching the peak of lactation. The persistency of lactation is a genetically controlled trait. For example, according to Chegini *et al.* (2019b), the heritability of lactation persistency is from 0.05 to 0.10. The importance of lactation persistency is primarily due to its relationship with animal health: cows with more persistent lactation suffer less from metabolic disorders and other diseases (Appuhamy *et al.*, 2007). In addition, a number of studies revealed a favorable genetic relationship between lactation persistency and reproductive traits of dairy cows (Strapakova *et al.*, 2016; Yamazaki *et al.,* 2014). According to (Torshizi *et al.*, 2019), the persistency of lactation of cows is an economically important trait and should be included in the breeding goal of dairy cattle.

The purpose of the research was to assess changes in the lactation curves of cows and their impact on the level of reproduction, as well as to study their fluctuations with respect to genetic and environmental factors.

MATERIALS AND METHODS

On the central unit of the farm, 1,500 cows are housed under a free box system with manure removal by a mobile device, and cows are milked on two "Parallel" (GEA Group AG, Germany) 2 × 16 milking units. Cows are fed according to lactation stages (1^{st} stage 1–120 days, 2^{nd} stage – 121–211 days, 3^{rd} stage 212 days, and more) using total mixed rations (TMR).

The sample for analysis included 807 lactations of local Ukrainian Black-Spotted dairy breed cows different ages. Ukrainian Black-Spotted breed was created by crossing black-spotted local cattle with Holstein breed. Data from Dairyplan C21 (GEA Group AG, Germany) used in the study included calving dates, conception dates, milk yields for 305 days, milk yields for complete lactation, origin (sires), test day milk yields with an interval of 7 days during the first 20 weeks of lactation.

To describe lactation curves Wood model was used (Wood, 1967):

$$Y_t = at^b e^{-ct}, \qquad (1)$$

where

t ....day in milk (1–305 days);
Y_t ....milk yield at day t, kg;
a ....scaling parameter representing milk yield at the beginning of lactation;
b ....raising up to lactation peak parameter);
c ....declining after lactation peak parameter).

Lactation persistency was calculated as (Weller, 2006):

$$\text{Lactation persistency} = \frac{\text{milk yield at } 225^{th} \text{ day of lactation}}{\text{milk yield at } 45^{th} \text{ day of lactation}} \times 100\%. \qquad (2)$$

Following linear model was used for the analysis:

$$y_{klij} = \mu + yc_k + sc_l + a_i + s_j + m_y + d_o + e_{klij},$$

where

y_{klijm}......observation (parameters of Wood model and lactation persistency);
μ...........general mean;
y_{ck}.........effect of k^{th} calving year;

sc_l.........effect of l[th] calving season;
d^o..........effect of days open;
a_i ....effect of i[th] parity;
s_j...........effect of j[th] sire;
m_y.........effect of milk yield for 305 days;
e_{klij}........residue.

Influence of effects was calculated as:

$$\eta^2 = \frac{SS_{effect}}{SS_{total}}, \quad (2)$$

where
SS_{effect}... sum of squares for the effect studied;
SS_{total}... total sum of squares.

Significance of effects was tested using F-statistic:

$$F = \frac{MSF}{MSR}, \quad (3)$$

where
MSF.....mean square for the effect studied;
MSR ....residual mean square.

Four levels of days open were used in the analysis:
1 – up to 100 days;
2 – 101–150 days,
3 – 151–200 days,
4 – more than 200 days.

Analysis was performed using R environment (http://cran.r-project.org).

RESULTS

Cows of the studied herd had high milk yields for both standard (305 days) (Tab. I).

The studied animals, along with high milk production, had an average days open of 134 days, and as a result, prolonged lactation.

The average values of daily milk yield of the cows of the herd in the first 20 weeks of lactation are presented in the Tab. II.

As it can be seen from the table that milk yields of cows increased up to the 42[nd] day of lactation, and then gradually decreased. Thus, milk yield at the peak of lactation of the studied cows was on average 7.72 kg more than on the 7[th] day of lactation.

I: *Descriptive statistics of cows in analyzed sample (n=807)*

Trait	M ± m	Cv, %
Milk yield for 305 days, kg	8956.9 ± 50.62	16.1
Days open, days	134 ± 2.1	44.1
Parameters of Wood model		
a	17.6 ± 0.22	35.9
b	0.23 ± 0.004	45.7
c	0.004 ± 0.00008	52.8
Lactation persistency, %	72.5 ± 0.68	26.7

Note: M – mean, m – standard error of mean, Cv – coefficient of variation

II: *Daily milk yields according to the results of test day milking of cows with a weekly interval, 807 cows*

Day in milk	M ± m	Cv, %
7	25.59 ± 0.24	26.4
14	28.96 ± 0.25	24.7
21	30.79 ± 0.26	24.0
28	32.26 ± 0.26	23.2
35	33.07 ± 0.26	22.0
42	**33.31 ± 0.24**	**20.8**
49	33.17 ± 0.24	20.3
56	33.16 ± 0.23	20.0
63	32.90 ± 0.22	19.3
70	32.72 ± 0.22	18.7
77	32.47 ± 0.21	18.5
84	32.14 ± 0.21	18.1
91	32.05 ± 0.21	18.2
98	31.73 ± 0.21	18.4
105	31.40 ± 0.20	18.4
112	31.14 ± 0.20	17.8
119	30.87 ± 0.20	18.2
126	30.73 ± 0.20	18.4
133	30.48 ± 0.20	18.2
140	30.11 ± 0.19	18.2

The coefficients of determination for the Wood model, depending on the calving season, were high and ranged from 95.5% to 97.3% (Tab. III).

Parameters Wood model changed according to the calving season of the cows. Cows that calved in the autumn and winter had the largest value of parameter *a* and at the same time were characterized by the smallest values of parameters *b* and *c*. This was reflected in the fact that cows that calved in these seasons had the largest persistence of lactation.

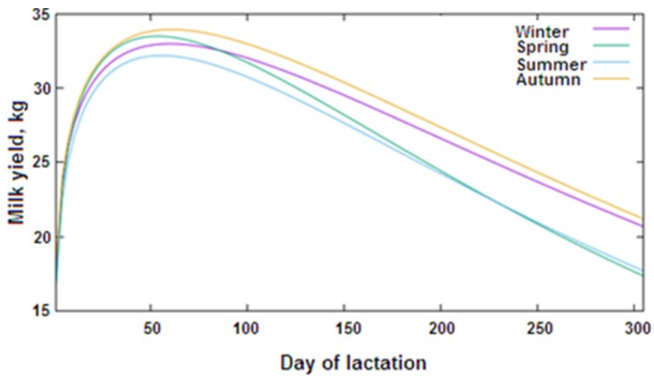
Lactation curves constructed according to the estimated parameters are shown in Fig. 1.

The values of these parameters are manifested in different forms of lactation curves depending on the calving season: the lactation curves of cows that calved in the autumn-winter period are characterized by a smaller decline in milk yield after the peak of lactation compared to the lactation curves of cows that calved in the spring-summer period.

Tab. IV shows the values of the parameters of the Wood model, the day of lactation peak (b/c), the coefficient of determination (R^2) and the Persistency of lactation depending on the days open.

III: *Parameters of Wood model, day of lactation peak (b/c), coefficient of determination (R^2) and persistency of lactation depending on the calving season of cows*

Calving season	n	Parameters of Wood model			Day of lactation peak	R^2	Lactation persistency, %
		a	b	c			
Winter	199	18.38	0.18919	0.00316	60	0.9551	76.8
Spring	138	17.38	0.22057	0.00414	53	0.9731	67.7
Summer	218	16.96	0.21282	0.00385	55	0.9566	70.4
Autumn	252	18.58	0.19427	0.00321	61	0.9585	76.7



1: *Lactation curves of cows d depending on the calving season*

IV: *Parameters of the Wood model, the day of lactation peak (b/c), the coefficient of determination (R^2) and the persistency of lactation depending on days open*

Days open, days	n	Parameters of Wood model			Day of lactation peak	R^2	Lactation persistency, %
		a	b	c			
Up to 100	299	17.19	0.20830	0.00351	59	0.9458	74.3
101–150	264	15.68	0.24456	0.00410	60	0.9620	70.9
151–200	135	17.14	0.22033	0.00379	58	0.9637	72.1
More than 200	109	18.59	0.20448	0.00387	53	0.9285	69.3

Analyzing the changes in the parameters of the Wood model, it should be noted that there is no constant tendency to increase or decrease of any parameter with an increase of days open. For example, if we look at parameter *b*, which characterizes the speed of the rise of the lactation curve to the peak, it is the smallest for cows with the largest days open, and the largest for cows with days open from 101 to 150 days. Cows with the least days open have almost the same value of parameter *b* as cows with the worst reproduction level, although their lactation curves are significantly different. Nevertheless, a clear trend is observed: with an increase of days open there is certain reduction in the period of reaching maximum milk yield and decrease in lactation persistency: cows with days open of more than 200 days reached the peak of lactation the fastest and were characterized by the lowest lactation persistency (Tab. IV).

Lactation curves of cows depending on the days open are visualized in Fig. 2.

The parameters of lactation activity of cows were evaluated using Wood model, depending on the origin (Tab. V).

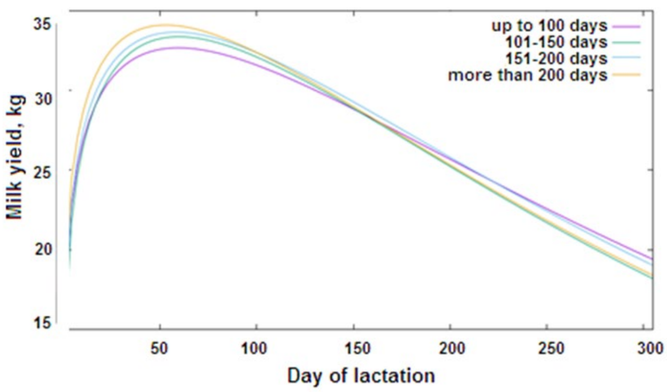
The coefficient of determination varies from 0.7718 to 0.9761. This means that only 2.39% to 22.82% of the variance in daily milk yield is not explained by the Wood model.

It can be seen from the Tab. V that cows that reach maximum milk yield faster have lower lactation persistency.

Daughters of Darny had the largest initial milk yields (parameter *a*), while daughters of Asket and Breez had the lowest values of this trait.

Daughters of Herzog had the least decline in milk yield and, as a result, the highest lactation persistency, which was 19.9% higher than of daughters of Reinhard.

The influence of genetic (sire) and non-genetic factors (parity, calving year, calving season, milk yield for 305 days of lactation and days open) on parameters



2: *Lactation curves of cows depending on the days open*

V: *Parameters of Wood model, day of lactation peak (b/c), coefficient of determination (R^2) and persistency of lactation depending on the origin (sire) of cows*

Sire	n	Parameters of Wood model			Day of lactation peak	R^2	Lactation persistency, %
		a	b	c			
Herzog	23	19.54	0.15017	0.00235	64	0.7718	83.4
Raul`	51	18.40	0.22698	0.00388	58	0.9611	71.7
Portulak	95	17.24	0.18744	0.00289	65	0.9612	80.4
Darny	24	22.79	0.16438	0.00330	50	0.8388	71.9
Kurok	22	19.58	0.19012	0.00354	54	0.8133	71.8
Reinhard	58	18.02	0.21745	0.00447	49	0.9698	63.5
Zorianyi	69	20.12	0.19759	0.00384	51	0.9537	68.9
Mars	25	18.46	0.19356	0.00376	52	0.9297	69.4
Patriot	159	18.19	0.19179	0.00348	55	0.9707	72.8
Trofei	55	21.70	0.17830	0.00356	50	0.9578	70.2
Briz	50	15.63	0.22273	0.00319	70	0.9761	80.6
Asket	27	14.91	0.23433	0.00372	63	0.9358	74.6

VI: *The influence (η^2, %) of the factors parity, calving year, calving season, sire, milk yield for 305 days and days open on parameters of the Wood model and persistency of lactation*

Factor	Parameters of Wood model			Lactation persistency
	a	b	c	
Parity	16.91***	0.95	4.83***	10.81***
Calving year	1.85***	2.21**	0.45	0.53
Calving season	1.89***	2.18***	2.92***	2.41***
Sire	5.48*	5.06	2.84	3.10
Milk yield for 305 days	2.15***	0.06	0.35	0.21
Days open	0.17	0.55*	0.53*	0.96**

Note: * – $\alpha < 0.05$; ** – $\alpha < 0.01$; *** – $\alpha < 0.001$

of Wood model and persistency of lactation were tested (Tab. VI).

Significant influence of days open on the parameters of the Wood model *b* and *c* and persistency of the lactation was established, but the influence was less than 1%.

It was also established that sire significantly ($\alpha < 0.05$) influenced only parameter *a* of the Wood model with an influence of 5.48%, for the other studied characteristics no significant influence of this factor was found.

VII: *Coefficients of correlation between parameters of Wood lactation curve model, days open, lactation persistency and milk yield for 305 days (n = 807)*

Trait	Milk yield	Days open	a	b	c	Lactation persistency
Milk yield	1.00	0.125***	0.334***	-0.017	0.021	-0.046
Days open	0.125***	1.00	0.015	0.066	0.094**	-0.074*
A	0.334***	0.015	1.00	-0.812***	-0.364***	-0.035
B	-0.017	0.066	-0.812***	1.00	0.739***	-0.363***
C	0.021	0.094**	-0.364***	0.739***	1.00	-0.874***
Lactation persistency	-0.046	-0.074*	-0.035	-0.363***	-0.874***	1.00

Note: * – $\alpha < 0.05$; ** – $\alpha < 0.01$; *** – $\alpha < 0.001$

Parity (10.81%) and calving season (2.41%) of cows had the greatest influence on lactation persistency ($\alpha < 0.001$).

It should be noted that the calving season had a significant ($\alpha < 0.001$) impact on all the studied traits with different influences, which ranged from 1.89% to 2.92% for parameters a and c, respectively.

Phenotypic correlations were calculated between milk yield, reproduction level, lactation persistency and parameters of Wood model (Tab. VII).

Negative correlations were found between the lactation persistency and days open ($\alpha < 0.05$) and parameters *b* ($\alpha < 0.001$) and *c* ($\alpha < 0.001$). When the parameter *a*, which characterizes the initial milk yield after calving, increases, the milk yield after 305 days of lactation also increases ($r = 0.334$; $\alpha < 0.001$).

High significant positive correlation between parameters *b* and *c* of the Wood model ($r = 0.739$; $\alpha < 0.001$) and negative relationship between lactation persistency and parameters *b* ($r = -0.363$; $\alpha < 0.001$) and *c* ($r = -0.874$; $\alpha < 0.001$) were obtained. Thus, when parameters c and b of the Wood model decreased, an increase in the persistency of lactation was observed in the cows of the studied population.

DISCUSSION

The shape of the lactation curve reflects the phenotypic expression of biological processes associated with milk secretion during lactation (Macciotta *et al.,* 2011).

For the best level of manifestation of milk production and reproduction traits, it is necessary to provide optimal feeding conditions and monitor the microclimate in barns, since natural climatic factors play an important role in the interaction system "genotype-environment" (Borshch *et al.,* 2021b).

According to results of the research all the studied factors (calving season, days open, sire of cow) affect the parameters of the Wood model, and as a result, the shape of the lactation curve and persistency of lactation.

Researchers revealed the influence of certain non-genetic factors on the parameters of the lactation curve for milk yield (Tekerli *et al.,* 2000) and its composition (Zhou *et al.,* 2022).

Cows with high lactation persistency have a slow rate of decline in milk production, whereas cows with a rapid decline in milk yield tend to have low lactation persistency (Cole and Null, 2009).

In our study the correlation between milk yield and parameter *a* of Wood model was positive, as in the study (Boujenane, 2012).

In the study of Appuhamy *et al.* (2007) it was shown that cows with higher lactation persistency reached lactation peak later (correlation between lactation persistency and day of lactation peak was 0.70–0.82). These results correspond to the data obtained in our research (Tabs III–V).

According to Yanizaki *et al.* (2014) the heritability for lactation persistency in Holstein cows, which were 0.16, 0.19, and 0.14 for first, second, and third lactations, respectively. These results indicate the possibility of genetic improvement of lactation persistence when it is included in breeding programs.

Decrease of reproduction in cows with reduced lactation persistency may be due to the fact that there is negative phenotypic correlation ($r = -0.15$) between cow metabolic diseases and lactation persistency (Harder *et al.,* 2006).

CONCLUSION

Calving season, days open, the origin (sire) of the cows significantly influenced on the parameters of the Wood lactation curve model. Lactation persistency of cows was more influenced by environmental factors (parity, calving season and days open) than by the sire.

To improve the level of reproduction in dairy herds, it is desirable to take into account the lactation persistency of cows, since it has a negative relationship with the days open (r = -0.074).

To improve the lactation persistency it is necessary to use for insemination of cows semen of sires with high breeding values for this trait.

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