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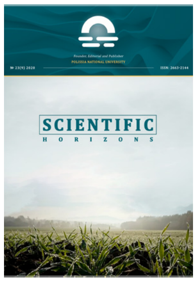

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Analysis of lactation length variability and its relationship to cow milk production

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Abstract. Lactation length is a key trait closely associated with both productivity levels and reproductive characteristics in dairy cattle. This study aimed to analyse the factors influencing lactation length variability and its impact on lactation curve formation, as well as the quantitative and qualitative traits of dairy herd productivity. The study utilised data from 604 complete lactations of cows that calved at PJSC "Plemzavod "Stepnoi" (Zaporizhzhia Region, Ukraine) between 2014 and 2017. Among the studied cows, lactation length ranged from 173 to 1,150 days, with a mean value of 356.1 ± 4.1 days. Cow age (in lactations) had a significant effect on lactation length ($P < 0.001$). No significant effect of the bull sire was observed on the lactation length of primiparous cows. However, when all lactations were considered together, a significant bull sire effect ($P = 0.005$) on lactation length was identified. Additionally, lactation length variability in the studied group was influenced by the year and season of calving. Overall, the lowest LSMestimated lactation length was observed in multiparous cows

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that calved in the autumn months (332.9 days), while the highest values were recorded in cows that calved in winter or autumn (ranging from 386.3 to 397.0 days). Lactation length was significantly associated with total milk yield ($P < 0.001$), whereas a significant correlation with 305-day milk yield was established only in multiparous cows ($P = 0.036$). The fat and protein milk percentages of the studied cows were also significant ($P \leqslant 0.001$-0.020) but negatively associated with lactation length. When approximating the lactation curves of the studied cows using Wood's model, it was found that as lactation length increased, the estimated value of coefficient "*a*" in Wood's model also increased, whereas the estimated values of coefficients "*b*" and "*c*" decreased. Overall, longer lactation length was associated with an increase in daily milk yield estimates for months 8-10, contributing to improved lactation curve persistency

Keywords: extended lactation; genotypic and environmental factors; lactation curve persistency

INTRODUCTION

Traditionally, the lactation cycle of a dairy cow is based on a 12-month interval between calvings, which includes 10 months of lactation and a two-month dry period. This means that a cow must be inseminated within two to three months after calving when she is at peak lactation and metabolically in a negative energy balance. However, due to these complex physiological conditions, it is difficult for a cow to conceive at this time, and therefore, delaying insemination after peak production and, as a result, extending lactation beyond 10 months, may be the most optimal solution to this problem. In addition, extended lactation may have other benefits, such as reducing the number of newborn calves that need to be culled at a young age, reducing health and welfare problems, and finally, improving environmental impacts (reducing greenhouse gas emissions or reducing the use of antibiotics) throughout the animal's life (Stelwagen *et al.*, 2024).

A range of both genotypic and environmental factors influence the lactation length in dairy cows. Among the genotypic factors, the breed of the cow and the breeding bull are primary influences (Alfonso *et al.*, 2024). As noted in the study of A. Toure *et al.* (2019), this factor is particularly significant for the offspring of crosses between dairy breeds of European and/or American origin and various zebu breeds. Among the environmental factors, the year and season of calving are influential. In addition, as indicated by N.S. Dangar and P.H. Vataliya (2021), the age of the cow (in lactation) also affects the variation in lactation length. However, in addition to these factors, it has also been noted that other factors can influence lactation length, such as the sex of the newborn calf. For example, in the research of S.K. Genena and M.H. ElSawy (2024), a significant ($P < 0.05$) predominance of the average lactation length of Friesian cows (Egypt) that calved heifers over the estimates obtained for cows that calved bull calves (318.9 and 268.9 days, respectively) was demonstrated.

The study of R. Kumar *et al.* (2023) demonstrates the complex and multifaceted relationship between the occurrence of subclinical mastitis (SCM) and lactation length in Jersey crossbred dairy cows in India. Increased SCM indicators were often associated with intramammary infection, including subclinical mastitis. Consequently, cows with persistent or severe mastitis experienced shortened lactation lengths due to reduced milk production increased culling rates, or veterinary care issues. In contrast, Friesian cows with a cup-shaped udder in Egypt exhibited higher milk production and lactation lengths (averaging 480.7 days) compared to cows with other udder shapes (Saleh *et al.*, 2023).

Finally, in Karan Fries cows (*Bos taurus* × *Bos indicus*) in India (Magotra *et al.*, 2020), a significant ($P < 0.05$) association between lactation length and the SNP G43737229T of the breast cancer 1 gene (*BRCA1*) was demonstrated, while in the research of D. Worku *et al.* (2022a) on the Sahiwal dairy breed, a significant ($P < 0.05$) association was noted between lactation length and the SNP g.306T > C of the *SIRT1* gene. In addition, in animals of this breed, a significant ($P < 0.05$) association was established between lactation length and the SNP rs41255599: C > T of the LAP3 gene (Worku *et al.*, 2022b). Several positive and negative effects of extending lactation length for dairy cattle have been identified. For example, the study of J. Sehested *et al.* (2019) showed that delaying insemination by extending the voluntary waiting period improves the cow's sexual behaviour and ensures her conception after the cow's energy balance becomes positive. Overall, the strategy of prolonging the lactation length of dairy cows leads to fewer calvings during their productive lifespan, and therefore, to a reduction in morbidity, a reduction in the number of replacement heifers, and a reduction in the number of dry days per cow per year.

When analysing the effects of extending lactation length in high-yielding cows in Mexico, I.J. Rodríguez-Godina *et al.* (2021) found that the average milk yield per lactation increased linearly with the number of prolonged lactations during the productive life, with a maximum yield of 19,099 kg of milk per lactation for cows with five prolonged lactations. At the same time, the average daily milk yield per day of productive use was significantly ($P < 0.01$) lower in cows that did not have any prolonged lactation (30.2 kg) compared to animals that had all five lactations prolonged (32.1 kg).

On the other hand, the implementation of a prolonged lactation length strategy has negative consequences. For example, the study of J.B. Clasen *et al.* (2019) showed that this strategy means an increase in calving intervals, which can have an inhibitory effect on the level of genetic variation in the herd. This occurs primarily due to the genetic lag between the additive genetic level of the cow population relative to the bull sire population. In the research of K. Reindl *et al.* (2024) on Holstein cows, Czech Fleckvieh cows and their crosses, it was shown that extended lactation in high-yielding dairy cows is as demanding on energy metabolism as the initial stages of lactation. In both cases, a significantly ($P < 0.001$) higher content of ketone bodies in milk was found than during the middle (101-200 days) and late (201-305 days) lactation periods.

Negative consequences of extending lactation length, in addition, include the fact that milk yields gradually decrease, which may be associated with an increased risk of cow obesity at the end of lactation. There is limited information on the consequences for cow productivity when lactation is prolonged and for calves born to cows with prolonged lactation. Therefore, a strategy based on individual cow characteristics may become the future approach to selecting high-yielding cows with persistent lactation curves when extending lactation length. This will make it possible to limit the risk of obesity and reduce milk yields at the end of lactation while benefiting from reducing the consequences of calving complications (van Knegsel *et al.*, 2022).

Therefore, the main goal of this study was to analyse the dependence of lactation length variability on genotypic (bull sire) and environmental (lactation number, year and season of calving) factors and to assess its effect on the formation of milk productivity of dairy cows.

MATERIALS AND METHODS

The study utilised data from 604 complete lactations of cows that calved at PJSC "Plemzavod "Stepnoi" (Zaporizhzhia Region, Ukraine) between 2014 and 2017. All animals were descendants of 231 cows and 14 Holstein bull sires, belonging to five lines (Starbuck, Bell, Chief, Vaillant and Elevation) and had an average of 1.9 ± 0.8 (*Mean* ± *SD*) lactations, ranging from 1 to 4 lactations. For each animal, the following data on their milk production were used: total milk yield for the entire lactation (TMY), 305 days milk yield (MY305), fat milk percentage (FP), protein milk percentage (PP), as well as daily milk yield for the test days 1-10 (TD1-TD10), which corresponded to 30, 60, ... 300 days of lactation.

The following factors were selected for the investigation of their influence on the lactation length of the cows in the study group: sire origin (14 subgroups), age in lactations (two subgroups: primiparous cows and multiparous cows with ⩾ 2 calvings), year of calving (three subgroups: 20142016 for primiparous cows and 2015-2017 for multiparous cows), season of calving (four subgroups: winter (December-February), spring (March-May), summer (June-August) and autumn (September-November)). For each subgroup, the least squares mean (*LSM*) estimates for lactation length were calculated based on the General Linear Model (GLM) (Al-Murrani, 2024; Atamanyuk *et al.*, 2019):

$$Y_{ijk} = \mu + \text{Parity}_i + \text{SG}_j + e_{ijk}, \quad (1)$$

where Y_{ijk} is the *LSM* estimate of lactation length; μ is the overall arithmetic mean; Parity_i is the fixed factor of lactation number (two gradations); SG_j is the fixed factor of subgroup, depending on origin, year or season of calving; e_{ijk} is the random error.

Pairwise comparisons of the means of individual subgroups were performed based on Tukey's HSD test (for groups of unequal size). To analyse the relationship between lactation length and milk production characteristics of cows, Spearman's rank correlation coefficient (*Rs*) was calculated. To approximate the lactation curves for the first 305 days of lactation of cows from different subgroups, based on the average daily milk yield estimates for TD 1-10, Wood's model was used:

$$Yt = at^b e^{-ct}, \quad (2)$$

where *Yt* is the daily milk yield at time *t* (30^{th}, 60^{th}, 90^{th}, ... 300^{th} day of lactation); *a*, *b*, and *c* are Wood's model coefficients. The adequacy of Wood's model to the original data was assessed based on the coefficient of determination (R^2).

In addition, based on the obtained estimates of Wood's model coefficients, Wood's model parameters were also calculated using the following formulas (Kramarenko *et al.*, 2022):

$$Ymax = a\left(\frac{b}{c}\right)^b e^{-b}, \quad (3)$$

$$Tmax = \frac{b}{c}, \quad (4)$$

$$Persistency = c^{-(b+1)}, \quad (5)$$

where *Ymax* is the estimate of peak (maximum) 305 days milk yield; *Tmax* is the time to reach peak milk yield of lactation; *Persistency* is the estimate of lactation persistency, which characterises the rate of decline in milk production from the moment of reaching peak milk yield to the 305^{th} day of lactation.

All mathematical and statistical analysis of the original data was performed using STATISTICA v.7 software (Stat Soft Inc.). When keeping experimental animals on the farm and during all manipulations with them, the provisions of the Law of Ukraine No. 249 (2012) and the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (1986) were observed.

RESULTS AND DISCUSSION

General characteristics of lactation length variability. In the study group of cows, lactation length ranged from 173 to 1,150 days, with an average of 356.1 ± 4.1 (*Mean* ± *SE*) days. Analysis of their distribution on normal probability paper revealed that the original data sample consists of four subgroups, characterised by a more or less normal distribution, which can be approximated by straight lines on probability paper. The intersection points of these four approximating straight lines correspond to 285, 365 and 435 days of lactation (Fig. 1).

Thus, all original data were divided into four subgroups according to lactation length: short lactation (less than 285 days), normal lactation (286-365 days), prolonged lactation (366-435 days) and extremely prolonged lactation (more than 436 days). The main indicators of variability of individual subgroups of Holstein cows by lactation length are shown in Table 1.

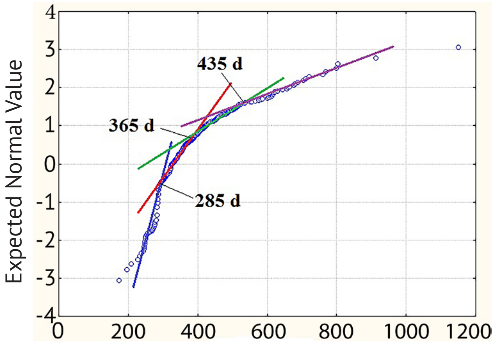

***Figure 1**. Distribution of Holstein cows by lactation length on normal probability paper*
***Note:** different colours indicate straight lines approximating individual lactation length subgroups. 285 d, 365 d, and 435 d – boundary limits for identifying individual subgroups*
***Source:** developed by the authors*

***Table 1**. Variability indicators of individual subgroups of Holstein cows by lactation length*

Lactation length subgroup	Lactation length limits (days)	*n*	*Mean* ± *SE* (days)	*SD* (days)
Short lactation	< 285	118	237.6 ± 1.8	19.1
Normal lactation	286-365	300	319.7 ± 1.4	24.4
Prolonged lactation	366-435	106	398.1 ± 1.9	20.0
Extremely prolonged lactation	> 436	80	558.9 ± 13.7	122.7
Overall	173-1,150	604	356.1 ± 4.1	100.8
F_L (3; 600); *P*	–	–	–	134.13; *P* < 0.001

***Note:** n – number of records; FL – Levene's test estimate for homogeneity of subgroup variances; P – significance level; Mean ± SE – estimate of the subgroup arithmetic mean and its statistical error; SD – subgroup standard deviation*
***Source:** developed by the authors*

Earlier, in the study of H. Mehta *et al.* (2021), Red Dane × Sahiwal × Holstein-Friesian crossbred cows (India) were also divided into subgroups according to their lactation length: short lactation (102-179 days), normal lactation (180-483 days), prolonged lactation (484-560 days) and extremely prolonged lactation (more than 560 days).

Table 2 shows the *LSM* estimates (± *SE*) of lactation length depending on the breed/crossbreed of European/American dairy cattle and the country of breeding. It can be noted that a significant number of the obtained estimates significantly exceeded the traditional 305 days of lactation, which is accepted as the standard. For example, in the research of K. El-Den *et al.* (2020) for Friesian cows, the *LSM* estimate of lactation length in Egypt was 358.3 days, and for Swedish Red cows in Turkey, it reached 361.0 days (Genç & Mendes, 2021). At the same time, for HolsteinFriesian cows and their crosses with Jersey cows in New Zealand, the *LSM* estimates of lactation length were shortest – only about 8 months, which is probably due to a certain technology of the dairy cattle industry in these farms (Curry *et al.*, 2024).

***Table 2**. Lactation length depending on the breed/crossbreed of European/American dairy cattle and the country of breeding, days*

Breed/crossbreed	Country	*n*	*LSM* ± *SE*	Source
Friesian	Egypt	1,018	301.0 ± 3.5	A.A. Badr & A.A. Amer (2020)
Friesian	Egypt	1,630	358.3 ± 2.3	K. El-Den *et al.* (2020)
Friesian	Egypt	4,413	319.9 ± 0.3	S.K. Genena & S.Z. Ebrahim (2023)
Friesian	Egypt	1,976	310.1 ± 2.5	S.S. Sanad *et al.* (2020)
Holstein	Costa Rica	17,269	333.0 ± 0.6	B. Vargas-Leitón *et al.* (2024)
Holstein	Morocco	4,737	347.1 ± 0.8	I. Boujenane (2019)
Holstein	Ukraine	604	356.1 ± 4.1	own data
Holstein	Turkey	823	350.0 ± 2.6	S. Genç and M. Mendes (2021)

Table 1. Continued

Breed/crossbreed	Country	*n*	*LSM* ± *SE*	Source
Holstein	Turkey	2,936	357.6 ± 1.3	S. Genç (2022)
Holstein	Turkey	530	316.5 ± 6.9	M. Ozdemir *et al.* (2021)
Holstein-Friesian	New Zealand	231	244.0 ± 1.0	B.A. Curry *et al.* (2024)
Holstein-Friesian	Pakistan	66	285.9 ± 31.8	I. Ali *et al.* (2019)
Holstein-Friesian	Turkey	9,844	350.9 ± 0.8	Y. Öztürk *et al.* (2021)
Holstein-Friesian	Egypt	937	301.0 ± 3.6	A.S. Khattab *et al.* (2021)
Holstein-Friesian	Pakistan	610	278.2 ± 10.9	M. Khalil *et al.* (2021)
Holstein-Friesian × Jersey	New Zealand	84	248.0 ± 2.0	B.A. Curry *et al.* (2024)
Jersey	Ethiopia	2,912	344.9 ± 3.8	N. Beneberu *et al.* (2020)
Jersey	Turkey	824	328.0 ± 2.2	S. Genc & M. Mendes (2021)
Jersey	Pakistan	39	290.5 ± 40.6	I. Ali *et al.* (2019)
Jersey	Ethiopia	3,495	352.9 ± 0.9	K. Abera *et al.* (2023)
Montbeliarde	Turkey	1,448	333.0 ± 3.6	S. Genc & M. Mendes (2021)
Swedish Red	Turkey	36	361.0 ± 15.3	S. Genc & M. Mendes (2021)

Note: *n – number of records; LSM ± SE – least squares mean estimate and its statistical error*
Source: *created by the authors based on literature and their own results*

In general, the lactation length is influenced by both the breed of the animals and the technology chosen in a particular country (or on a particular farm). The lactation length can be affected by the adaptation process. For example, the study of N. Beneberu *et al.* (2020) found that when breeding the Jersey breed, the average lactation length of imported individuals, which were imported from Denmark as pregnant heifers, was significantly ($P < 0.001$) longer than in the offspring of imported animals that were raised in Ethiopia (361.3 and 328.6 days, respectively). In addition, the research of R.E. Alfonso *et al.* (2024) showed that when crossing dairy cows with beef sire bulls, their average lactation length was shorter than when using dairy sire bulls for breeding.

The maximum possible lactation lengths can also vary significantly. For example, the study of J. Mellado *et al.* (2021) noted that in the hot climate of Mexico, Holstein cows are effectively fertilised more than 300 days after calving. Therefore, they are characterised by prolonged lactation with an average length of 696 days. In another research on Holstein cows in Mexico, it was noted that the maximum lactation length could reach 1018 days (Rodríguez-Godina *et al.*, 2021). In Europe, the maximum length of prolonged lactation of Holstein-Friesian cows (Poland) reached 622 days (Salamończyk, 2023), and in Holstein cows in Turkey – 550 days. Finally, in the study of T. Kopec *et al.* (2020), primiparous Simmental cows were studied, the lactation length of which maximally reached 1,348 days.

Analysis of the effect of cow age on their lactation length. The age of the cows (in lactations) significantly affected lactation length (one-way analysis of variance: $F_{3;600} = 8.04$; $P < 0.001$). *LSM* estimates for primiparous cows and multiparous cows for the 2nd, 3rd and 4th lactations were 337.9 ± 6.4, 377.8 ± 6.4, 357.7 ± 9.6 and 310.5 ± 21.1 days, respectively. Using Tukey's HSD test, significant differences were noted only between the lactation length of primiparous cows and animals for the 2nd lactation. Therefore, in further analysis, only two age groups were considered according to lactation length – primiparous cows and multiparous cows, which had two or more lactations. In general, the age of the cows significantly affected the ratio of subgroups by lactation length (Pearson's chi-square test: $\chi^2 = 10.58$; $df = 3$; $P = 0.014$). At the same time, the longer lactation period of multiparous cows was due to an almost twice higher proportion of animals among them that belong to the subgroup with extremely prolonged lactation (> 436 days) and, accordingly, a low proportion of animals with short and normal lactation (Fig. 2).

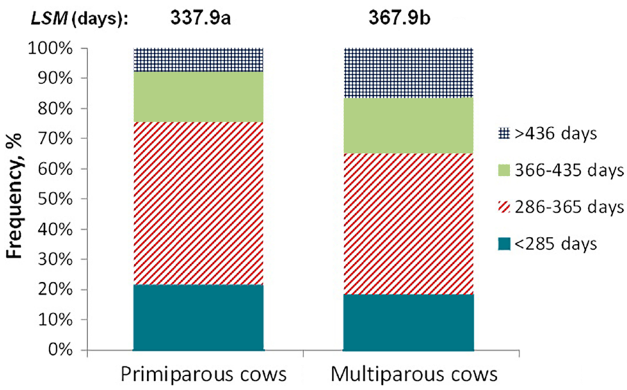

Figure 2*. Distribution by lactation length of primiparous cows and multiparous cows of the Holstein breed*
Note: *LSM estimates for the corresponding subgroups are shown. Significant differences between the means of individual subgroups (P < 0.05) based on Tukey's HSD multiple comparison test are indicated by different letters*
Source: *developed by the authors*

The obtained results are consistent with data previously obtained in studies analysing the influence of cow age on lactation length. Of the 14 studies reviewed, which investigated dairy cattle of European/American origin and crossbred animals, nine reported a significant effect ($P < 0.001$ to 0.05), while the remaining five did not find a significant effect (Table 3). Regarding the pattern of lactation length changes across cows of different ages, it was inconsistent, ranging from a gradual increase in lactation length with each subsequent lactation (as observed in Holstein cows in Turkey (Ozdemir *et al.*, 2021)) to complete similarity in the respective lactation length estimates during the first four lactations, with a significant increase only in the 5th lactation (as seen in Jersey cows in Ethiopia (Abera *et al.*, 2023)).

The most common pattern was characterised by the same lactation length during the 1st and 2nd lactations, but a significant increase during the 3rd lactation. While in the current study, on the contrary, lactation length significantly increased between the 1st and 2nd lactations, but then almost did not change. A similar pattern was also noted for crossbred animals (HolsteinFriesian × Sahiwal) in India (Chopade *et al.*, 2023).

***Table 3**. Results of the effect of cow age (in lactations) on lactation length depending on the breed/crossbreed of European/American dairy cattle and the country of breeding*

Breed/crossbreed	Country	*n*	P_{Parity}	Lactation order	Source
Friesian	Egypt	1,018	< 0.01	-	A.A. Badr & A.A. Amer (2020)
Friesian	Egypt	1,630	< 0.05	1 = 2 > 3 < 4	K. El-Den *et al.* (2020)
Friesian	Egypt	1,300	ns	-	A.A. Saleh *et al.* (2023)
Friesian	Egypt	4,913	< 0.001	1 = 2 > 3 = 4	S.K. Genena and M.H. ElSawy (2024)
Friesian	Egypt	1,976	< 0.001	1 = 2 = 3 < 4	S.S. Sanad *et al.* (2020)
Friesian	Pakistan	608	ns	-	M. Khalil *et al.* (2021)
Holstein	Turkey	530	< 0.05	1 < 2 < 3 > 4	M. Ozdemir *et al.* (2021
Holstein	Ukraine	604	< 0.001	1 < 2 = 3 = 4	own data
Holstein-Friesian	Turkey	796	ns	-	C. Sipahi (2022)
Holstein-Friesian	Egypt	937	ns	-	A.S. Khattab *et al.* (2021)
Holstein-Friesian × Sahiwal	Pakistan	641	ns	-	M.N. Tahir *et al.* (2023)
Holstein-Friesian × Sahiwal	India	9,094	< 0.01	1 < 2 = 3 = 4	M.M. Chopade *et al.* (2023)
Jersey	Ethiopia	2,912	< 0.001	1 = 2 > 3 = 4	N. Beneberu *et al.* (2020)
Jersey	Ethiopia	3,495	< 0.01	1 = 2 = 3 = 4 < 5	K. Abera *et al.* (2023)

***Note:** n – number of records; P_{Parity} – significance level of the effect of lactation number (according to GLM results); ns – $P_{sire} > 0.05$. Lactation order – the presence of significant differences between LSM estimates for different lactations. The signs "<" or ">" mean that significant differences between adjacent lactations are established, and the sign "=" means that significant differences are absent*
***Source:** created by the authors based on literature and their own results*

Analysis of the influence of the bull sire on the lactation length in cows. No significant influence of the bull sire on the lactation length of primiparous cows was found. However, when considering all lactations together, a significant effect of the bull sire on lactation length was established (one-way ANOVA: $F_{13;590} = 2.33$; $P = 0.005$). These results are consistent with earlier findings on the impact of the bull sire on the lactation length of dairy cows of different breeds (Table 4). Furthermore, the results of an analysis conducted during 18 independent studies on dairy cows or crossbred animals (nine of which considered only the 1st lactation and another nine analysed all lactations) indicate a significant relationship between the lactation number and the influence of the bull sire on lactation length (odds ratio: $OR_{prim/multi} = 0.082$; $P = 0.027$). Thus, the influence of the bull sire on lactation length was more likely to be observed when analysing cows of all age groups, compared to when only primiparous cows were included in the analysis.

***Table 4**. Results of the bull sire's influence on lactation length based on breed/origin and country of dairy cattle breeding*

Breed/crossbreed	Country	*n*	n_{sire}	P_{sire}	Source
			1st lactation		
Holstein	Ukraine	237	14	ns	own data
Holstein-Friesian	India	973	42	ns	V.K. Singh *et al.* (2020)
Holstein-Friesian × Gir	India	421	48	ns	S.S. Jadhav *et al.* (2019)
Kankrej	India	291	66	ns	N.K. Thakkar *et al.* (2021)
Kankrej	India	475	75	ns	K. Ankuya *et al.* (2020)
Sahiwal + Crossbreds	India	965	78	< 0.05	D.G. Girimal *et al.* (2020)
Crossbreds	India	2,204	54	< 0.05	V.A.R. Panwar *et al.* (2022)
Crossbreds	India	529	79	ns	S. Kaur *et al.* (2023)

Table 4. Continued

Breed/crossbreed	Country	*n*	n_{sire}	P_{sire}	Source
Crossbreds	India	1,029	107	ns	M. Dangi *et al.* (2021)
All lactations					
Friesian	Egypt	1,018	54	< 0.01	A.A. Badr and A.A. Amer (2020)
Friesian	Egypt	1,300	180	ns	A.A. Saleh *et al.* (2023)
Friesian	Egypt	1,976	117	< 0.001	S.S. Sanad *et al.* (2020)
Holstein	Ukraine	604	14	< 0.01	own data
Holstein-Friesian	Egypt	937	50	< 0.01	A.S. Khattab *et al.* (2021)
Crossbreds	India	529	79	ns	S. Kaur *et al.* (2023)
Holstein-Friesian × Sahiwal	India	9,094	239	< 0.01	M.M. Chopade *et al.* (2023)
Sahiwal	India	567	42	< 0.01	P. Ratwan *et al.* (2019)
Tharparkar	India	284	-	< 0.01	G. Choudhary *et al.* (2019)

Note: *n – number of records;* n_{sire} *– number of bull sires used in the analysis;* P_{sire} *– significance level of the bull sire's influence (according to GLM results); ns –* $P > 0.05$*. Crossbreds – crosses between local breeds and breeds of European origin*
Source: *created by the authors based on literature and their own results*

Analysis of the influence of calving year and season on the lactation length in cows. It was found that the variability in lactation length among cows in the study group depended on the calving year. The calving year significantly influenced the distribution of lactation length subgroups for both primiparous cows (Pearson's chi-square test: $\chi^2 = 16.22$; $df = 6$; $P = 0.013$) and multiparous cows (Pearson's chi-square test: $\chi^2 = 38.64$; $df = 6$; $P < 0.001$). In general, the lowest *LSM* estimate of lactation length was observed for multiparous cows that calved in 2017 (329.2 days) and primiparous cows that calved in 2016 (330.3 days). The highest lactation length was recorded for multiparous cows that calved in 2016 (401.6 days). This prolonged lactation period was mainly due to a significant proportion of animals in the extremely prolonged lactation subgroup (> 436 days) and a correspondingly lower proportion of animals with normal lactation (Fig. 3).

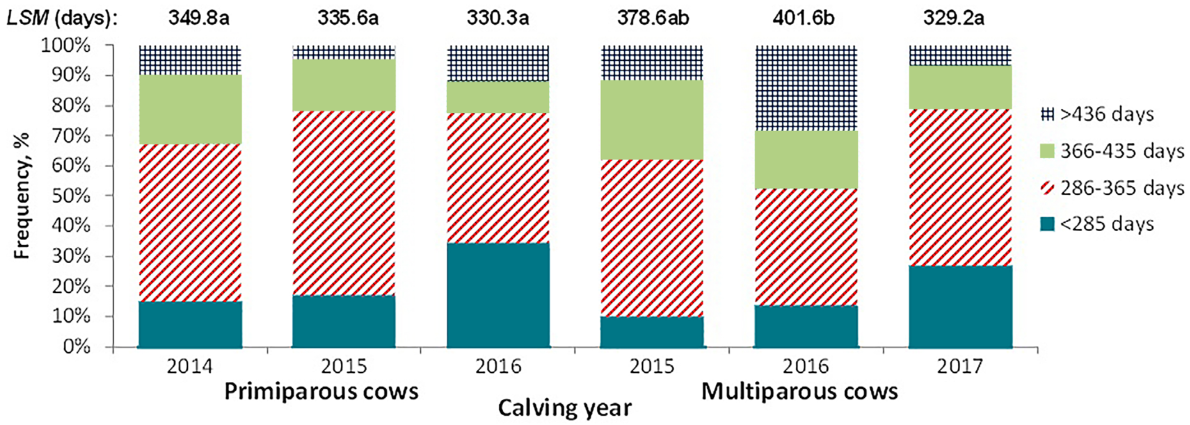

Figure 3*. Distribution of lactation length for primiparous cows and multiparous cows of Holstein breed based on calving year*
Note: *LSM estimates for the corresponding subgroups are shown. Significant differences between the means of individual subgroups (*$P < 0.05$*) based on Tukey's HSD multiple comparison test are indicated by different letters*
Source: *developed by the authors*

It was also found that the variability in lactation length among cows in the study group depended on the calving season. Similarly, the calving season significantly influenced the distribution of lactation length subgroups only for multiparous cows (Pearson's chi-square test: $\chi^2 = 54.95$; $df = 9$; $P < 0.001$), while no significant influence of calving season was found for primiparous cows (Pearson's chi-square test: $\chi^2 = 8.98$; $df = 9$; $P = 0.429$). Overall, the lowest *LSM* estimate for lactation length was observed for multiparous cows that calved in the autumn months (332.9 days), while the highest estimates were recorded for animals that calved in winter or autumn (386.3 to 397.0 days). Animals that calved in the summer had intermediate lactation length. Notably, among the multiparous cows that calved in summer, the highest proportion of animals had normal lactation length (Fig. 4).

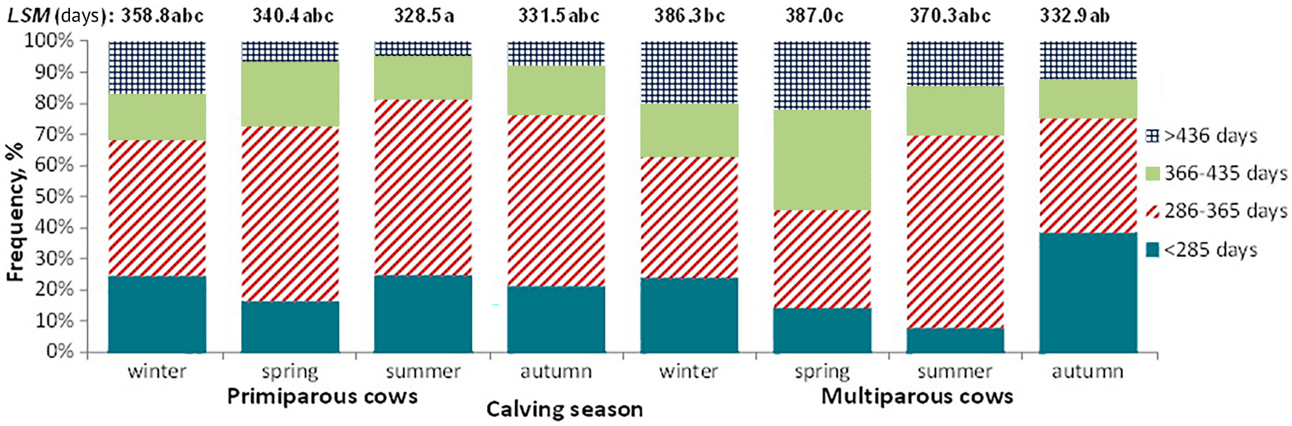

***Figure 4**. Distribution of lactation length for primiparous cows and multiparous cows of Holstein breed based on calving season*
***Note:** LSM estimates for the corresponding subgroups are shown. Significant differences between the means of individual subgroups (P < 0.05) based on Tukey's HSD multiple comparison test are indicated by different letters*
***Source:** developed by the authors*

The results, in general, are consistent with previously obtained results of the analysis of the effect of year and season of calving on the lactation length of dairy cows of different breeds (Table 5). Of the 15 analysed studies in which European/American dairy cattle and crossbred animals were studied, 12 cases showed a significant effect ($P < 0.001$ to 0.05) of calving year (Table 5). At the same time, the chance of establishing a significant effect of the year of calving on lactation length was not related to either the length of the study period (in years) or the number of periods into which the study period was divided. However, this change had a significant relationship with the total number of animals included in the analysis (non-parametric Mann-Whitney test: $Z = -2.02$; $P = 0.044$). Thus, with an increase in sample size, the chance of obtaining confirmation of the hypothesis regarding the significant effect of the year of calving on the lactation length of cows increased.

On the other hand, out of the 15 analysed studies in which European/American dairy cattle and crossbred animals were studied, nine cases showed a significant effect ($P < 0.001$ to 0.05) of the season of calving (Table 5). In this case, the chance of establishing a significant effect of the season of calving on lactation length was not related to the total number of animals included in the analysis (non-parametric Mann-Whitney test: $Z = 0.72$; $P = 0.514$).

In general, studies by other authors confirmed the results obtained regarding the longest lactation length of cows that calved in winter or spring, in contrast to animals that calved in autumn and/or summer (Fig. 4). Similar results were obtained for Friesian cows in Egypt (ElDen *et al.*, 2020; Genena & ElSawy, 2024) and for crossbred cows based on the HolsteinFriesian Crossbreds in Pakistan (Ihsanullah *et al.*, 2020; Tahir *et al.*, 2023). In countries with very hot climates, the lactation length of cows that calved during the wet season of the year was also longer than in animals that calved during the dry season of the year (Hakoueu *et al.*, 2022; Chopade *et al.*, 2023)

***Table 5**. Results of the effect of year and season of calving on lactation length depending on the breed/crossbreed of European/American dairy cattle and the country of breeding*

Breed/crossbreed	Country	*n*	$n_{Y/P}$	P_{YoC}	P_{SoC}	Order of the seasons	Source
Friesian	Egypt	1018	6/6	< 0.01	< 0.01	na	A.A. Badr & A.A. Amer (2020)
Friesian	Egypt	1,630	10/10	< 0.01	< 0.01	(win + spr) > aut	K. El-Den *et al.* (2020)
Friesian	Egypt	4,913	36/5	< 0.001	< 0.05	(win + spr) > (sum + aut)	S.K. Genena and M.H. ElSawy (2024)
Friesian	Egypt	1,976	12/12	< 0.001	ns	-	S.S. Sanad *et al.* (2020)
Friesian	Pakistan	608	16/16	< 0.001	na	na	M.Khalil *et al.* (2021)
Holstein	Ukraine	604	4/4	< 0.001	0.003	(win + spr) > aut	own data
Holstein-Friesian	Turkey	796	7/7	ns	< 0.05	sum > win	C. Sipahi (2022)
Holstein-Friesian	Egypt	937	6/6	< 0.01	na	na	A.S. Khattab *et al.* (2021)
Holstein-Friesian Crossbreds	India	529	30/6	< 0.01	ns	-	S. Kaur *et al.* (2023)
Holstein-Friesian × Gir	India	161	10/2	ns	ns	-	M.G. Mote *et al.* (2020)

Table 5. Continued

Breed/crossbreed	Country	n	$n_{Y/P}$	P_{YoC}	P_{SoC}	Order of the seasons	Source
Holstein-Friesian × Jersey × Gir	India	114	8/2	ns	ns	-	M.G. Mote *et al.* (2020)
Holstein-Friesian × Sahiwal	India	9,094	36/4	< 0.01	< 0.05	rainy > sum	M.M. Chopade *et al.* (2023)
Holstein-Friesian × Sahiwal	Pakistan	641	20/4	< 0.001	< 0.001	win > sum	M.N. Tahir *et al.* (2023)
Holstein-Friesian Crossbred	Pakistan	1,131	17/-	na	0.01	(win + spr) > (sum + aut)	M. S. Q. Ihsanullah *et al.* (2020)
Holstein-Friesian Crossbred, Jersey Crossbred	Cameroon	403	14/-	na	< 0.05	rainy > dry	F. Hakoueu *et al.* (2022)
Jersey	Ethiopia	2,912	31/11	< 0.001	ns	-	N. Beneberu *et al.* (2020)
Jersey	Ethiopia	3,495	17/6	< 0.01	ns	-	K. Abera *et al.* (2023)

Note: *n – number of records; $n_{Y/P}$ – number of years and study periods; P_{YoC} – significance level of the effect of the year/period of calving (according to GLM results); P_{SoC} – significance level of the effect of the season of calving (according to GLM results); ns – $P > 0.05$; na – data not available. The sign ">" means that significant differences between the corresponding calving seasons are established. win, spr, sum, aut – winter, spring, summer and autumn calving season; rainy, dry – wet and dry calving season*
Source: *created by the authors based on literature and their own results*

Analysis of the effect of lactation length on cow milk production. Lactation length was significantly associated with total milk yield in both primiparous cows and multiparous cows (Spearman's rank correlation coefficient: $P < 0.001$ in both cases). As for 305 days of milk yield, a significant correlation was found only for multiparous cows (Spearman's rank correlation coefficient: $Rs = 0.109$; $Rs = 0.036$). In addition, milk yields for the TD6-TD10 were also significantly (in all cases: $P \leqslant 0.001$ to 0.030) correlated with the lactation length of multiparous cows, while in primiparous cows a significant estimate of the Spearman's rank correlation coefficient ($Rs = 0.169$; $P = 0.024$) was found only for milk yield on the TD9 (Table 6). The fat and protein milk percentage of the cows in the study group were also significantly (in all cases: $P \leqslant 0.001$ to 0.020) associated with lactation length, but unlike the quantitative characteristics of milk production, for qualitative characteristics, the Spearman's rank correlation coefficient estimates had a negative sign. At the same time, in multiparous cows, the strength of the relationship between fat and protein milk percentage depending on lactation length was more pronounced than in primiparous cows.

Table 6*. Spearman's rank correlation coefficient (Rs) estimates of lactation length of primiparous cows and multiparous cows with milk production traits*

Traits	Primiparous cows		Multiparous cows	
	n	***Rs (P)***	***n***	***Rs (P)***
TMY	237	0.692 ($P < 0.001$)	367	0.602 ($P < 0.001$)
MY305	237	0.064 (ns)	367	0.109 ($P = 0.036$)
FP	237	-0.251 ($P < 0.001$)	367	-0.475 ($P < 0.001$)
PP	237	-0.151 ($P = 0.020$)	367	-0.341 ($P < 0.001$)
TD1	176	0.028 (ns)	364	-0.013 (ns)
TD2	179	-0.051 (ns)	364	-0.090 (ns)
TD3	180	-0.074 (ns)	363	-0.080 (ns)
TD4	180	-0.062 (ns)	363	-0.024 (ns)
TD5	180	-0.042 (ns)	363	0.047 (ns)
TD6	180	-0.047 (ns)	362	0.121 ($P = 0.022$)
TD7	180	-0.044 (ns)	359	0.114 ($P = 0.030$)
TD8	179	0.014 (ns)	360	0.186 ($P < 0.001$)
TD9	178	0.169 ($P = 0.024$)	338	0.244 ($P < 0.001$)
TD10	103	0.072 (ns)	275	0.234 ($P < 0.001$)

Note: *TMY – total milk yield for the entire lactation; MY305 – 305 days milk yield; FP – fat milk percentage; PP – protein milk percentage; TD1-TD10 – average daily milk yield estimates for test days 1-10. Rs – Spearman's rank correlation coefficient estimate; P – significance level; ns – $P > 0.05$*
Source: *developed by the authors*

A high level of correlation between lactation length and total milk yield has already been noted in various studies. For example, in the research of D. Hunde *et al.* (2022) in crossbred cows between the Friesian and Jersey breeds with the local cattle breed Boran (Ethiopia), the corresponding estimate was 0.55 ($P < 0.001$). In crossbred animals based on the Holstein-Friesian Crossbreds in India, it was 0.72 ($P < 0.001$) (Kaur *et al.*, 2023). The article of D. Worku *et al.* (2022a) noted that in zebu-like cattle of the Sahiwal breed (Ethiopia), the correlation coefficient between lactation length and total milk yield was very high – 0.92 ($P < 0.001$). The correlation estimates between lactation length and 305 days milk yield were significantly lower – for Friesian cows in Egypt, it was only 0.159 ($P < 0.05$) (Sanad *et al.*, 2020).

Regarding the fat and protein milk percentage, a study by I. Boujenane (2019) on Holstein animals in Morocco obtained significant but positive correlation coefficient estimates with lactation length (0.425 and 0.768; $P < 0.001$ in both cases), while in the current study, the corresponding estimates had a negative sign. In the research of A.S. Khattab *et al.* (2021) on Holstein-Friesian cattle in Egypt, no significant relationship was found between lactation length and fat milk percentage. Thus, for the qualitative traits of milk production, their relationship with lactation length is inconsistent for different breeds kept in different conditions.

Analysis of the effect of lactation length on cow lactation curves. Figure 5 shows the lactation curves for the first 305 days of lactation of cows from different subgroups depending on their lactation length. Among primiparous cows, daily milk yield estimates for TD1-TD10 did not differ significantly between animals with different lactation lengths, and accordingly, their lactation curves were similar in shape. At the same time, among multiparous cows, daily milk yield estimates for the last three months of lactation significantly depended on the lactation length subgroup. In general, with increasing lactation length, the corresponding daily milk yield estimates for TD8TD10 increased, which ensured an increase in the persistency of the lactation curve (Fig. 5B).

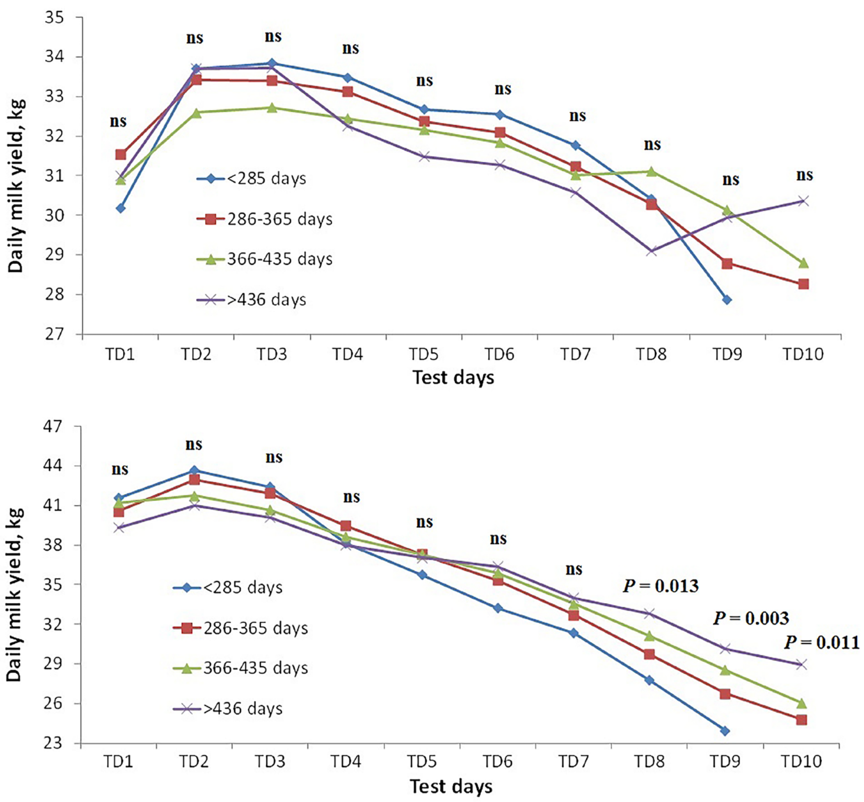

***Figure 5**. Lactation curves for the first 305 days of lactation of cows from different subgroups depending on lactation length: A – primiparous cows; B – multiparous cows*

***Note:** the results of the Fisher's test for homogeneity of subgroup means are shown. ns – P > 0.05. TD1-TD10 – average daily milk yield estimates for test days 1-10*

***Source:** developed by the authors*

When approximating the lactation curves of the cows in the study group with the Wood's model, it was found that with increasing lactation length, the estimates of the Wood's model coefficient "*a*" increased, while the estimates of the coefficients "*b*" and "*c*", on the contrary, decreased (Table 7). The obtained patterns had a similar character in both primiparous cows and multiparous cows. This caused a gradual increase in the estimate of the persistency of the lactation curve of cows with increasing lactation length.

***Table 7**. Estimates of Wood's model coefficients and parameters of the lactation curve of primiparous cows and multiparous cows of different subgroups depending on lactation length*

Subgroup by lactation length	Wood's model coefficient			Wood's model parameter			
	a ± SE	*b ± SE*	*c ± SE*	R^2, %	*Ymax*, kg	*Tmax*, days	*Persistency*
Primiparous cow							
Short lactation	14.641 ± 1.629	0.2351 ± 0.0308	0.00239 ± 0.00027	93.73	34.0	98.4	-0.00988
Normal lactation	20.416 ± 0.830	0.1428 ± 0.0111	0.00164 ± 0.00009	98.73	33.5	87.1	-0.00410
Prolonged lactation	21.591 ± 1.150	0.1167 ± 0.0144	0.00121 ± 0.00012	95.33	32.7	96.4	-0.00265
Extremely prolonged lactation	24.916 ± 4.207	0.0809 ± 0.0461	0.00102 ± 0.00038	67.62	32.7	79.3	-0.00178
Multiparous cow							
Short lactation	21.120 ± 2.724	0.2392 ± 0.0366	0.00439 ± 0.00035	98.94	43.3	54.5	-0.01608
Normal lactation	20.164 ± 1.074	0.2400 ± 0.0148	0.00388 ± 0.00013	99.75	42.7	61.9	-0.01471
Prolonged lactation	25.974 ± 2.055	0.1599 ± 0.0219	0.00294 ± 0.00019	99.22	41.9	54.6	-0.00747
Extremely prolonged lactation	26.395 ± 1.997	0.1389 ± 0.0209	0.00233 ± 0.00018	98.78	40.5	59.6	-0.00541

***Note:** a, b, c – estimates of Wood's model coefficients of the lactation curve; R2 – coefficient of determination. Ymax – peak milk yield of lactation; Tmax – time to reach peak milk yield of lactation; Persistency – estimate of lactation persistency*
***Source:** developed by the authors*

From the point of view of the shape of the lactation curve, multiparous cows, unlike primiparous cows, show higher estimates of peak milk yield (*Ymax* = 40.5 to 43.3 kg for different subgroups by lactation length) with earlier achievement of peak milk yield (*Tmax* = 54.5 to 61.9 days for different subgroups by lactation length). Earlier, the research of T. Kopec *et al.* (2020) also found that the smallest value of parameter "*a*" (15.2317) of Wood's model of the lactation curve of Simmental primiparous cows was found for lactations lasting up to 305 days, in contrast to parameters "*b*" and "*c*", which had the highest estimates for these lactations (0.1029 and 0.0015, respectively). The maximum value of parameter "*a*" (17.4329) was found in animals with prolonged lactations (up to 640 days), in contrast to parameters "*b*" and "*c*", which had the minimum estimates for this lactation length (0.0603 and 0.0010, respectively).

Thus, the formation of a lactation curve shape specific to prolonged lactation manifests itself already during the 8^{th}-10^{th} months of lactation. In general, lactation length is determined by the influence of both genotypic (breed, crossbreed, bull sire) and environmental factors (lactation number, year and season of calving) and, in turn, affects the formation of a specific lactation curve shape and the level of milk production of dairy cows.

CONCLUSIONS

In Holstein cows at PJSC "Plemzavod "Stepnoi" (Zaporizhzhia Region, Ukraine), lactation length varied from 173 to 1,150 days and averaged 356.1 ± 4.1 days. The lactation length of multiparous cows significantly $P < 0.001$) exceeded the corresponding estimate for primiparous cows. Significant ($P = 0.005$) differences in lactation length estimates were found among the offspring of different bull sires only for multiparous cows. Environmental factors (year and season of calving) significantly affected the variability of lactation length in the study group of cows. The shortest lactation length was noted for multiparous cows that calved in the autumn months (332.9 days), and the highest estimates were for animals that calved in winter or autumn (386.3 to 397.0 days).

It was established that lactation length is significantly ($P < 0.001$) associated with total milk yield, but only for multiparous cows was a significant ($P = 0.036$) correlation established between lactation length and 305 days milk yield. On the other hand, a significant ($P \leqslant 0.001$ to 0.020) but negative correlation was established between lactation length and fat and protein milk percentage. Using Wood's model to approximate the lactation curve for TD1-TD10, it was found that with increasing lactation length, the estimates of the "*a*" coefficient increased, while the estimates of the "*b*" and "*c*" coefficients, on the contrary, decreased. In general, animals with prolonged lactation showed an increase in daily milk yield for TD8-TD10, which ensured an increase in the persistence of the lactation curve.

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CONFLICT OF INTEREST

None.

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Аналіз мінливості тривалості лактації та її зв'язок із молочною продуктивністю корів

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Анотація. Тривалість лактації є важливою ознакою, що тісно пов'язана як із рівнем продуктивності, так і відтворювальними якостями молочної худоби. Головною метою даного дослідження став аналіз факторів, що обумовлюють мінливість тривалості лактації та її вплив на формування лактаційної кривої, кількісні та якісні ознаки молочної продуктивності корів дійного стада. В роботі було використано дані щодо 604 повних лактацій корів, які отелилися у ПрАТ «Племзавод «Степной» (Запорізька область, Україна) протягом 2014-2017 років. У піддослідних корів тривалість лактації коливалася в межах від 173 до 1150 днів із середньою оцінкою 356,1 ± 4,1 днів. Вік корів (у лактаціях) вірогідно впливав на тривалість лактації ($P < 0{,}001$). Для корів-первісток не було встановлено вірогідного впливу бугая-плідника на тривалість лактації. Але при розгляді всіх лактацій разом, було доведено вірогідний вплив ($P = 0{,}005$) бугая-плідника на їх тривалість. Також встановлено, що мінливість тривалості лактації корів дослідної групи залежала від року та сезону їх отелення. В цілому, найнижчою LSM-оцінкою тривалості лактації характеризувалися повновікові корови, які отелилися в осінні місяці року (332,9 днів), а найвищі відповідні оцінки було відмічено серед тварин, які отелилися взимку або восени (386,3…397,0 днів). Тривалість лактації була вірогідно пов'язана із сумарним надоєм ($P < 0{,}001$), у той час як для надою за 305 днів лактації вірогідну кореляцію було встановлено лише для повновікових корів ($P = 0{,}036$). Вміст жиру і білка в молоці корів дослідної групи були також вірогідно ($P \leq 0{,}001…0{,}020$), але від'ємно пов'язані із тривалістю лактації. При апроксимації лактаційних кривих корів дослідної групи моделлю Вуда було встановлено, що зі зростанням тривалості лактації оцінки коефіцієнта "*a*" моделі Вуда збільшувалися, у той час як оцінки коефіцієнтів "*b*" та "*c*", навпаки, зменшувалися. В цілому, зі зростанням тривалості лактації відповідні оцінки добового надою за 8-10-й місяці збільшувалися, що забезпечувало підвищення сталості лактаційної кривої

Ключові слова: подовжена лактація; генотипові та паратипові фактори; сталість лактаційної кривої