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Effect of sire, Dam, parity and year of calving on parameters and characteristics of lactation curve of Friesian-Holstein cows

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Abstract

This study aimed to model the lactation curves of Friesian–Holstein cows to estimate key curve characteristics and to quantify the effects of sire, dam, parity, and year of calving on these parameters.A total of 290 lactation records from 85 cows (progeny of 34 sires) were collected from the Alexandria University herd between 2003 and 2013. The incomplete Gamma function (Wood's model) was fitted to individual lactation data to derive parameters: initial yield (a), ascending rate to peak (b), and post–peak decline rate (c). These were used to calculate total milk yield (TMY), peak yield (PMY), time to peak (PW), lactation length (LL), and persistency measures (LnS, PER). Data were analyzed using an ANOVA model that included sire and dam (within sire) as random effects, and parity and year of calving as fixed effects.The results revealed substantial variation in all studied traits. The mean TMY was 5820.7 kg, with a high coefficient of variation (40.97%). The average PMY was 231.6 kg/week, and cows reached their peak yield around the 5th week. The analysis of variance indicated that the year of calving had a highly significant ($P < 0.0001$) influence on TMY and LL. The maternal effect (Dam within Sire) was significant for the post–peak decline rate (c) ($P < 0.0001$) and for TMY ($P = 0.0018$). In contrast, the sire effect and parity did not significantly affect most of the curve parameters or production traits. It concluded that the study concludes that annual environmental and management factors (year of calving) are the primary drivers of total milk production and lactation length in this herd. Maternal effects are crucial for lactation persistency. The high variability in key traits presents an opportunity for genetic improvement; however, enhancing overall herd management remains the most critical strategy for boosting productivity, as most traits were predominantly influenced by environmental conditions.

Key words: Friesian–Holstein – lactation curves – factors – milk – functionAbstract :

The study aims to identify the obstacles hindering the implementation of active learning strategies in basic education in Al-Marj city. A questionnaire was used as the main tool for data collection from a sample of 100 teachers, and the results were analyzed using the t-test and one-way ANOVA. Findings revealed statistically significant differences between the hypothetical and actual means across all four dimensions (school environment, students, curricula, and administration), confirming that these obstacles are real and substantial. The results also indicated no significant differences based on gender, specialization, or years of experience, while a significant difference was found in administrative obstacles among educational stages, with higher perceptions reported by teachers in the early years. The study concludes that classroom environment, curricula, and administrative support represent the most critical challenges, and recommends continuous teacher training, curriculum development, and the provision of supportive classroom and administrative environments to ensure the successful application of active learning.
Keywords: Active learning, Basic education, Curricula, School administration.

المستخلص العربي

تأثير الأب والأم وترتيب وسنة الوضع على معاملات وخصائص منحنى الإدرار في أبقار الفريزيان–الهولشتاين

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هدفت هذه الدراسة إلى نمذجة منحنيات الإدرار في أبقار الفريزيان–الهولشتاين لتقدير الخصائص الرئيسية للمنحنى، وتقدير حجم تأثيرات الأب، والأم، وترتيب الوضع وسنة الوضع على هذه المعاملات. تم جمع ما مجموعه 290 سجلا إدراريا من 85 بقرة (نسل 34 طلوقة) من قطيع أبقار اللبن التابع لجامعة الإسكندرية بين عامي 2003 و 2013. تم استخدام دالة جاما غير الكاملة (نموذج Wood) على بيانات الإدرار الفردية لاستنباط المعاملات: الإنتاج الأولي (a)، ومعدل الصعود إلى القمة (b)، ومعدل الانحدار بعد الذروة (c). واستخدمت هذه المعاملات لحساب إنتاج الحليب الكلي (TMY)، وإنتاج الذروة (PMY)، والزمن إلى الوصول للذروة (PW)، وطول فترة الإدرار (LL)، ومقاييس المثابرة (LnS, PER) تم تحليل البيانات باستخدام نموذج تحليل التباين (ANOVA) الذي تضمن الأب والأم (داخل الأب) كتأثيرات عشوائية، وترتيب وسنة الوضع كتأثيرات ثابتة. أظهرت النتائج ع وجود تباين كبير في جميع الصفات المدروسة. بلغ متوسط إنتاج الحليب الكلي 5820.7 كجم، بمعامل اختلاف مرتفع (40.97٪). وكان متوسط إنتاج القمة 231.6 كجم/أسبوع، ووصلت الأبقار إلى قمة إنتاجها في الأسبوع الخامس تقريبا. أشار تحليل التباين إلى أن سنة الوضع كان لها تأثير عالي المعنوية (P < 0.0001) على كل من إنتاج الحليب الكلي وطول فترة الإدرار. كان التأثير الأمومي (الأم داخل الأب) معنويا لمعدل الانحدار بعد القمة (P < 0.0001) (c) ولمجموع إنتاج الحليب (P = 0.0018). في المقابل، لم يؤثر تأثير الأب وترتيب الوضع بشكل معنوي على معظم معاملات المنحنى أو صفات الإنتاج.

وخلصت الدراسة إلى أن عوامل البيئة والإدارة السنوية (سنة الوضع) هي الدافع الأساسي لإنتاج الحليب الكلي وطول فترة الإدرار في هذا القطيع. كما أن التأثيرات الأمومية حاسمة لصفة المثابرة. إن التباين العالي في الصفات الرئيسية يمثل فرصة للتحسين الوراثي؛ ومع ذلك، يظل تحسين إدارة القطيع بشكل عام الاستراتيجية الأكثر أهمية لتعزيز الإنتاجية، حيث أن معظم الصفات تأثرت في الغالب بالظروف البيئية.

الكلمات المفتاحية : فريزيان–هوليشتاين – منحنى – عوامل – حليب – دالة

Introduction

Milk and its products are a cornerstone of food security and the agricultural value chain. Within this framework, the Friesian-Holstein breed stands out as one of the most important milk-producing breeds globally, renowned for its high productivity and relative adaptability. However, the productive performance of these cows is often negatively affected by environmental conditions (such as heat stress) and challenges related to management and nutrition, leading to a failure to achieve their full genetic potential.

The lactation curve provides a graphical and mathematical representation of changes in daily or weekly milk yield throughout the lactation period, from calving until drying off. Analyzing this curve goes beyond merely describing total production quantity; it serves as a powerful diagnostic tool for assessing herd productivity efficiency, overall health, nutritional response, and reproductive efficiency (Solodneva et al., 2022). The typical curve is characterized by a rapid initial increase to a peak yield reached several weeks after calving, followed by a phase of gradual and persistent decline until dry-off.

Mathematical modeling has long been a cornerstone in analyzing these curves. Wood (1967) introduced his famous algebraic model (Wood's Model), which became the foundation for many subsequent models like those of Wilmink, Dijkstra, and Gamma (Macciotta et al., 2011). These models allow for comparisons of responses between animals, prediction of total yield, and, most importantly, the estimation of the trait of persistency – the cow's ability to maintain her production after the peak at the highest possible rate. Persistency is closely linked to overall udder health and metabolic efficiency and has significant economic implications by reducing rearing and feeding costs per unit of milk produced (Dekkers et al., 1998; Togashiand Lin, 2003).

On the genetic front, studies have shown the potential for genetic determination of persistency using Random Regression Models (RRM), opening avenues for improving this trait through breeding programs (Jakobsen et al., 2002; Weller et al., 2006). Furthermore, an abnormal curve shape, such as a sudden drop or failure to reach an expected peak, can be an early indicator of diseases like mastitis or post-partum disorders (Solodneva et al., 2022).

This study aims to model Friesian cow lactation curves using mathematical model to estimate key characteristics of lactation curve and analyze effects of some genetic and non-genetic factors. It will also explore clustering techniques to classify cows by lactation patterns for improved management and selection decisions.

Material and methods

This study analyzed 290 lactation records from 85 cows, which were the offspring of 34 bulls. The data was collected from the Friesian- Holstein herd at the Alexandria University dairy project in Abees farm between 2003 and 2013. Records were excluded if they lacked pedigree information, breeding dates, or if the cows had been affected by disease or had aborted.

Herd management

The cows were managed in open-sided sheds year-round with constant access to clean water and were fed a seasonal forage diet of Egyptian clover and rice straw from November to May, followed by sorghum sudan grass and berseem hay from June to October, supplemented year-round with a concentrate mix containing at least 16% crude protein tailored to their milk production and physiological status. The herd was bred through artificial insemination using frozen semen with random sire assignment, with heifers first inseminated at 18 months and 350 kg, and pregnancy was confirmed by veterinary rectal palpation 45 days post-service. Cows were machine-milked twice daily at 6:00 AM and 6:00 PM with precise yield recording, and those producing over 10 kg of milk daily or in the final two months of pregnancy received additional concentrate rations.

Statistical analysis

A gamma function (Wood, 1967) wasused to describe the lactation patterns in thispopulation:

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

where:

$\mathbf{y_n}$isweekly yield at the **n**week,

a, **b**, and **c** are the constants.

The constant **a** is a scale factor associated withinitial weekly yield at the start of the lactation, **b**is associated to the increase in milk before peakyield, and **c** is related to the decrease in milk afterpeak yield. To determine the value of the constants**a**, **b** and **c** for a particular cow, the gamma functionwas transformed logarithmically into a linear form $Ln(y_n) = Ln(a) + bLn(n) - c(n)$ and then fitted tomonthly test-day milk records for individual cowsusingProc REG in SAS (SAS, 2002). Then, estimates of the constants **a**, **b** and **c** were used tocalculate total milk yield (TMY, kg) wascalculated as the sum of weekly test-day milk, peak milk yield (PMY,kg) was estimated equalto $pmy = a(b/c)^b e^{-b}$, days to reach peak yield (PW, kg) was estimatedas **b/c**, the duration of lactation(LL, weeks)Natural logarithm of Persistency (LnS) was computed as $S = -(b+1)LnC$ andPersistency Coefficient (PER) $PER = C^{-(b+1)}$ for an individual cow.

An ANOVA was carried out for the lactation curve fitting parameters and characteristics a, b, c, TMY, PMY, PW, LL, Ln(s) and PER coefficient according to the following model:

$$y_{ijklm} = \mu + S_i + D_j + P_k + YC_l + e_{ijklm}$$

Where:
y = the response
μ = overall mean
S= the random effect of sire
D= the random effect of dam
P= the fixed effect of parity (eight levels)
YC= the fixed effect of year of calving (fourteen levels)
e = the random effect of residual

Results and Discussion

Table (1) presents the basic statistical values for a set of variables describing the lactation curve and herd performance. The results indicate notable diversity among the cows in the studied sample. Similar studies, such as Boujenane and Hilal (2012), confirm that this variation can be attributed to genetic and non-genetic effects like herd, parity, dam's age, and calving season

Lactation Curve Parameters (a, b, c) and the Effect of Environmental Factors

Parameter (a): Represents the predicted milk yield at the beginning of lactation. The mean value was 131.95 kg/week with a large standard deviation (51.96) and a high coefficient of variation (39.37%). This indicates significant fluctuation in the initial production level among herd individuals. This variation aligns with the findings of Rekik et al. (2003) in Tunisia, who found that factors such as production sector (investors, cooperatives) and calving season had a significant effect on milk yield at the start of lactation. This difference may be due to factors like age, number of lactations, and health status.

Parameter (b): Related to the rate of increase in milk yield until peak production is reached. Its mean was 0.71 with a standard deviation of 0.38 and the highest coefficient of variation (54.4%) among the parameters. The very high coefficient of variation indicates substantial differences in the efficiency of cows reaching their production peak. A study by Kopec et al. (2013) on Czech Fleckvieh cows showed that calving season had a significant effect on lactation curve parameters (a, b, c), which may explain part of this variation, as different environmental and nutritional conditions affect the speed of curve development.

Parameter (c): Represents the rate of decline in milk yield after the peak. Its mean was 0.14 with a standard deviation of 0.054 and also high coefficient of variation (38.58%). This reflects a significant difference in the ability of cows to maintain their production after the peak. Cows with low values for parameter (c) are more persistent. A study by Franci et al. on ewes showed that the type and length of the lactation significantly affected peak time and persistence, supporting the idea that the decline pattern is influenced by management and environmental factors.

Production Characteristics Associated with the Lactation Curve (TMY, PMY, PW, LL) and the Importance of Peak Yield and Persistence

Total Milk Yield (TMY): The average total production was 5820.7 kg, with a high coefficient of variation (40.97%). This confirms the tremendous disparity in productive efficiency. A study by Seangjun et al. (2009) in Thailand found that peak yield (PY) and persistence (PST) had high positive genetic correlations with 305-day milk yield (MY), indicating that selection to improve these two traits would increase total production. This explains the presence of cows with high total yield (15423 kg) in our data.

Peak Milk Yield (PMY): The average peak was 231.6 kg/week, with a high coefficient of variation (53.88%). A study by Boujenane and Hilal (2012) indicated that the highest heritability estimate was for the trait of peak yield (PMY), and its genetic correlation with 305-day yield was positive and strong. This supports the importance of using peak yield as a standard trait in breeding programs to improve the herd's overall productivity.The wide variation in the studied traits, especially peak yield (PMY) which has a relatively higher heritability, represents an opportunity for herd improvement through genetic selection. Selection in favor of cows with high peak yield and good persistence is recommended to enhance total production.

Time to Peak Yield (PW): On average, cows reached their production peak in the fifth week. The study conducted by Kopec et al. (2013) found that calving season significantly affected the time to peak yield, with cows calving in summer reaching their peak faster. This illustrates how environmental factors can explain part of the variation observed in our data (ranging from 1 to 10 weeks).

Lactation Length (LL): The results showed that the average lactation length (LL) was 43.4 weeks, which is equivalent to approximately 304 days. When analyzing this average in the context of dairy cow production, it is considered an acceptable and realistic rate. The typical lactation length in well-managed herds ranges between 305 and 315 days (equivalent to 43.5 to 45 weeks). The average recorded in this study (304 days) indicates that the herd's performance falls within the expected and practically acceptable range. The study by Solodneva et al. (2022) emphasizes the importance of monitoring deviations in the lactation curve as a health indicator. The large variation in lactation length data, with a standard deviation of 11.85 weeks, is a clear indicator of unstable herd performance. This variation suggests that some cows suffer from recurrent health problems (such as subclinical mastitis or postpartum disorders) leading to early drying off, while others suffer from fertility problems leading to an uneconomical extension of the lactation. Therefore, focus should be placed on addressing short lactation length (LL) by investigating underlying causes such as diseases (using the lactation curve as a monitoring tool as suggested by Solodneva et al. (2022)), poor nutrition, and heat stress. Improving the management of the calving season (preferring winter and autumn for better stability as in the Kopec et al. study) can improve herd performance.

Natural Logarithm of Persistency (LnS) and Persistency Coefficient (PER): The persistence coefficient (PER) shows considerable variation (52.49%). The large variation confirms that there are cows with very good production persistence and others with weak persistence. Although Boujenane and Hilal (2012) mentioned that the heritability estimates for lactation curve traits were generally low, they confirmed that there is still potential for improvement through selection. The positive genetic correlation between persistence and total yield found in Seangjun et al. (2009) makes persistence a useful secondary trait in selection.

Analysis of Variance (ANOVA) for Milk Curve Parameters and Traits

ANOVA in Tables (2) and (3) reveals the relative importance of genetic (Sire, Dam within Sire) and environmental (Parity, Year of Calving) effects on production traits, providing a deeper insight into herd dynamics. Table (2) shows the ANOVA for the parameters (a), (b), (c) of the incomplete Gamma function lactation curve (Wood, 1967).

Table (1) The statistics values for the lactation curve parameters a, b, c, Total Milk Yield (TMY, kg), Peak Milk Yield (PMY, kg), Time to Peak (PW, week), Lactation Length (LL, day), Natural logarithm of Persistency (LnS), and Persistency Coefficient (PER)

Variables	no. of Records	mean	SD	SE	cv%	max	min
a	237	131.9515	51.95537	3.374864	39.37461	259	14
b	237	0.711071	0.386793	0.025125	54.39584	2.4	0.040816
c	237	0.140869	0.054346	0.00353	38.57889	0.4	0.027211
TMY(kg)	237	5820.684	2384.892	154.9154	40.97271	15423	481
PMY (kg)	237	231.5852	124.786	8.105724	53.88342	731.013	17.05701
PW (week)	237	5.07173	2.037394	0.132343	40.17157	10	1
LL (week)	237	43.37553	11.85168	0.769849	27.32343	60	12
Ln(s)	237	3.383991	0.562925	0.036566	16.63495	4.54931	1.459513
PERcoef.	237	34.1481	17.92401	1.16429	52.48904	94.56715	4.303861

Table (2): Analysis of variance of the lactation curve parameters (a, b, and c)

Source of variation	df	a		b		c	
		Mean square	Pr> F	Mean square	Pr> F	Mean square	Pr> F
Residual	146	2513.16		0.1381		0.0032	
Sire	21	2615.15	0.42	0.0828	0.914	0.0022	0.087
Dam within sire	46	2629.85	0.41	0.1311	0.569	0.0040	<0.0001
Parity	7	2689.07	0.39	0.0793	0.776	0.0011	0.618
Year of calving	13	2713.04	0.38	0.1962	0.156	0.0032	0.013

Table (3): Analysis of variance of Total Milk Yield (TMY), Peak Milk Yield (PMY), Time to Peak (TP), Lactation Length (LL), Natural Logarithm of Persistency (LnS), and Persistency Coefficient (PER).

Source of variation	df	TMY		PMY		PW		LL		Ln(s)		PER	
		Mean square	Pr> F	Mean square	Pr> F	Mean square	Pr> F	Mean square	Pr> F	Mean square	Pr> F	Mean square	Pr> F
Residual	146	3027087		17148		4.284		108.315		0.310		326.411	
Sire	21	8763626	<0.0001	11540	0.854	3.987	0.552	146.017	0.155	0.279	0.593	328.636	0.459
Dam within sire	46	5813156	0.0018	10371	0.975	3.614	0.744	140.872	0.123	0.292	0.585	277.229	0.736
Parity	7	5882381	0.0668	7547	0.875	2.597	0.750	94.051	0.533	0.203	0.710	129.167	0.904
Year of calving	13	23301678	<0.0001	23274	0.187	5.124	0.288	430.881	<0.0001	0.358	0.319	336.051	0.426

Genetic Effects (Sire and Dam within Sire)

The post-peak decline rate parameter (c) was the only parameter among the three that showed a statistically significant effect. The Dam within Sire effect was highly significant (P < 0.0001) for parameter (c). Parameter (c) indicates the rate of production decline after the peak, making it a key indicator of persistence. This aligns with the conclusions of Boujenane and Hilal (2012), who indicated that lactation curve traits have small genetic variance (low heritability estimates). The results demonstrate that the maternal effect (encompassing genetics and common environment) is most crucial in controlling lactation persistence. This is logical, as this trait is significantly influenced by the environment provided by the dam (e.g., in utero, early rearing) and part of her genetic makeup.

Absence of Significance for Genetic Effects on Parameters (a) and (b): The lack of a statistically significant effect of Sire or Dam on initial production level (a) and the ascending rate (b) confirms that these traits are heavily influenced by environmental, nutritional, and management factors more than by direct genetic effects.

Environmental Effects (Parity and Year of Calving)

Year of Calving: Had a statistically significant effect (P = 0.013) on parameter (c). This strongly coincides with the findings of Kopec et al. (2013) and Rekik et al. (2003), who found that annual factors like changes in weather conditions, feed quality, management strategies, and disease pressures significantly impact the pattern of the lactation curve's decline and its persistence.

Parity: Interestingly, parity did not have a significant effect on any of the Wood's model parameters. This differs from some studies, like Rekik et al. (2003), which found a parity effect on peak yield and total production. This might indicate that the herd management in this study provided similar conditions for different parities regarding nutrition and care, or that the sample size was insufficient to detect true differences.

Total Milk Yield (TMY) and Lactation Length (LL)

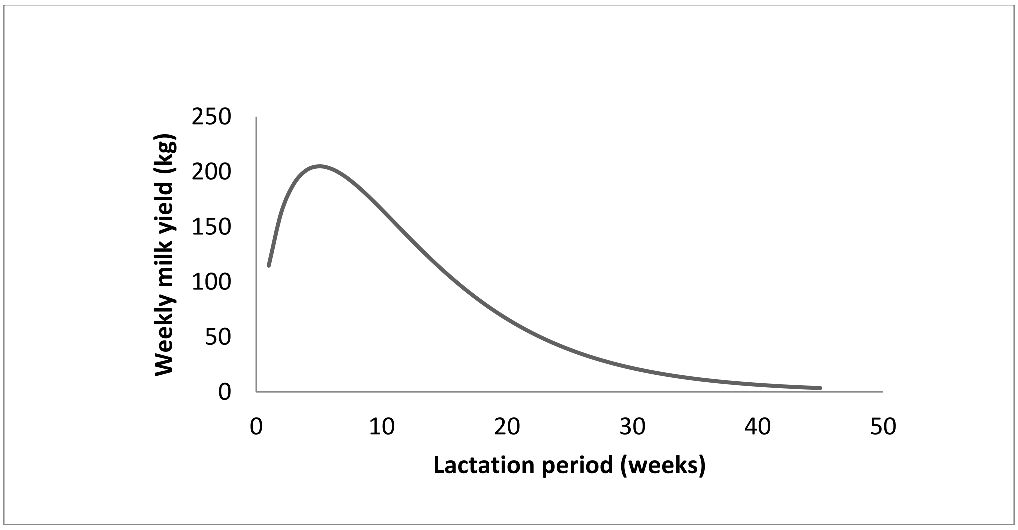
Year of Calving had a highly statistically significant effect (P < 0.0001) on both TMY and LL. This is the most prominent finding in this table, as it strongly emphasizes the fundamental impact of annual environmental and managerial factors on the herd's productive performance. Year-to-year changes in farm management, feeding programs, weather conditions, and disease pressure, as indicated by Solodneva et al. (2022), are the primary determinants of total milk quantity and the length of its production period. The short lactation length observed in Table (1) is likely a reflection of these unstable annual factors.

The **Dam within Sire** effect had a significant influence (P = 0.0018) on TMY, further reinforcing the importance of the maternal effect observed for parameter (c).

Importance of the Maternal Effect: The significant effect of "Dam within Sire" on both total yield (TMY) and the decline rate parameter (c) suggests that selection based on families (Family Selection) might be a more effective strategy than selection based solely on the sire.

Peak and Persistence Traits (PMY, PW, LnS, PER)

None of the variance sources (genetic or environmental) showed a significant effect on peak yield (PMY), time to peak yield (PW), or persistence measures (LnS, PER). This superficially contrasts with Seangjun et al. (2009), who found genetic correlations between peak yield, persistence, and total production. However, it supports the main conclusion of Boujenane and Hilal (2012) regarding the low heritability of these traits.



This indicates that the extreme variation we observed in Table (1) for traits like PMY and PER is largely due to random or unmeasured micro-environmental factors not captured in this model, such as individual health, within-herd competition, and measurement accuracy. To improve these traits, the focus should first be on enhancing environmental conditions and general management rather than relying solely on genetic selection, at least in this specific herd.

It is crucial to note that the study by Boujenane and Hilal confirmed that the peak yield (PMY) trait had the highest heritability estimate and a strong positive genetic correlation with total yield. Therefore, selection for high peak yield (PMY) remains a sound recommendation, as any genetic improvement, even if slow, will positively reflect on TMY.

Figure (1) illustrates the lactation curve, characterized by a rapid production increase that peaks around week five, followed by a gradual and persistent decline. This classic pattern indicates efficient initial production, while the steady post-peak decline suggests potential for enhancing yield persistence through targeted management improvements.

In conclusion, this study revealed substantial variation in lactation curve parameters and production traits within the herd. While annual environmental factors significantly influenced total milk yield and lactation length, maternal effects were crucial for post-peak persistency. The high variability in key traits like peak yield presents a valuable opportunity for genetic selection. However, improving overall herd management remains the primary strategy for enhancing productivity, as most traits were strongly influenced by environmental conditions rather than direct genetic effects.

References

1) Dekkers, J. C. M., Ten Hag, J. H., and Weersink, A. (1998). Economic aspects of persistency of lactation in dairy cattle. Livestock Production Science, 53(3), 237–252. https://doi.org/10.1016/S0301-6226(97)00124-3
2) Jakobsen J.H., Madsen P., Jensen J., Pedersen J., Christensen L.G., Sorensen D.A. Genetic parameters for milk production and persistency for Danish Holsteins estimated in random regression models using REML. Journal of Dairy Science, 2002, 85(6): 1607-1616 (doi: 10.3168/jds.S0022-0302(02)74231-8).
3) Koeck, A., Jamrozik, J., Schenkel, F. S., Moore, R. K., Lefebvre, D. M., Kelton, D. F., and Miglior, F. (2014). Genetic analysis of milk β-hydroxybutyrate and its association with fat-to-protein ratio, body condition score, clinical ketosis, and displaced abomasum in early first lactation of Canadian Holsteins. Journal of Dairy Science, 97(11), 7286–7292. https://doi.org/10.3168/jds.2014-8405
4) Macciotta, N. P. P., Dimauro, C., Rassu, S. P. G., Steri, R., and Pulina, G. (2011). The mathematical description of lactation curves in dairy cattle. Italian Journal of Animal Science, 10(4), e51. https://doi.org/10.4081/ijas.2011.e51
5) Nørgaard, J. V., Sørensen, M. T., Theil, P. K., Sehested, J., and Sejrsen, K. (2008). Effect of pregnancy and feeding level on cell turnover and expression of related genes in the mammary tissue of lactating dairy cows. Animal, 2(4), 588–594. https://doi.org/10.1017/S1751731108001626

6) Rekik, B., Ben Gara, A., Ben Hamouda, M., and Hammami, H. (2003). Fitting lactation curves of dairy cattle in different types of herds in Tunisia. Livestock Production Science, 83(2-3), 309-315.
7) Seangjun, A., Koonawootrittriron, S., and Elzo, M. A. (2009). Characterization of Lactation Patterns and Milk Yield in a Multibreed Dairy Cattle Population in the Central Thailand. Asian-Australasian Journal of Animal Sciences, 22(5), 644-653.
8) Solodneva, E. V., Smolnikov, R. V., Bazhenov, S. A., Vorobyeva, D. A., and Stolpovsky, Y. A. (2022). Lactation curves as a tool for monitoring the health and performance of dairy cows — A mini-review. Veterinary World, 15(3), 765-771.
9) Togashi, K., and Lin, C. Y. (2003). Modifying the lactation curve to improve lactation milk and persistency. Journal of Dairy Science, 86(4), 1487–1493. https://doi.org/10.3168/jds.S0022-0302(03)73734-5
10) Weller J.I., Ezra E., Leitner G. Genetic analysis of persistency in the Israeli Holstein popula-tion by the multitrait animal model. *Journal of Dairy Science*, 2006, 89(7): 2738-2746 (doi: 10.3168/jds.S0022-0302(06)72350-5).
11) Wood, P. D. P. (1967). Algebraic model of the lactation curve in cattle. Nature, 216(5111), 164–165. https://doi.org/10.1038/216164a0