PROFESSIONAL PAPER

RELATIONSHIPS BETWEEN SOME FERTILITY AND MILK PRODUCTION CHARACTERISTICS IN HOLSTEIN FRIESIAN CATTLE

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ABSTRACT

This study examined how key reproductive and milk-production traits interacted in 582 Holstein Friesian cows on a commercial farm in Malkara, Thrace, over five years. After screening 1,305 lactation and breeding records for consistency, researchers recorded milk-yield parameters—lactation length, total and standardized 305-day yield, dry period, day of peak production, and peak yield—alongside fertility traits: age at first insemination, conception and calving, calving interval, inseminations per conception, days open, and parity. Traits were grouped by lactation number, calving year and season, and production level, and persistency indices for Days 0–100, 100–200, and 200–300 were calculated. Using General Linear Models and Duncan's test, least-squares means were compared, while Pearson correlations and simple regressions evaluated interdependencies. Cows averaged 2.29 inseminations per conception and a 395.1-day calving interval; mean lactation yield was 8,508.8 kg. Lactation length ($r = 0.783$) and calving interval ($r = 0.649$) showed the strongest positive correlations with milk yield (all $P < 0.001$), whereas peak day and age at first calving were weakly associated. These results highlight the close link between reproductive efficiency and milk production, underscoring the importance of integrated genetic and management strategies for optimizing herd performance.

Keywords: Calving interval, insemination frequency, lactation milk yield, persistency indices, reproductive efficiency

INTRODUCTION

The primary objective of cattle farming is to produce meat and milk, and considerable efforts over the past several decades have led to the development and widespread adoption of high-yielding breeds. Initially, breeding programs focused on maximizing the quantity of output per production cycle; more recently, however, the attention has shifted toward ensuring animal health and product quality.

Enhancements in production performance hinge on two principal factors: the genetic potential of the herd and the prevailing environmental conditions, especially management and nutrition. Crossbreeding and traditional selection methods have been employed to increase the frequency of favourable traits within populations (Alpan, 1993; Evrim and Güneş, 2000). While crossbreeding can introduce genetic improvement, sustained progress across generations requires systematic selection. Technological advances have further refined selection methodologies, notably through the integration of genomic evaluations. However, possessing superior genetics alone does not guarantee performance. The phenotypic expression of high-yield traits is profoundly influenced by the environment, including the consistency with which optimal management practices are applied across successive generations (Aritürk and Yalçın, 1966; Evrim and Güneş, 2000). Thus, even genetically elite animals will underperform if subjected to suboptimal feeding, care, or herd management.

Although nutrition and veterinary care are traditionally addressed within the domain of animal nutrition, this study centres on herd management strategies that directly influence reproductive efficiency -the foundation of sustained milk production. Successful lactation depends on timely parturition, making reproductive milestones such as age at first insemination, conception, and calving critical for initiating productive life without compromising physiological development (Harrison et al., 1990; Noakes et al., 2001; Heinrichs et al., 2013). Reproductive efficiency is further characterized by metrics, such as the number of inseminations per conception, days open, and overall calving interval, all of which must remain within optimal thresholds to ensure both productivity and sustainability.

Key milk yield parameters include lactation duration, total and standardized 305-day yields, dry period length, peak production day, and peak yield. Given the intrinsic interplay between fertility and milk production traits, this study aims to elucidate the relationships between selected reproductive and lactation characteristics, thereby providing actionable insights for producers and a robust foundation for future academic inquiry.

MATERIAL AND METHODS

This study drew upon five years of systematically maintained records from Holstein Friesian cattle on a commercial farm in Malkara, Thrace - an area of strategic importance to Turkish cattle production. Animals were managed under standard husbandry and feeding protocols, with no additional experimental treatments.

Data Collection and Trait Definitions

Milk production traits included lactation duration, milk yield over the full lactation and standardized 305-day period, dry period length, peak milk yield day, and peak yield amount. The 305-day yield was calculated from completed lactations, or, for cows dried off early, from raw unadjusted data. Records from animals culled before the lactation completions were excluded. Reproductive traits comprised age at first insemination, age at first conception and calving, calving interval, inseminations per conception, interval from calving to first insemination, and days open.

Data Quality and Classification

All digital records were screened for consistency, and entries with missing or invalid values were removed, yielding a final dataset of 1.305 records from 582 cows. Selected traits were then categorized based on key factors -lactation number, year and season of calving, and overall production level- using the criteria detailed in Tables 1 and 2. Records marginally outside predefined thresholds were reassigned to the nearest group. While the interval ranges were generally uniform, lactation duration categories were adjusted to reflect the actual data distribution (one-, two-, or three-month groupings).

Table 1 Study groups I: Insemination number for pregnancy, age at first calving, days open, and calving interval

Insemination number for pregnancy (number)	First calving age (month)	Days open (day)	Calving interval (day)
1	24	-60	-355
2	25	61-90	356-385
3	26	91-120	386-415
4	27	121-150	416-445
5+	28	151+	446+

Table 2 Study groups II: Lactation duration, lactation number, lactation milk yield, and parity

Lactation duration (day)	Lactation number	Lactation milk yield (kg)	Parity
-270	1	-5000	1
271-300	2	5001-7000	2
301-360	3	7001-9000	3
361-450	4	9001-11000	4
451+	5+	11001+	5+

Peak Yield and Persistency Measures

Peak yield was defined as the highest daily milk production during lactation; the corresponding day was noted as the peak day. Peak duration spanned the period in which daily yields remained within ±10 percent of that maximum, with both total and average yields calculated for this interval.

To assess persistency, total milk yields were computed for Days 0–100, 100–200, and 200–300, and persistency indices ($P_{2:1}$, $P_{3:1}$, $P_{3:2}$) were calculated, according to Johansson and Hansson (1940).

$$P_{2:1} = \frac{\text{Milk yield between days } 101-200 \text{ of lactation}}{\text{Milk yield in the first 100 days of lactation}} * 100$$

$$P_{3:1} = \frac{\text{Milk yield between days } 201-300 \text{ of lactation}}{\text{Milk yield in the first 100 days of lactation}} * 100$$

$$P_{3:2} = \frac{\text{Milk yield between days } 201-300 \text{ of lactation}}{\text{Milk yield between days } 101-200 \text{ of lactation}} * 100$$

The study evaluated the effects of environmental factors, namely, year and season of production, lactation and parity order, insemination number, production level, and age at first calving on both milk yield and fertility traits. Milk yield parameters included lactation duration, total and 305-day yields, dry period length, persistency indices, peak period characteristics, and daily yield during the peak. Fertility traits comprised age at first conception and first calving, service period (days open), calving interval, number of inseminations per conception, and interval from calving to subsequent insemination.

Statistical Analysis

Fixed-effect models were constructed to analyze calving interval and lactation yield, incorporating environmental factors, such as year and season of lactation, parity, gestation order, number of inseminations, production level, and age at first calving. Least Squares Means (LSM) were estimated via the General Linear Models (GLM) procedure (Harvey, 1975), and group differences were tested with Duncan's multiple range test (Duncan, 1955; Searle, 1971). Pearson correlations and linear regressions explored inter-trait relationships (Evrim and Güneş, 1994), under the assumption of no significant factor interactions. Multivariate equation systems were solved by using SPSS (Goodnight and Harvey, 1978; Searle et al., 1980; Welsch, 1977; Einot and Gabriel, 1975).

The statistical model used to analyze calving interval (CI) incorporated the following fixed effects: parity order (G), lactation milk-yield class (L_s), lactation duration (P_t), days-open (D_o), age at first calving (F_p), and inseminations-per-conception (T_i) (Equation 1)

Equation 1: $Y_{ilstopa} = \bar{\mu} + G_l + L_s + P_t + D_o + F_p + T_i + e_{ilstopa}$

For lactation milk yield (LMY), the fixed-effects model incorporated the following factors: lactation order (N_l), lactation duration (P_t), age at first calving class (Fp), number of inseminations per conception class (T_i), days-open (D_o), and calving-interval (C_l). The model can be expressed as in Equation 2.

Equation 2: $Y_{iltopna} = \bar{\mu} + N_l + P_t + T_i + D_o + F_p + C_n + e_{iltopna}$

Where:

$Y_{iltopna}$: Observed value of the trait under study for an individual.

μ: Overall mean of the trait across all records.

C_n: Effect of calving-interval class, where n = <356, 356–385, 386–415, 416–445, ≥446 days.

D_o: Effect of days-open class, where o = <61, 61–90, 91–120, 121–150, ≥151 days.

F_p: Effect of age-at-first-calving class, where p = 24, 25, 26, 27, 28 months.

G_l: Effect of parity (gestation order), where l = 1, 2, 3, 4, ≥5.

L_s: Effect of lactation-milk-yield class, where s = <5,000, 5,001–7,000, …, 9,001–11,000, ≥11,001 kg.

N_m: Effect of lactation number, where m = 1, 2, 3, 4, ≥5.

P_t: Effect of lactation-duration class, where t = <270, 271–300, 301–360, 361–450, ≥451 days.

T_i: Effect of insemination-number class, where i = 1, 2, 3, 4, ≥5 per conception.

$e_{iltopna}$: Random residual error term for each observation.

RESULTS

A total of 1,305 records from 582 Holstein Friesian cows were analyzed over a five-year period.

Descriptive statistics for reproductive and milk yield traits are summarized in Table 3.

Cows on the study farm required an average of 2.29 inseminations per conception (n = 1,302).

Table 3 General production traits of the cattle

Yield characteristics	*n*	$\bar{x}$	$s_{\bar{x}}$
Reproduction traits			
First insemination age (month)	573	14.46	0.053
First pregnancy age (month)	573	16.99	0.094
First calving age (month)	573	25.20	0.091
First service period (day)	515	69.48	1.275
Days open (day)	515	107.03	1.966
Inseminations number for pregnancy	1302	2.29	0.046
Gestation period (day)	1302	279.54	0.192
Calving interval (day)	743	395.06	2.632
Milk production traits			
Lactation duration (day)	1094	326.67	2.342
Dry period (day)	715	67.70	1.073
Lactation milk yield (kg)	1094	8508.84	83.418
305-day milk yield (kg)	1094	7720.73	58.168
Lactation period daily milk yield (kg)	1094	25.96	0.168
305-day period daily milk yield (kg)	1094	25.31	0.191
$P_{2:1}$ (%)	1094	71.12	0.420
$P_{3:1}$ (%)	1094	48.94	0.615
$P_{3:2}$ (%)	1094	67.29	0.683
Milk yield peak day	1094	57.66	0.578
Peak milk yield (kg)	1094	37.91	0.191
Peak period (day)	1094	19.01	0.200
Peak period daily milk yield (kg)	1094	36.39	0.191
Peak period total milk yield (kg)	1094	695.88	8.586

Table 4 presents the mean calving intervals (days) stratified by lactation milk yield, lactation duration, age at first calving, days open, number of inseminations per conception, and parity. The statistical significance of these subgroup differences was evaluated via analysis of variance (ANOVA), with sources of variation and detailed results reported in Table 5.

The mean calving interval, based on 743 records, was 395.06 days (range: 337.53–508.40 days; Table 4). When grouped by lactation milk yield and lactation duration (n = 727), the mean interval was 395.49 days, while classification by age at first calving, insemination number, and parity (n = 743) yielded the same average of 395.06 days. Grouping by days open (n = 341) produced a slightly higher mean calving interval of 406.26 days. All subgroup differences in calving interval were statistically significant ($P < 0.05$).

Table 4 Mean calving intervals (days) by lactation milk yield, lactation duration, age at first calving, days open, number of inseminations per conception, and parity, with significance of group differences assessed by Duncan's multiple range test

Factors	Groups	Calving interval (day)		
		n	$\bar{x}$	$s_{\bar{x}}$
Lactation milk yield (kg)	-5000	35	352.83[c]	7.457
	5001-7000	146	352.82[c]	3.581
	7001-9000	210	361.56[c]	3.004
	9001-11000	186	406.46[b]	4.355
	11001+	150	480.89[a]	5.499
	overall	727	395.49	2.665
Lactation duration (day)	-270	115	337.53[d]	3.294
	271-300	181	344.11[d]	2.016
	301-360	216	387.49[c]	2.349
	361-450	122	454.47[b]	4.889
	451+	93	508.40[a]	6.650
	overall	727	395.49	2.665
First calving age (month)	24	377	395.51[a]	3.549
	25	169	394.25[a]	5.744
	26	100	402.97[a]	7.944
	27	44	367.70[b]	8.447
	28	53	402.23[a]	10.317
	overall	743	395.06	2.632
Days open (day)	-60	62	351.18[d]	9.129
	61-90	72	394.96[c]	9.005
	91-120	87	409.47[b,c]	7.383
	121-150	58	423.86[b]	8.046
	151+	62	453.50[a]	6.956
	overall	341	406.26	4.037
Insemination number	1	321	371.18[c]	3.481
	2	209	388.08[c]	4.267
	3	96	417.17[b]	7.921
	4	55	449.20[a]	10.310
	5+	62	460.03[a]	7.817
	overall	743	395.06	2.632
Gestation number	1	402	385.56[b]	3.387
	2	200	403.62[a,b]	5.199
	3	90	407.60[a,b]	8.089
	4	30	417.63[a]	13.229
	5+	21	409.48[a,b]	17.686
	overall	743	395.06	2.632

[a,b,c,d,e] : Differences between groups with different letters are statistically significant ($P<0.05$).

Lactation milk yield, lactation duration, days open, and insemination number each exerted highly significant effects on calving interval (P<0.001), and parity was also significant (P<0.01). In contrast, age at first calving had no statistically significant effect (P>0.05) (Table 5).

Cattle play a central role in livestock production, and within this industry, milk yield stands out as a fundamental performance metric. Accordingly, this study evaluated a comprehensive suite of lactation-related traits, including lactation duration, dry period length, total lactation yield, 305-day yield, persistency indices, and both daily and cumulative yields during the peak production period. Moreover, the statistical effects of several derived factors, such as lactation duration class, age at first calving, insemination count, days open, and calving interval, were examined individually. Consistent with most of the dairy research, analyses of lactation milk yield here accounted not only for management, nutrition, and husbandry practices but also for key environmental variables, namely, lactation order, year and season of lactation onset, and month of calving. Additionally, two specialized classification schemes were employed. The first scheme grouped cows by fertility-related characteristics (lactation duration, age at first calving, insemination count, days open, and calving interval) to assess their impact on milk yield. The second scheme, though not detailed in this section, categorizes cows by peak production parameters (peak day, peak yield, peak duration, and total yield during peak).

Table 5 Analysis of variance for calving interval, with fixed effects of lactation milk yield, lactation duration, age at first calving, days open, number of inseminations per conception, and parity

Factors	Source	Degrees of freedom	Type III Sum of squares	Mean square	*F*-value
			Calving interval		
Lactation milk yield	Between groups	4	1,687,752.6	421,938.15	147.730***
	Within groups	722	2,062,141.1	2,856.15	
	Total	726	3,749,893.7		
Lactation duration	Between groups	4	2,487,906.7	621,976.67	355.841***
	Within groups	722	1,261,987.0	1,747.90	
	Total	726	3,749,893.7		
First calving age	Between groups	4	42,092.4	10,523.11	2.057$^{n.s.}$
	Within groups	738	3,775,733.6	5,116.17	
	Total	742	3,817,826.0		
Days open	Between groups	4	354,537.8	88,634.44	19.406***
	Within groups	336	1,534,620.0	4,567.32	
	Total	340	1,889,157.8		
Insemination number	Between groups	4	663,136.3	165,784.08	38.783***
	Within groups	738	3,154,689.7	4,274.65	
	Total	742	3,817,826.0		
Parity	Between groups	4	84,686.0	21,171.51	4.185**
	Within groups	738	3,733,140.0	5,058.46	
	Total	742	3,817,826.0		

$^{n.s.}$: P>0.05 ** : P<0.01 *** : P<0.001

In this section, in addition to primary factors such as lactation order, year, season, and month of lactation onset, milk yields were evaluated according to secondary factors derived from other performance metrics, namely, calving interval, lactation duration, age at first calving, insemination count, days open, and parity. The resulting subgroup means are presented in Table 6, and the corresponding ANOVA results for these classifications are detailed in Table 7.

Table 6 Mean lactation milk yields (kg), stratified by calving interval, lactation duration, age at first calving, days open, number of inseminations per conception, and parity, with subgroup differences assessed for significance using Duncan's multiple range test

Factors	Groups	Lactation milk yield (kg)		
		n	$\bar{x}$	$s_{\bar{x}}$
Calving interval (day)	-355	264	7291.95[e]	110.766
	356-385	136	8128.13[d]	158.848
	386-415	92	9131.39[c]	185.298
	416-445	71	9685.80[b]	300.724
	446+	164	11774.35[a]	188.831
	overall	727	8926.10	98.992
Lactation duration (day)	-270	239	5942.46[e]	106.400
	271-300	261	7271.61[d]	98.723
	301-360	317	8819.50[c]	103.973
	361-450	171	10600.96[b]	135.345
	451+	106	13037.57[a]	206.187
	overall	1094	8508.84	83.418
First calving age (month)	24	545	8687.14[a,b]	119.505
	25	233	8471.76[a,b]	170.177
	26	152	8171.13[b]	219.470
	27	78	7417.55[c]	275.606
	28	86	9066.00[a]	331.783
	overall	1094	8508.84	83.418
Days open (day)	-60	80	8291.68[c]	261.380
	61-90	87	8590.66[b,c]	304.386
	91-120	114	8997.02[b,c]	281.476
	121-150	90	9221.27[b]	274.952
	151+	95	10521.53[a]	325.776
	overall	466	9154.16	135.302
Insemination number	1	435	8035.43[d]	108.765
	2	300	8219.99[c,d]	144.023
	3	156	8770.87[b,c]	245.713
	4	89	9345.67[b]	318.076
	5+	114	10063.47[a]	341.614
	overall	1094	8508.84	83.418

Factors	Groups	Lactation milk yield (kg)		
		n	$\bar{x}$	$s_{\bar{x}}$
Lactation number	1	542	8226.28[b]	105.633
	2	280	8877.35[a]	183.706
	3	173	8804.01[a]	227.761
	4	58	8582.98[a]	387.783
	5+	41	8377.07[a]	408.895
	overall	1094	8508.84	83.418

[a,b,c,d,e] : Differences between groups with different letters are statistically significant (P<0.05).

Mean lactation milk yields (n = 1,094) are presented in Table 6. The overall average was 8,508.84 kg. When grouped by days open (n = 466), mean yield increased to 9,154.16 kg; grouping by calving interval (n = 727) yielded 8,926.10 kg. Depending on the grouping factor, average yields ranged from 5,942.46 kg to 13,037.57 kg.

It is important to note that when subgroup sample sizes were equal across different classification schemes, identical mean values occasionally appeared in multiple tables. However, where subgroup distributions varied, differences in mean values became more pronounced, underscoring the influence of classification criteria on the observed averages.

Analysis of variance (Table 7) demonstrated that calving interval, lactation duration, age at first calving, days open, and insemination number each had highly significant effects on lactation milk yield (P<0.001), whereas lactation number was significant at P<0.01. These findings underscore the critical interplay between reproductive efficiency and milk production.

Table 7 Analysis of variance for lactation milk yield, with fixed effects of calving interval, lactation duration, age at first calving, days open, number of inseminations per conception, and lactation order

Factors	Source	Degrees of freedom	Type III Sum of squares	Mean square	*F*-value
Lactation milk yield					
Calving interval	Between groups	4	2,166,900,952.2	541,725,238.05	130.148***
	Within groups	722	3,005,238,426.7	4,162,380.09	
	Total	726	5,172,139,378.9		
Lactation duration	Between groups	4	4,926,702,317.0	1,231,675,579.24	395.206***
	Within groups	1089	3,393,915,257.4	3,116,542.94	
	Total	1093	8,320,617,574.4		
First calving age	Between groups	4	154,568,527.2	38,642,131.81	5.153***
	Within groups	1089	8,166,049,047.2	7,498,667.63	
	Total	1093	8,320,617,574.4		
Days open	Between groups	4	267,977,205.2	66,994,301.29	8.350***
	Within groups	461	3,698,905,702.5	8,023,656.62	
	Total	465	3,966,882,907.6		

Factors	Source	Degrees of freedom	Type III Sum of squares	Mean square	*F*-value
		Lactation milk yield			
Insemination number	Between groups	4	471,083,610.5	117,770,902.63	16.339***
	Within groups	1089	7,849,533,963.9	7,208,020.17	
	Total	1093	8,320,617,574.4		
Lactation number	Between groups	4	97,399,897.3	24,349,974.32	3.224**
	Within groups	1089	8,223,217,677.1	7,551,164.07	
	Total	1093	8,320,617,574.4		

** : P<0.01 *** : P<0.001

Key milk production parameters include lactation duration, total lactation yield, length of the dry period, time to peak yield, and daily yield during the peak phase. Fertility and milk production traits are inherently interdependent and cannot be viewed in isolation; rather, they continuously interact and influence each other.

In the preceding sections, we examined how groups defined by reproductive traits influenced milk production parameters and vice versa. In this section, we focus specifically on the interrelationships, quantified by correlation and regression, between selected fertility and milk yield traits. Although all reproductive and lactation parameters were evaluated throughout the study, here we concentrate on lactation milk yield and calving interval, as these two metrics encapsulate the core influences on overall productivity. Correlation and regression coefficients between lactation milk yield, calving interval, and their associated traits are presented in Table 8.

Table 8 Correlation (*r*) and regression (*b*) coefficients between lactation milk yield, calving interval, and selected reproductive and milk production traits

	Lactation milk yield			Calving interval		
	n	***r***	***b***	***N***	***r***	***b***
Milk yield parameters						
Lactation milk yield	1094	-	-	727	64.9***	0.000$^{n.s.}$
Lactation number	1094	6.0*	472.98***	727	13.3**	5.235***
Lactation duration	1094	78.3***	26.45***	727	80.6***	0.709***
Dry period	715	5.8$^{n.s.}$	-8.97***	687	39.4***	1.067***
Daily milk yield	1094	67.3***	396.83***	727	26.3**	5.063***
Peak day	1094	2.1$^{n.s.}$	2.13$^{n.s.}$	727	0.2$^{n.s.}$	0.148$^{n.s.}$
Peak milk yield	1094	39.6***	-20.05**	727	18.0***	0.518$^{n.s.}$
Peak duration	1094	25.4***	-214.13***	727	23.2***	0.207$^{n.s.}$
Peak total milk yield	1094	39.4***	8.30***	727	27.1***	0.057$^{n.s.}$
Reproduction parameters						
Calving interval	727	64.9***	21.87***	727	-	-
Gestation number	1094	6.0*	-45.27$^{n.s.}$	727	13.5**	1.889$^{n.s.}$
Days open	466	23.6***	5.79*	341	41.9***	0.726***

	Lactation milk yield			Calving interval		
	n	*r*	*b*	*N*	*r*	*b*
Insemination number	1094	23.4***	421.55***	743	39.0***	16.390***
First service period	466	8.2$^{n.s.}$	12.75**	341	25.3***	0.764***
First calving age	543	2.6$^{n.s.}$	28.81$^{n.s.}$	402	-1.9$^{n.s.}$	-0.645$^{n.s.}$

$^{n.s.}$: P>0.05 * : P<0.05 ** : P<0.01 *** : P<0.001

Correlation and regression analyses (Table 8) further elucidated these relationships. The strongest correlations with lactation milk yield were lactation duration (r = 0.783, P<0.001) and calving interval (r = 0.649, P<0.001), whereas peak day (r = 0.021) and age at first calving (r = 0.026) showed no significant associations. Calving interval exhibited its strongest correlations with lactation duration (r = 0.806, P<0.001) and days open (r = 0.419, P<0.001), with negligible correlations for peak day (r = 0.002) and age at first calving (r = –0.019). Regression coefficients indicated that lactation number (b = 472.98 kg) and insemination count (b = 421.55 kg) exerted the greatest effects on milk yield, while these same factors influenced calving interval by 5.235 days and 16.390 days, respectively.

Regression analyses (Table 8) revealed that the magnitude of effects on both lactation milk yield and calving interval varied with the nature and levels of the traits examined. Lactation number emerged as the most influential factor on milk yield, increasing output by 472.98 kg per additional lactation, followed by the number of inseminations, which contributed 421.55 kg. These same variables also significantly affected calving interval, extending it by 5.235 days per additional lactation and by 16.390 days per extra insemination, respectively. Together, these results highlight the interdependence of fertility and milk production traits and underscore the importance of optimizing both genetic and management factors to enhance overall herd performance.

DISCUSSION AND CONCLUSION

Based on the lactation milk yield categories, calving intervals ranged from 352.82 to 480.89 days (Table 4). Cows producing 5.001–7.000 kg exhibited the shortest intervals and required the fewest inseminations, whereas those yielding over 11,001 kg had the longest intervals and highest insemination frequencies (P<0.05). These findings suggest that higher-yielding cows with extended lactations tend to need more inseminations and experience longer calving intervals, an interdependence that herd managers must carefully navigate.

When grouped by lactation duration, intervals varied from 337.53 to 508.40 days (P<0.05), with the shortest in cows milked fewer than 270 days and the longest in those milked beyond 451 days. This mirrors the milk yield results: extended milking periods correlate with increased insemination requirements and prolonged calving intervals, particularly in cows exceeding the standard 305-day lactation.

Classification by age at first calving yielded intervals between 367.70 and 402.97 days. Cows calving first at 27 months had the briefest intervals, whereas those calving at 28 months had the longest (P<0.05), highlighting the impact of delayed reproductive onset on subsequent calving rhythm.

Analysis by days open revealed intervals of 351.18 to 453.50 days (P<0.05). Cows conceiving within 60 days post-calving had the shortest intervals, while those requiring more than 151 days to reconceive had the longest, underscoring the importance of prompt conception. When grouped by days open, calving intervals increased progressively with longer open periods, reaching their maximum in cows with days-open of 151 days or more. This extension of the open period, reflecting additional insemination efforts, demonstrated a concomitant increase in both insemination count and calving interval.

Grouping by number of inseminations per conception showed intervals ranging from 351.18 days (one insemination) to 460.03 days (five or more inseminations) (P<0.05), confirming that reproductive inefficiency directly extends the calving interval. Cows that conceived on a single insemination exhibited the shortest calving intervals, whereas those requiring five or more inseminations had the longest (P<0.05). Calving interval increased steadily with each additional service, peaking in the group with five or more inseminations. These findings confirm that higher insemination counts adversely affect the calving interval.

Parity-based classification produced intervals of 385.56 to 417.63 days, with the shortest intervals after first parity and progressive increases in later parities (P<0.05). ANOVA confirmed that lactation milk yield, lactation duration, days open, and insemination count all exerted highly significant effects on calving interval (P<0.001), whereas age at first calving did not (P>0.05), emphasizing the dominant roles of service period and insemination frequency in reproductive efficiency.

Analysis of variance revealed highly significant differences (P<0.001) in calving intervals when cows were grouped by lactation milk yield, lactation duration, and days open. In contrast, grouping by age at first calving did not produce statistically significant differences in calving intervals (P>0.05). Additionally, insemination count was identified as a highly significant factor (P<0.001). The pronounced effects of days open and service number, alongside their interactions with other key factors, underscore their central role in determining calving interval.

Lactation milk yields varied from 7,291.95 kg to 11,774.35 kg across calving-interval classes. A clear positive trend was observed, with longer calving intervals corresponding to higher milk yields and increased cumulative production. Because calving interval is inherently influenced by service number and days open, this relationship is unsurprising: cows with intervals under 355 days produced the least milk, whereas those with intervals exceeding 446 days yielded the most (P<0.05). Despite most intervals clustering below 385 days, a substantial proportion of cows fell into the >446-day category—a finding of potential concern for farm efficiency. Analysis confirmed that differences in milk yield among calving-interval groups were highly significant (P<0.001).

In a study conducted across four Danish herds, each having between 87 and 151 Holstein, Jersey, and crossbred cows, calving intervals were classified into five groups (<13, 14–15, 16–17, 18–19, and >19 months). Results indicated that milk yield increased both with longer calving intervals and higher parity (Lehmann et al., 1996), mirroring our findings. Conversely, an investigation of 1,509 lactations from Holstein Friesians on a private farm near Mansoura, Egypt, categorized calving intervals as <13, 13–19, and >19 months; this study reported no significant effect of calving interval on lactation yield (Shalan et al., 2022). These divergent results highlight the influence of herd-specific management and environmental conditions on the interval–yield relationship.

Lactation milk yield varied from 5,942.46 to 13,037.57 kg across lactation-duration categories, primarily reflecting the cumulative increase in milk production with longer lactations (P<0.05). When grouped into intervals of <270, 271–300, 301–360, 361–450, and >451 days, the highest yield occurred in the >451-day class, while the lowest was in the <270-day group. Notably, most lactations fell within the 301–360-day range. Differences in milk yield among these duration classes were highly significant (P<0.001).

Lactation milk yield ranged from 7,417.55 to 9,066.00 kg across the first-calving–age categories, with older age at first calving associated with significantly higher yields (P<0.05). In this herd, most heifers calved for the first time at 24 or 25 months. Physiologically, delaying first calving allows for more complete mammary gland development, greater metabolic maturity, increased live-weight gain, and enhanced uterine growth, all of which can contribute to higher milk production and reduced postpartum health complications. Consequently, optimal age at first calving not only influences lifetime productivity but also represents a critical economic milestone for the farm. While excessively early calving may compromise both milk and reproductive performance, calving that is too late can similarly incur production losses. Our findings underscore the importance of re-evaluating the practice of targeting first insemination at 13 months; in addition to body weight, heifer management should consider reproductive tract maturity. Notably, a separate study of 2.233 lactations from 1.579 cows in four farms in the Aegean and Marmara regions (2013–2018) reported the highest yields in heifers calved at 24 months (İlhan, 2023), a result that contrasts with our observations (P<0.001).

Lactation milk yield ranged from 8,035.43 to 10,063.47 kg across service-number groups, with a significant positive trend observed as the number of inseminations increased (P<0.05). This pattern likely reflects extended lactation and delayed dry-off associated with additional insemination attempts. Cows conceiving on the first insemination exhibited the lowest yields, whereas those requiring five or more inseminations achieved the highest yields. As service number increased, both the milking period and the subsequent dry period were prolonged, cumulatively extending total lactation length. These findings underscore service number as a key fertility parameter influencing milk yield. From a management perspective, the goal should be to achieve prompt conception, thereby minimizing the number of inseminations, while maintaining annual calving and optimal milk production. Animals that calve once per year and sustain high yields represent critical assets for both farm profitability and genetic improvement. ANOVA confirmed that service number exerted a highly significant effect on lactation milk yield (P<0.001).

Lactation milk yield ranged from 8,291.68 to 10,521.53 kg across the days-open categories, with longer days open positively associated with higher cumulative yields (P<0.05). Cows conceiving within 60 days of calving exhibited the lowest yields, whereas those with days open exceeding 151 days achieved the highest yields. Variations in the length of the days-open period may reflect factors such as postpartum uterine infections, metabolic disorders, nutrition management, seasonal influences, heat stress, abortion, embryonic loss, silent heats, and overlooked oestrus signs. Analysis confirmed that days open exerted a highly significant effect on lactation milk yield (P<0.001).

Several regional studies have similarly demonstrated significant effects of the days-open interval on lactation performance. In a commercial herd in Konya, 480 lactations from 307 Holstein-Friesian cows were grouped by service period, revealing the lowest milk yields in cows with days-open under 60 and the highest yields in those with 151–180 days open. The authors recommended extending the interval beyond 90 days to optimize yield and reported significant impacts on 305-day yield, peak yield, and persistency (Güler, 2023). Similarly, Bayrıl and Yılmaz (2017) found that classifying days open into 50–75, 76–100, and ≥101 days in 106 Holsteins at the Kazova Vasfi Diren farm produced significant differences in milk yield. Long-term records from the Koçaş farm in Aksaray (362 cows; 1988–1995) identified an average service period of 93.3 days (Duru and Tuncel, 2002). A subsequent analysis of 959 lactations at the same site, classifying days open as <40, 40–60, 61–80, 81–100, 101–120, 121–140, and >140 days, indicated that intervals exceeding 81 days enhanced 305-day yield and persistency, with an optimal range of 61–100 days (Duru and Tuncel, 2004). Data from four government farms in Balıkesir, Muğla, and Kırklareli (1,259 cows; 1980–1992) further supported these findings, showing significant yield differences across days-open classes of ≤60, 61–100, 101–140, 141–180, and ≥181 days, and endorsing 61–141 days, and ideally around 100 days, as most favourable (Kaya et al., 2003). Kino et al. (2019) analyzed 7.083 lactations from 2,000 Holsteins in Japan (2012–2016), classifying days open as ≤52, 53–

65, 66–110, and ≥111 days, and likewise observed significant yield effects. In the UK, Taylor et al. (2003) recommended a 135-day service period, while Esslemont and Kossaibati (2000) reviewed national databases and identified optimal intervals of 86–109 days, acceptable intervals of 110–120 days, and increasing fertility issues beyond 133 days. Collectively, these studies corroborate our findings that moderate days-open intervals are critical to maximizing milk yield and reproductive efficiency.

Lactation milk yield varied from 8,226.28 to 8,877.35 kg across lactation orders, with differences between orders reaching statistical significance ($P<0.05$). Contrary to expectations, cows in their second and third lactations produced more milk than those in later lactations. This likely reflects the numerical distribution of cows by lactation order in our dataset and temporal changes in herd structure over the study period, rather than a biological decline in yield after peak lactations.

During the study, it became apparent that variations in milk yield traits were largely influenced by calving interval, and conversely, that fertility traits impacted lactation performance. Consequently, we evaluated the strength of the relationship between lactation milk yield and calving interval. The resulting correlation coefficients for both reproductive and lactation traits underscore that fertility and milk production are inseparable characteristics in dairy management.

The strongest associations with lactation milk yield were observed for lactation duration ($r = 0.783$) and daily milk yield ($r = 0.673$). Among fertility traits, calving interval exhibited the highest correlation with milk yield ($r = 0.649$). In contrast, correlations between milk yield and dry period length, time to peak yield, first service interval, and age at first calving were negligible and statistically non-significant. Although the correlation coefficients for lactation order ($r = 0.060$) and parity order ($r = 0.060$) were similarly low, they reached statistical significance, reflecting their predictable impact on production and reproductive performance.

The strongest fertility-related correlations mirrored those for milk yield, with calving interval showing high associations with both lactation milk yield ($r = 0.649$) and lactation duration ($r = 0.806$). Among reproductive traits, days open exhibited the highest correlation with calving interval ($r = 0.419$). In contrast, correlations between calving interval and peak day or age at first calving were negligible and non-significant. Notably, whereas first service interval had no significant association with milk yield, it emerged as a meaningful predictor of calving interval.

Milk secreted by cows originally evolved to nourish their calves, yet today the volume produced per animal far exceeds the requirements of calf rearing. Consequently, both production- and economic-driven efforts continue to target further increases in milk yield, alongside occasional shifts toward enhancing milk quality rather than quantity. High lactational performance remains a primary goal, and while genetic improvement plays a major role, management practices, particularly nutrition, housing, and herd monitoring, offer critical, actionable avenues for optimization.

When interpreting the interrelationships between lactation milk yield and calving interval, it is essential to consider not only the magnitude of correlation and regression coefficients but also the class-interval widths for each trait. Moreover, future analyses may benefit from larger and more uniformly distributed datasets to strengthen the robustness of these parameter estimates across all production and fertility characteristics.

One of the most pressing challenges in modern cattle production is the failure to integrate advanced technologies with traditional husbandry practices. Even in Thrace, where some farms exceed optimal herd sizes and possess near-standard facilities, expected performance standards are often unmet. This discrepancy reflects a lack of technical proficiency among many producers, making it unrealistic to expect high-level management from individuals without specialized training. In contrast, family-run enterprises, driven not solely by profit but by a sense of social responsibility and genuine commitment to animal welfare, often provide more conscientious stewardship. Consequently, strategically supporting and developing these family enterprises, which serve as the true engines of livestock progress, should be a priority for the industry.

The farm in Thrace boasts advanced infrastructure-integrated automation systems, an automatic milking station, on-site feed formulation, synchronized breeding and calving monitoring, separate rearing facilities for male and female calves, multiple age-group paddocks, and its own nucleus herd. Despite this capacity to generate and analyze daily, weekly, and monthly performance data, these management tools remain underutilized. To drive productivity gains, the farm should prioritize the effective deployment of its herd-management automation, with particular focus on optimizing nutritional strategies and ration formulations based on real-time data insights.

In conclusion, the farm's management practices fall short of the performance standards expected for a facility of its calibre in the region. Although the infrastructure could be classified as elite, actual productivity parameters have not met their potential. It is, therefore, recommended that herd-management protocols be systematically revised and that the existing record-keeping systems be leveraged more effectively. By conducting frequent, short-interval reviews of daily, weekly, and monthly data, and by applying the same analytical rigor demonstrated in this study to drive continuous improvements, farm managers can optimize decision-making and ultimately enhance both reproductive and milk-production performance.

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest.

CONTRIBUTION

SÇK: Funding, Materials, Data Collection, Literature review, Writing; NÖ: Literature review, HİK: Data Processing, Data Analysis; TB: Data Processing, ZT: Data Processing, OK: Data Analysis, Data Interpretation, Writing, Literature Review, HG: Conception, Design, Supervision, Writing, Literature Review, Critical Review.

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ODNOSI IZMEĐU FERTILITETA I PROIZVODNIH KARAKTERISTIKA MLIJEKA KOD HOLŠTAJN-FRIZIJSKOG GOVEDA

SAŽETAK

U ovom radu smo istražili povezanost ključnih karakteristika reprodukcije i mliječnosti kod 582 krave holštajn-frizijske pasmine na komercijalnoj farmi u Malkari, u Trakiji u petogodišnjem periodu. Pregledano je 1305 izvještaja o mliječnosti i uzgoju u smislu konzistentnosti, pri čemu su zabilježeni podaci o parametrima prinosa mlijeka - dužini laktacije, ukupni i standardizirani prinos mlijeka u 305 dana; suhi period, dan najvećeg prinosa mlijeka i najveći prinos mlijeka - zajedno s karakteristikama fertiliteta: starosti na prvoj inseminaciji, začeću i teljenju, dane otvorenosti i paritet. Karakteristike su potom grupirane po broju laktacija, godini i sezoni teljenja i razini proizvodnje, nakon čega su izračunati indeksi perzistentnosti za dane 0–100, 100–200 i 200–300. Korištenjem Generalnog linearnog modela i Duncanovog testa su komparirane najniže srednje kvadratne vrijednosti, a Pearsonovom korelacijom i jednostavnim regresijama su ispitane međuovisnosti. Krave su u prosjeku imale 2.29 inseminacije po začeću uz interval teljenja od 395.1 dana; srednja vrijednost prinosa mlijeka je iznosila 8.508,8 kg. Dužina laktacije ($r = 0.783$) i interval teljenja ($r = 0.649$) su pokazali najjaču pozitivnu korelaciju sa prinosom mlijeka (svi $P < 0.001$), dok su dan najvećeg prinosa i starost pri prvom teljenju bili veoma slabo povezani. Ovi rezultati naglašavaju čvrstu vezu između reproduktivne učinkovitosti i proizvodnje mlijeka, naglašavajući važnost integriranih genetskih i upravljačkih strategija u optimizaciji performansi stada.

Ključne riječi: Indeksi perzistentnosti, interval teljenja, prinos mlijeka u laktaciji, reproduktivna učinkovitost, učestalost inseminacije