Spanish Journal of Agricultural Research
17 (1), e0401, 13 pages (2019)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2019171-13673
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, O.A, M.P. (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Comparison of the parameters of the lactation curve between normal and difficult calvings in Iranian Holstein cows

Navid Ghavi Hossein-Zadeh

University of Guilan, Faculty of Agricultural Sciences, Dept. of Animal Science, Rasht, 41635-1314, Iran.

Abstract

To evaluate effect of dystocia on the lactation curve characteristics for milk yield and composition in Holstein cows, six non-linear models (Brody, Wood, Sikka, Nelder, Dijkstra and Rook) were fitted on 5,917,677 test day records for milk yield (MY), fat (FP) and protein (PP) percentages, fat to protein ratio (FPR) and somatic cell score (SCS) of 643,625 first lactation Holstein cows with normal calving or dystocia from 3146 herds which were collected by the Animal Breeding Center of Iran. The models were tested for goodness of fit using adjusted coefficient of determination, root means square error, Akaike's information criterion and Bayesian information criterion. Rook model provided the best fit of the lactation curve for MY and SCS in normal and difficult calvers and dairy cows with dystocia for FP. Dijkstra model provided the best fit of the lactation curve for PP and FPR in normal and difficult calvers and dairy cows with normal calving for FP. Dairy cows with dystocia had generally lower 100-d, 200-d and 305-d cumulative milk yield compared with normal calvers. Time to the peak milk yield was observed later for difficult calvers (89 days in milk *vs*. 79 days in milk) with lower peak milk yield (31.45 kg *vs*. 31.88 kg) compared with normal calvers. Evaluation of the different non-linear models indicated that dystocia had important negative effects on milk yield and lactation curve characteristics in dairy cows and it should be reduced as much as possible in dairy herds.

Additional keywords: calving difficulty; dairy cow; mathematical model; peak yield; productive performance.

Abbreviations used: AIC (Akaike's information criterion); BIC (Bayesian information criterion); FP (fat percentage of milk); FPR (fat to protein ratio); MY (milk yield); PP (protein percentage of milk); PT (peak time); PY (peak yield); SCS (somatic cell score).

Authors' contributions: This manuscript has one author who conceived and designed the study, performed the study, analyzed the data and wrote the manuscript.

Citation: Ghavi Hossein-Zadeh, N. (2019). Comparison of the parameters of the lactation curve between normal and difficult calvings in Iranian Holstein cows. Spanish Journal of Agricultural Research, Volume 17, Issue 1, e0401. https://doi.org/10.5424/sjar/2019171-13673

Received: 09 Jul 2018. **Accepted:** 08 Feb 2019.

Funding: The author received no specific funding for this work.

Competing interests: The author declares no conflict of interests with respect to this research.

Correspondence should be addressed to Navid Ghavi Hossein-Zadeh: nhosseinzadeh@guilan.ac.ir or navid.hosseinzadeh@gmail.com

Introduction

Reproductive problems happen frequently in lactating dairy cows and can largely influence reproductive efficiency in a dairy farm (Sewalem *et al.*, 2008; Ghavi Hossein-Zadeh, 2013). These problems result in high economic losses and public health issues in dairy industry. Therefore, low reproductive efficiency is known as the main reason for involuntary culling and has a negative effect on the later productive performance of a dairy herd. One of the major health problems which has a negative effect on reproductive ability of dairy cows and imposed major economic losses in dairy herds is dystocia. These are different disorders that are similar in that they all can lead to impaired reproductive performance. Dairy producers should emphasize on the prevention and control of risk factors for dystocia and consult with their herd veterinarian to apply appropriate management interventions when essential (Fricke, 2001).

Dystocia is routinely defined as difficult or lengthened calving (Mee, 2008), although different range of definitions was provided for dystocia in the literature varying from assistance requirement to substantial force or surgery for taking out the newborn calf (Mee, 2008). Several methods are existed to evaluate the calving difficulty (also known as calving ease in cattle). Ordinal scales with three to five rating points are accepted in cattle to score various degrees of difficulty (Mee, 2008). The lowest and highest scores are usually assigned to the easiest and the most difficult calvings, respectively. Previous studies reported different outcomes for dystocia including increased rate of calf mortality and morbidity (Lombard *et al.*, 2007; Ghavi Hossein-Zadeh, 2014b), decreased fertility (Lopez de Maturana *et al.*, 2007; Tenhagen *et al.*, 2007) and milk yield (McGuirk *et al.*, 2007; Ghavi Hossein-Zadeh, 2014b) as well as cow survival and longevity (Lopez de Maturana *et al.*, 2007), and increase in the culling rate in dairy herds (Ghavi Hossein-Zadeh, 2016).

Lactation curve provides information on the relationship between milk yield and milking time beginning at calving (Ghavi Hossein-Zadeh, 2014a). Models which characterize productive performance over time can be very helpful in genetic breeding strategies, feeding management of dairy herd, and making decision on keeping or removal of dairy cows from the herd and designing simulation systems of milk production (Cankaya *et al.*, 2011; Ghavi Hossein-Zadeh, 2014a). There are different empirical and mechanistic functions which characterize the lactation curve features to provide information on the biology of lactation in dairy cows (Wood, 1967; Rook *et al.*, 1993; Dijkstra *et al.*, 1997). These functions are beneficial to study effect of dystocia on different parts of lactation curve for milk yield and composition more accurately and in much more detail (Rajala & Gröhn, 1998; Atashi *et al.*, 2012). However, studies on the effect of dystocia on the lactation curve features of dairy cows are scarce in the literature. Therefore, the aim of the current study was to evaluate effects of dystocia on the main features of lactation curves for MY and its composition (milk fat percentage (FP), milk protein percentage (PP), milk fat to protein ratio (FPR) and somatic cell score (SCS)) for the first lactation of Iranian Holsteins, using six non-linear mathematical models (Brody, Wood, Sikka, Nelder, Rook and Dijkstra).

Material and methods

Data set

Data set consisted of 5,917,677 test day records for milk yield (MY), fat (FP) and protein (PP) percentages, fat to protein ratio (FPR) and somatic cell score [SCS = 3 + $\log_2$ (SCC/100); where SCC is somatic cell count in cells/µL] of 643,625 first lactation Holstein cows from 3146 herds which were collected by the Animal Breeding Center of Iran from April 1987 to February 2014. Because previously collected data was used in this study it was not required to obtain ethical approval for conducting it. General characteristics of dairy herds in Iran along with their management were reported in previous study (Ghavi Hossein-Zadeh *et al.*, 2008). Outliers and out of range productive records were deleted from the analyses. Records from days in milk (DIM) <5 and >305 days were eliminated and only cows with at least four test-day records were remained in the data set. Records were also eliminated if no registration number was present for a given cow. Analyses were applied to only the first lactation and, therefore, data from later lactations were also discarded. Age at first calving varied between 20 and 40 months. Individual daily milk production should be between 3 and 90 kg. Also, fat and protein percentages should be in a range from 1 to 9%. Calvings were scored on a 5-point system of difficulty with increments of 1, where score 1 = unassisted, score 2 = slight assistance, score 3 = considerable assistance, score 4 = considerable force needed, and score 5 = caesarian. In the current study, dystocia scores of 1 and 2 were combined to consider as normal or easy calving (92.03% of total calvings), and other scores were considered as difficult calving (7.97% of total calvings). Therefore, data set was stratified into two parts based on dystocia score and different non-linear lactation models considered were fitted on these two sub data. Descriptive statistics for test-day productive records in the first lactation of Holstein cows are shown in Table 1.

Lactation curve models

The non-linear models used to describe the lactation curves for milk yield and compositions are presented in Table 2. The Brody, Wood, Sikka, Nelder, Dijkstra and Rook functions were non-linear functions to model the relationship between productive traits and days in milk. For all models, peak yield (PY) was assumed as the maximum test day milk yield or minimum milk constituents and peak time (PT) was accepted as the test time, at which daily milk yield was maximum or milk constituents were

Table 1. Descriptive statistics for test-day productive records in the first lactation of Holstein cows.

Trait	All dairy cows				Dairy cows with normal calving				Dairy cows with dystocia			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
MY (kg)	28.88	8.18	3	90	28.92	8.19	3	90	28.35	7.93	3	87
FP (%)	3.23	0.85	1	9	3.22	0.85	1	9	3.28	0.86	1	9
PP (%)	3.12	0.40	1	9	3.12	0.40	1	9	3.12	0.41	1	9
FPR	1.06	0.29	0.13	9	1.06	0.29	0.13	9	1.09	0.30	0.18	6.72
SCS	2.56	1.89	0.06	10.64	2.56	1.89	0.06	10.64	2.48	1.86	0.06	10.54

MY: milk yield; FP: fat percentage; PP: protein percentage; FPR: fat to protein ratio; SCS: somatic cell score.

Table 2. Equations and their features used to describe the lactation curve of Holstein cows.

Equation	Functional form	PT	PY
Brody	$y = a\left(1-\left(be^{-ct}\right)\right)$	Not applicable	Not applicable
Wood	$y = at^{b}e^{-ct}$	$\frac{b}{c}$	$a\left(\frac{b}{c}\right)^{b} e^{-b}$
Parabolic (Sikka)	$y = ae^{\left(bt-ct^{2}\right)}$	$\frac{b}{2c}$	$ae^{\left(\frac{b^2}{4c}\right)}$
Inverse polynomial (Nelder)	$y = \frac{t}{\left(a+bt+ct^{2}\right)}$	$\sqrt{\frac{a}{c}}$	$\frac{1}{b}+2\sqrt{ac}$
Rook	$y = a\left(\frac{1}{1+\left(\frac{b}{c+t}\right)}\right)e^{-dt}$	$-\left(\frac{b}{2}+c\right)+\sqrt{\left(\left(\frac{b}{2}+c\right)^{2}-c\left(b+c\right)+\frac{b}{d}\right)}$	$\frac{ae^{-c(PT)}}{\left(1+\frac{b}{\left(c+PT\right)}\right)}$
Dijkstra	$y = ae^{\left[\frac{b\left(1-e^{-ct}\right)}{c}-dt\right]}$	$c^{-1}\ln\left(\frac{b}{d}\right)$	$a\left(\frac{d}{b}\right)^{\frac{d}{c}} e^{\left[\frac{(b-d)}{c}\right]}$

y= milk yield and composition; PY= maximum value for MY and minimum value for FP, PP, FPR and SCS; PT= peak time for MY and minimum time for FP, PP, FPR and SCS; a, b, c and d are parameters that define the scale and shape of the lactation curve; t= time from parturition.

minimum. The ratio between the milk yields of the second 100 days of lactation and those of the first 100 days ($P_{2:1}$) was considered as a persistency measure in this study (Johansson & Hansson, 1940).

Statistical analyses

Each model was fitted separately to monthly productive records of normal and dystocial dairy cows using the NLIN and MODEL procedures in SAS (SAS Inst., 2002) and the parameters were estimated. When non-linear functions were fitted, the Gauss-Newton method was applied as the iteration method. The models were tested for goodness of fit (quality of prediction) using adjusted coefficient of determination (R^2_{adj}), residual standard deviation or root means square error (RMSE), Akaike's information criterion (AIC) and Bayesian information criterion (BIC).

R^2_{adj} was calculated using the following formula:

$$R^2_{adj} = 1-\left[\frac{(n-1)}{(n-p)}\right]\left(1-R^2\right)$$

where, R^2 is the coefficient of determination ($R^2 = 1-\frac{RSS}{TSS}$), TSS is total sum of squares, RSS is residual sum of squares, n is the number of observations (data points) and p is the number of parameters in the equation. The coefficient of determination lies always between 0 and 1, and the fit of a model is satisfactory if R^2 is close to unity.

RMSE is a kind of generalized standard deviation and was calculated as follows:

$$RMSE = \sqrt{\frac{RSS}{n-p-1}}$$

The best model was considered one with the lowest RMSE. AIC was calculated as using the equation:

$$AIC = n \times \ln\left(RSS\right)+2p$$

A smaller numerical value of AIC indicates a better fit when comparing models. BIC was calculated as using the equation:

$$BIC = n\ln\left(\frac{RSS}{n}\right)+p\ln\left(n\right)$$

A smaller numerical value of BIC indicates a better fit when comparing models.

Results

Estimated parameters of non-linear equations for the dairy cows with normal or dystocial calvings are

Table 3. Parameter estimates for the different lactation equations of the dairy cows with normal calving.

Trait	Parameter	Model					
		Brody	**Wood**	**Sikka**	**Nelder**	**Rook**	**Dijkstra**
MY	a	29.16	18.51	28.32	0.12	37.78	21.23
	b	0.50	0.15	0.001	0.03	8.21	0.02
	c	0.14	0.002	0.000006	0.00003	7.31	0.05
	d	-	-	-	-	0.001	0.001
FP	a	3.20	4.75	3.40	-0.56	2.71	4.28
	b	-0.46	-0.12	-0.001	0.34	-6.37	-0.02
	c	0.11	-0.001	-0.000005	-0.0001	14.60	0.05
	d	-	-	-	-	-0.0007	-0.0005
PP	a	3.12	3.58	3.04	-0.36	2.85	4.06
	b	-0.54	-0.05	-0.0001	0.35	-1.19	-0.04
	c	0.26	-0.001	-0.000001	-0.0002	0.75	0.11
	d	-	-	-	-	-0.0005	-0.0004
FPR	a	1.04	1.38	1.16	-0.83	0.84	1.21
	b	-0.18	-0.07	-0.001	0.95	-29.04	-0.004
	c	0.03	-0.0004	-0.000004	0.00006	94.36	0.02
	d	-	-	-	-	-0.0005	-0.0003
SCS	a	2.54	3.81	2.63	-0.82	2.10	3.58
	b	-0.66	-0.13	-0.001	0.44	-5.23	-0.03
	c	0.16	-0.002	-0.000005	-0.0003	9.72	0.06
	d	-	-	-	-	-0.0009	-0.0007

MY: milk yield; FP: fat percentage; PP: protein percentage; FPR: fat to protein ratio; SCS: somatic cell score; a, b, c and d are parameters that define the scale and shape of the lactation curve.

presented in Tables 3 and 4, respectively. Also, goodness of fit statistics for the six functions fitted to average standard curves of MY according to dystocia score are shown in Table 5. The Rook model provided the lowest values of AIC and BIC in normal and difficult calvers. For normal calvers, Wood, Rook and Dijkstra equations provided the lowest RMSE values. For difficult calvers, Rook and Dijkstra equations provided the lowest RMSE values. In general, the Brody model had the greatest values of AIC, BIC and RMSE. R^2_{adj} values were generally similar among models. Therefore, Rook model provided the best fit of the lactation curve for MY in normal and difficult calvers, while Brody model provided the worst fit.

Goodness of fit statistics for the six functions fitted to average standard curves of FP according to dystocia score are shown in Table 6. The Dijkstra model provided the lowest values of AIC and BIC in dairy cows with normal calving, while Rook model had the lowest values for difficult calvers. For normal calvers, Wood, Nelder, Rook and Dijkstra equations provided the lowest RMSE values. For difficult calvers, Wood, Nelder, Rook and Dijkstra models had the lowest values of RMSE. In general, the Brody model had the greatest values of AIC, BIC and RMSE. R^2_{adj} values were generally similar among models. Therefore, Dijkstra and Rook equations provided the best fit of the lactation curve for FP in normal and difficult calvers, respectively, while Brody model provided the worst fit.

Goodness of fit statistics for the six functions fitted to average standard curves of PP according to dystocia score are shown in Table 7. The Dijkstra model provided the lowest values of AIC and BIC in dairy cows with normal calving and dystocia. The Wood, Nelder, Sikka, Rook and Dijkstra equations provided the lowest RMSE values for normal and difficult calvers. In general, the Brody model had the greatest values of AIC, BIC and RMSE. R^2_{adj} values were generally similar among models. Therefore, Dijkstra equation provided the best fit of the lactation curve for PP in normal and difficult calvers, respectively, while Nelder model provided the worst fit.

Goodness of fit statistics for the six functions fitted to average standard curves of FPR according to dystocia score are shown in Table 8. The Dijkstra model provided the lowest values of AIC and BIC in dairy cows with normal and difficult calvings. Brody model had the greatest values of AIC and BIC. R^2_{adj} and

Table 4. Parameter estimates for the different lactation equations of the dairy cows with dystocia.

Trait	Parameter	Model					
		Brody	Wood	Sikka	Nelder	Rook	Dijkstra
MY	a	28.66	16.54	27.10	0.14	38.03	19.69
	b	0.53	0.18	0.002	0.03	10.27	0.02
	c	0.12	0.002	0.000007	0.00004	7.73	0.05
	d	-	-	-	-	0.001	0.001
FP	a	3.26	5.16	3.52	-0.62	2.71	4.57
	b	-0.55	-0.14	-0.002	0.34	-7.27	-0.02
	c	0.11	-0.001	-0.000005	-0.0002	15.06	0.05
	d	-	-	-	-	-0.0008	-0.0006
PP	a	3.11	3.62	3.02	-0.40	2.80	4.19
	b	-0.66	-0.06	-0.0001	0.35	-1.33	-0.04
	c	0.28	-0.0009	-0.000002	-0.0002	0.84	0.11
	d	-	-	-	-	-0.0006	-0.0005
FPR	a	1.07	1.53	1.22	-1.02	0.87	1.30
	b	-0.24	-0.09	-0.002	0.92	-25.56	-0.005
	c	0.03	-0.0005	-0.000004	0.0001	75.03	0.02
	d	-	-	-	-	-0.0005	-0.0002
SCS	a	2.46	3.92	2.59	-0.93	2.00	3.56
	b	-0.72	-0.15	-0.001	0.46	-6.34	-0.03
	c	0.15	-0.002	-0.000006	-0.0003	11.30	0.06
	d	-	-	-	-	-0.001	-0.0007

MY: milk yield; FP: fat percentage; PP: protein percentage; FPR: fat to protein ratio; SCS: somatic cell score; a, b, c and d are parameters that define the scale and shape of the lactation curve.

Table 5. Comparing goodness of fit for average standard curves of milk yield according to dystocia class, for Brody, Wood, Sikka, Nelder, Rook and Dijkstra models.

Dystocia score	Statistics	Model					
		Brody	Wood	Sikka	Nelder	Rook	Dijkstra
1	R^2_{adj}	0.93	0.93	0.93	0.93	0.93	0.93
	RMSE	8.10	7.91	7.97	7.92	7.91	7.91
	AIC	62974684	62818297	62863812	62823084	62815423	62816222
	BIC	12508854	12370457	12410736	12374694	12367927	12368634
2	R^2_{adj}	0.93	0.93	0.93	0.93	0.93	0.93
	RMSE	7.82	7.64	7.70	7.64	7.63	7.63
	AIC	4741424	4727993	4733017	4728538	4727689	4727751
	BIC	1169786	1156355	1161379	1156900	1156062	1156123

R^2_{adj} : adjusted coefficient of determination; RMSE: root means square error; AIC: Akaike information criteria; BIC: Bayesian information criteria.

RMSE values were generally similar among models. Therefore, Dijkstra equation provided the best fit of the lactation curve for FPR in normal and difficult calvers, respectively, while Brody model provided the worst fit.

Goodness of fit statistics for the six functions fitted to average standard curves of SCS according to dystocia score are shown in Table 9. The Rook model provided the lowest values of AIC and BIC in dairy cows with normal and difficult calvings. R^2_{adj} and RMSE values were generally similar among models in normal calvers. However, R^2_{adj} values were similar among models for difficult calvers. The Brody, Wood and Sikka provided

Table 6. Comparing goodness of fit for average standard curves of fat percentage according to dystocia class, for Brody, Wood, Sikka, Nelder, Rook and Dijkstra models.

Dystocia score	Statistics	Model					
		Brody	**Wood**	**Sikka**	**Nelder**	**Rook**	**Dijkstra**
1	R^2_{adj}	0.94	0.94	0.94	0.94	0.94	0.94
	RMSE	0.84	0.83	0.84	0.83	0.83	0.83
	AIC	42383327	42341812	42377058	42351232	42339209	42339170
	BIC	-1036986	-1078501	-1043255	-1069081	-1081091	-1081130
2	R^2_{adj}	0.94	0.94	0.94	0.94	0.94	0.94
	RMSE	0.85	0.84	0.85	0.84	0.84	0.84
	AIC	3053561	3049372	3053282	3050509	3049100	3049140
	BIC	-84032	-88221	-84311	-87084	-88482	-88443

R^2_{adj}: adjusted coefficient of determination; RMSE: root means square error; AIC: Akaike information criteria; BIC: Bayesian information criteria.

Table 7. Comparing goodness of fit for average standard curves of protein percentage according to dystocia class, for Brody, Wood, Sikka, Nelder, Rook and Dijkstra models.

Dystocia score	Statistics	Model					
		Brody	**Wood**	**Sikka**	**Nelder**	**Rook**	**Dijkstra**
1	R^2_{adj}	0.98	0.98	0.98	0.98	0.98	0.98
	RMSE	0.40	0.39	0.39	0.39	0.39	0.39
	AIC	26549101	26436874	26468663	26420835	26419995	26415997
	BIC	-3800479	-3912706	-3880916	-3928745	-3929573	-3933570
2	R^2_{adj}	0.98	0.98	0.98	0.98	0.98	0.98
	RMSE	0.40	0.39	0.39	0.39	0.39	0.39
	AIC	1868571	1854560	1857850	1852914	1852822	1852442
	BIC	-329944	-343956	-340665	-345602	-345683	-346063

R^2_{adj}: adjusted coefficient of determination; RMSE: root means square error; AIC: Akaike information criteria; BIC: Bayesian information criteria.

Table 8. Comparing goodness of fit for average standard curves of milk fat to protein ratio according to dystocia class, for Brody, Wood, Sikka, Nelder, Rook and Dijkstra models.

Dystocia score	Statistics	Model					
		Brody	**Wood**	**Sikka**	**Nelder**	**Rook**	**Dijkstra**
1	R^2_{adj}	0.93	0.93	0.93	0.93	0.93	0.93
	RMSE	0.29	0.29	0.29	0.29	0.29	0.29
	AIC	24970319	24970068	24971633	24976869	24968755	24968683
	BIC	-5135501	-5135752	-5134187	-5128951	-5137053	-5137125
2	R^2_{adj}	0.93	0.93	0.93	0.93	0.93	0.93
	RMSE	0.30	0.30	0.30	0.30	0.30	0.30
	AIC	1747029	1747025	1747379	1747888	1746911	1746904
	BIC	-436427	-436432	-436078	-435568	-436535	-436542

R^2_{adj}: adjusted coefficient of determination; RMSE: root means square error; AIC: Akaike information criteria; BIC: Bayesian information criteria.

Table 9. Comparing goodness of fit for average standard curves of somatic cell score according to dystocia class, for Brody, Wood, Sikka, Nelder, Rook and Dijkstra models.

Dystocia score	Statistics	Model					
		Brody	Wood	Sikka	Nelder	Rook	Dijkstra
1	R^2_{adj}	0.65	0.65	0.65	0.65	0.65	0.65
	RMSE	1.88	1.88	1.88	1.88	1.88	1.88
	AIC	19235273	19230435	19232762	19230595	19230145	19230154
	BIC	1591300	1586462	1588788	1586622	1586184	1586192
2	R^2_{adj}	0.64	0.64	0.64	0.64	0.64	0.64
	RMSE	1.86	1.85	1.86	1.85	1.85	1.85
	AIC	1361734	1361325	1361548	1361353	1361305	1361308
	BIC	131696	131286	131510	131314	131276	131279

R^2_{adj} : adjusted coefficient of determination; RMSE: root means square error; AIC: Akaike information criteria; BIC: Bayesian information criteria.

the greatest values for dairy cows with dystocia. Therefore, Rook equation provided the best fit of the lactation curve for SCS in normal and difficult calvers, respectively, while Brody model provided the worst fit.

Observed and predicted PT and PY for milk yield and composition predicted by six non-linear models are shown in Table 10. Also, predicted lactation curves for milk yield, fat and protein percentages, fat to protein ratio and somatic cell score by different non-linear models in dairy cows with normal calving and dystocia are presented in Figures 1 and 2, respectively. Dairy cows with difficult calving had generally lower 100MY (100-d cumulative milk yield), 200MY (200-d cumulative milk yield) and 305MY (305-d cumulative milk yield) compared with normal calvers. Time to the peak milk yield was observed later for difficult calvers (89 days in milk *vs*. 79 days in milk) with lower peak milk yield (31.45 kg *vs*. 31.88 kg) compared with normal calvers. Evaluation of lactation curve features of normal calvers showed that the Dijkstra and Nelder equations were able to estimate time to the peak more accurately than the other equations, but Rook model provided more accurate estimate of peak milk yield, 100MY and 200MY than other models. Brody equation provided more accurate 305MY compared with other models. In addition, the Wood model provided more persistent lactation curves of dairy cows with normal calving compared with other models. Evaluation of lactation curve features of difficult calvers showed that the Rook equation was able to estimate time to the peak more accurately than the other equations, but Sikka model provided more accurate estimate of peak milk yield than other models. The Wood equation predicted more accurate 100MY and 200MY and Brody equation provided more accurate 305MY compared with other models. The Nelder model provided more persistent lactation curves of dairy cows with dystocia compared with other models (Table 10).

Time to the minimum FP was observed later for normal calvers (79 days in milk *vs*. 70 days in milk) with lower minimum FP (3.06% *vs*. 3.09%) compared with difficult calvers. Evaluation of lactation curve features of normal calvers showed that the Nelder equation was able to estimate time to minimum FP more accurately than the other equations, but Rook model provided more accurate estimate of minimum FP than other models. Evaluation of lactation curve features of difficult calvers showed that the Dijkstra equation was able to estimate time to minimum FP more accurately than the other equations, but Rook model provided more accurate estimate of minimum FP than other models (Table 10).

Time to the minimum PP was observed later for normal calvers (51 days in milk *vs*. 46 days in milk) with greater minimum PP (2.95% *vs*. 2.91%) compared with difficult calvers. Evaluation of lactation curve features of normal calvers showed that the Wood and Sikka equations were able to estimate time to minimum PP more accurately than the other equations, but Rook model provided more accurate estimate of minimum PP than other models. Evaluation of lactation curve features of difficult calvers showed that the Nelder and Rook equations were able to estimate time to minimum PP more accurately than the other equations, but Rook model provided more accurate estimate of minimum PP than other models (Table 10).

Time to the minimum FPR was observed later for normal calvers (161 days in milk *vs*. 130 days in milk) compared with difficult calvers, but minimum FPR was similar between two groups (1.03). Evaluation of lactation curve features of normal calvers showed that the Rook model was able to estimate time to minimum

Table 10. Different features of lactation curve for MY, PP, FP and SCS according to dystocia score class, predicted by Brody, Wood, Sikka, Nelder, Rook and Dijkstra models*.

Trait	Dystocia score	Statistics	Observed	Model					
				Brody	Wood	Sikka	Nelder	Rook	Dijkstra
MY	1	PT (day)	62	-	75	83	63	79	60
		PY (kg)	31.57	-	30.45	29.52	29.59	31.88	29.24
		100MY (kg)	2883	2744	2815	2805	2728	2918	2705
		200MY (kg)	5859	5660	5714	5666	5559	6003	5429
		305MY (kg)	8675	8722	8401	8265	8318	8989	8013
		$P_{2:1}$	-	1.04	1.00	0.99	1.01	1.03	0.98
	2	PT (day)	83	-	90	143	59	89	60
		PY (kg)	31.19	-	31.05	31.26	28.79	31.45	27.12
		100MY (kg)	2801	2678	2819	2821	2645	2842	2509
		200MY (kg)	5715	5544	5828	5928	5350	5908	5035
		305MY (kg)	8514	8553	8661	8927	7933	8890	7431
		$P_{2:1}$	-	1.05	1.04	1.08	1.00	1.05	0.98
FP	1	PT	79	-	120	100	75	84	74
		PY	3.06	-	3.02	3.23	2.82	3.07	3.01
	2	PT	70	-	140	200	56	84	70
		PY	3.09	-	2.97	2.88	2.76	3.13	3.23
PP	1	PT	51	-	50	50	42	49	42
		PY	2.95	-	3.09	3.03	2.73	2.99	2.88
	2	PT	46	-	67	25	45	47	40
		PY	2.91	-	2.99	3.02	2.72	2.96	2.98
FPR	1	PT	161	-	175	125	118	162	130
		PY	1.03	-	1.03	1.09	1.07	1.03	1.05
	2	PT	130	-	180	250	101	164	161
		PY	1.03	-	1.05	0.95	1.11	1.06	1.06
SCS	1	PT	57	-	65	100	52	69	63
		PY	2.34	-	2.52	2.50	2.12	2.39	2.30
	2	PT	64	-	75	83	56	72	63
		PY	2.07	-	2.38	2.48	2.03	2.33	2.28

* PY= maximum value for MY and minimum value for FP, PP, FPR and SCS; PT= peak time for MY and minimum time for FP, PP, FPR and SCS; 100MY: 100-d cumulative milk yield; 200MY: 200-d cumulative milk yield; 305MY: 305-d cumulative milk yield; $P_{2:1}$ = measure of persistency based on the ratio between the milk yields of the second 100 days of lactation and those of the first 100 days.

FPR more accurately than the other equations, but Rook and Wood models provided more accurate estimate of minimum FPR than other models. Evaluation of lactation curve features of normal calvers showed that the Nelder model was able to estimate time to minimum FPR more accurately than the other equations, but Wood model provided more accurate estimate of minimum FPR than other models (Table 10).

Time to the minimum SCS was observed later for difficult calvers (64 days in milk *vs*. 57 days in milk) with lower minimum SCS (2.34% *vs*. 2.07%) compared with normal calvers. Evaluation of lactation curve features of normal calvers showed that the

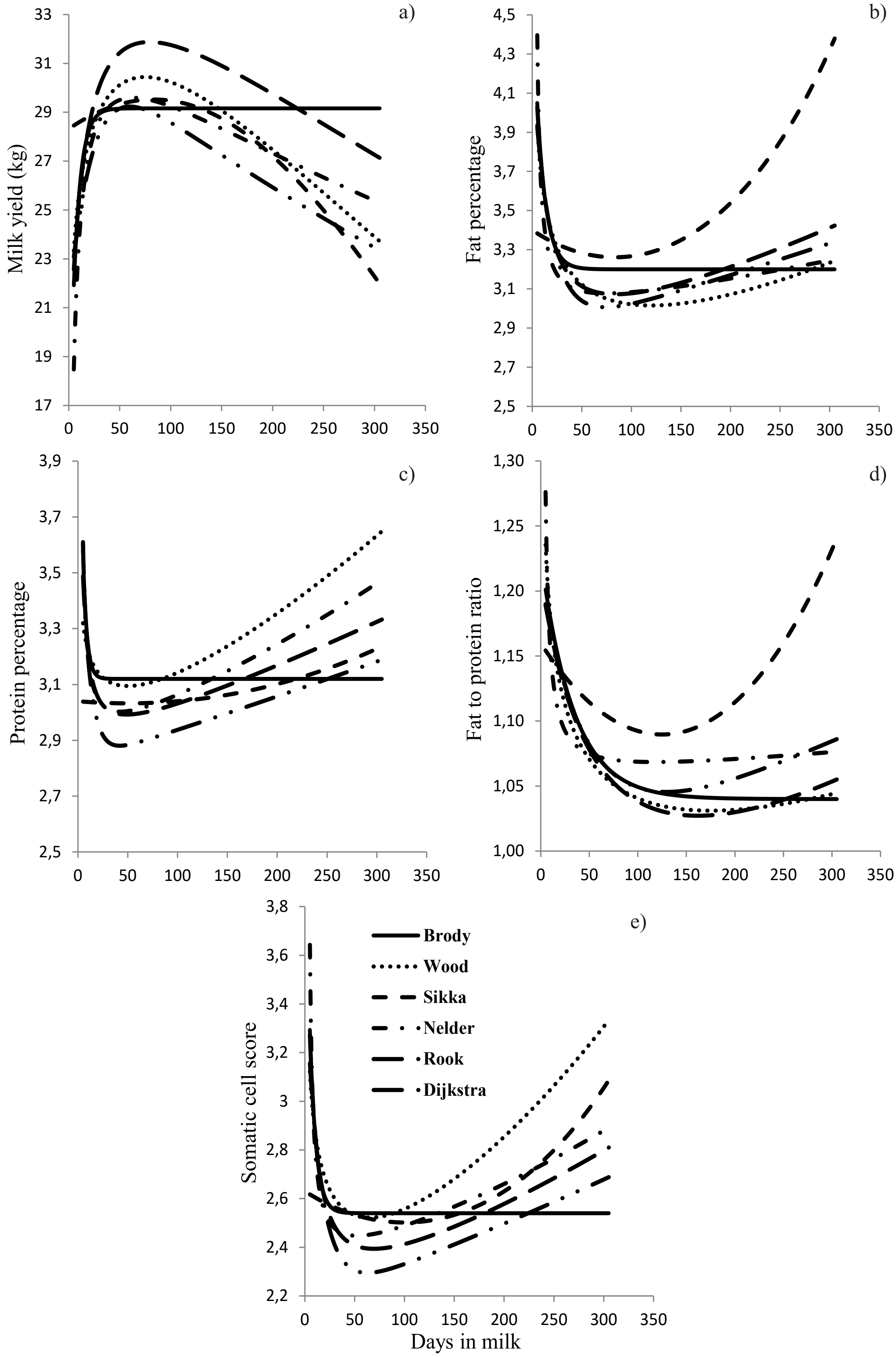

Figure 1. Predicted lactation curves for milk yield, fat and protein percentages, fat to protein ratio and somatic cell score by different non-linear models in dairy cows with normal calving.

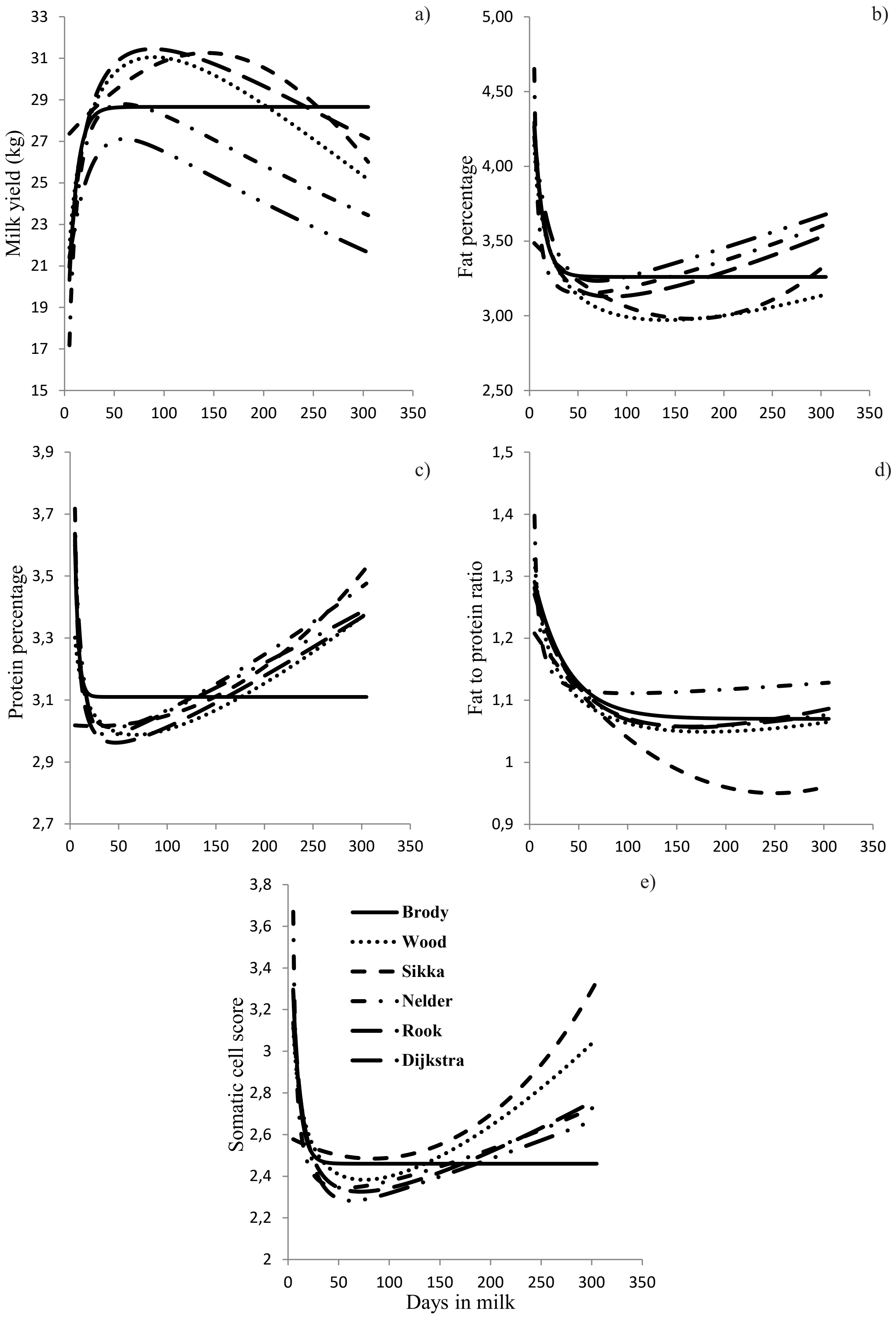

Figure 2. Predicted lactation curves for milk yield, fat and protein percentages, fat to protein ratio and somatic cell score by different non-linear models in dairy cows with dystocia.

Nelder and Dijkstra equations were able to estimate time to minimum SCS more accurately than the other equations, but Dijkstra model provided more accurate estimate of minimum SCS than other models. Evaluation of lactation curve features of difficult calvers showed that the Dijkstra equation was able to estimate time to minimum SCS more accurately than the other equations, but Nelder model provided more accurate estimate of minimum SCS than other models (Table 10).

Discussion

Although several researches have conducted to study the effect of calving difficulty on milk yield performance of Holstein cows (Berry *et al.*, 2007; Bicalho *et al.*, 2008; Atashi *et al.*, 2012), there is no published research to report the effect of dystocia on the lactation curve characteristics not only for milk yield but also for milk composition traits according to the best fitted non-linear model in Holstein cows. Six non-linear models with different complexity were assessed and compared using two large data sets from first lactation Holstein cows with normal or difficult calving. Comparison of their predictive ability permits to introduce the best mathematical equation for characterizing the lactation curve features of dairy cows which classified based on their calving ease score. With fitting non-linear lactation models, it is possible to predict lactation production of dairy cows over a specific time period or whole lactation. Also, it is possible to predict missing test day production records of dairy cows which are lost due to unpredictable events such as injury, diseases and etc. Therefore, the decision on the keeping or culling a cow in the herd based on the first lactation milk production and also in the early phases of the lactation period would be likely. If possible shape of the lactation curve is known, dairy cows with normal or difficult calving can be classified based to their expected lactation performance and more suitable nutritional programs and management enterprises can be considered which are compatible with the requirements for each group of animals by taking into consideration the variations among the groups.

Inconsistent with the current results, Domecq *et al.* (1997) observed no significant association between dystocia and milk production at 120 days in milk in primiparous high yielding Holstein cows. Also, Rajala & Gröhn (1998) reported no relationship between calving difficulty with 305-day milk production in dairy cows, but consistent with the results of this study, Dematawewa & Berger (1997), Berry *et al.* (2007), Gaafar *et al.* (2011), Atashi *et al.* (2012) and Ghavi Hossein-Zadeh (2014b) reported milk yield was lower in cows that experienced dystocia at calving compared with those that did not. Also, inconsistent with current results, Thompson *et al.* (1983) reported no significant effect of dystocia on 90-day milk yield or mature equivalent milk yield and Tenhagen *et al.* (2007) also reported there were no clear influences of severe degree of dystocia on monthly test day milk yield. Djemali *et al.* (1987) reported that 305-d milk yield of cows experienced difficult calving was decreased by 465 kg in the first lactation cows in comparison with cows which did not. Also, they reported 305-d fat yield of cows which experienced calving difficulty was 20.7 kg lower than cows with dystocia. Kaya *et al.* (2015) observed first lactation cows with calving difficulty produced 85 and 219 kg less milk in 100 and 305 days in milk, respectively, but no difference was observed between 200-d milk yield of cows with normal and difficult calving. The discrepancies observed between the results of different studies might be attributable to different definitions of dystocia, different statistical methods and models, measures and time periods used to estimate the milk loss, animal genetics and management factors (Rajala & Gröhn, 1998; Barrier & Haskell, 2011). Several factors could justify the variation in models' fit such as differences in mathematical formula for each equation, differences in the number of test day records and test day yield, the data amount, and the test intervals. Also, lactation curve observed for each animal would be an outcome of combining non-genetic and genetic factors (Pérochon *et al.*, 1996; Ghavi Hossein-Zadeh, 2014a). Reduced milk production in the first 100 days of lactation and postponed peak time in cows with calving difficulty may be associated with trauma in calving and heightened risk of postpartum problems. The possible reasons for reduced milk production in cows with dystocia would be changes in the concentrations of hormones and decreased appetite (Barrier & Haskell, 2011). It has been reported that incidence of dystocia in primiparous cows is chiefly because of disproportioned fetal-maternal size (Ghavi Hossein-Zadeh, 2014b). Except for SCS, minimum values of other composition traits (FP, PP, FPR) were observed later in cows with normal calving compared with cows experiencing dystocia. In general, the values of SCS were lower in cows with dystocia than normal calvers, this would be assigned to lower milk yield produced by cows with dystocia. A greater milk yield over the lactation, for normal calvers in this study, may increase the udder infection risk and this would act as stress factor, as a result of that increasing the SCS (de los Campos *et al.*, 2006). The reverse condition would be likely for dairy cows with dystocia which experienced lower milk yield over the lactation.

Improvement of lactation persistency would be associated with the reduction of the production system costs, because milk yield persistency is connected with health and feeding costs, resistance to disease, reproductive performance and the income from milk sales (Dekkers *et al.* 1996, 1998; Ghavi Hossein-Zadeh, 2014a). The incidence of reproductive and metabolic diseases could be reduced for cows with flatter lactation curves and the proportion of roughage in the ration of these cows could be increased, therefore, decreasing the costs of production (Tekerli *et al.*, 2000). A genetic modification towards a persistent lactation curve could be applied as a means to decreased disease susceptibility in dairy cows (Ghavi Hossein-Zadeh, 2014a). There was a positive relationship between 305MY and persistency measure, calculated by different models, in the current study. Lactation persistency is relied on yields, especially total yields, but the direction of the relationship relies on the measure applied. The reason for this positive relationship could be that the ratio measure of persistency is greatly influenced by the production level (Gengler, 1996; Ghavi Hossein-Zadeh, 2014a).

Physiological and biological characteristics of each system along with mathematical properties of non-linear function should be considered when derived outputs of models were interpreted by researchers. The results of current study indicated that a reproductive disorder as dystocia would change different properties of lactation curve and its shape for milk yield and composition. Therefore, this disorder could be considered as a factor generating problems in the expression of the actual genetic potential of dairy cows for production traits. Understanding the effect of a disorder, such as dystocia, on different features of a lactation curve would provide a perspective to help dairy managers and herders in designing feeding plans to keep the production of dairy cows high as long as possible. Also, it is necessary to reduce the incidence of dystocia by management and breeding strategies to assure economics and animal welfare in dairy herds.

In conclusion, although the accuracy of the fit of the non-linear model would be one of the main variables for selecting the best equation to describe lactation curve, the possibility for characterizing curve features and the interpretation of its parameters is as critical. The choice of a suitable non-linear model to characterize lactation curve for milk yield and composition in dairy cows which classified based on their calving type could provide the possibility of direct selection on the lactation curve level for individual cow. Therefore, it is likely to develop an optimal strategy to reach a desired lactation curve shape via changing the parameters of model. Of the six models explored in the current study, Rook model provided the best fit of the lactation curve for MY and SCS in normal and difficult calvers and dairy cows with dystocia for FP. In addition, Dijkstra model provided the best fit of the lactation curve for PP and FPR in normal and difficult calvers and dairy cows with normal calving for FP. The results of this study showed that dystocia had important negative effects on milk yield and lactation curve characteristics in dairy cows.

Acknowledgement

Author wishes to thank the Animal Breeding Center of Iran for providing the data used in this study.

References

Atashi H, Abdolmohammadi AR, Asaadi A, Akhlaghi A, Dadpasand M, Jafari Ahangari Y, 2012. Using an incomplete gamma function to quantify the effect of dystocia on the lactation performance of Holstein dairy cows in Iran. J Dairy Sci 95: 2718-2722. https://doi.org/10.3168/jds.2011-4954

Barrier AC, Haskell MJ, 2011. Calving difficulty in dairy cows has a longer effect on saleable milk yield than on estimated milk production. J Dairy Sci 94: 1804-1812. https://doi.org/10.3168/jds.2010-3641

Berry DP, Lee JM, Macdonald KA, Roche JR, 2007. Body condition score and body weight effects on dystocia and stillbirths and consequent effects on postcalving performance. J Dairy Sci 90: 4201-4211. https://doi.org/10.3168/jds.2007-0023

Bicalho RC, Galvão KN, Warnick LD, Guard CL, 2008. Stillbirth parturition reduces milk production in Holstein cows. Prev Vet Med 84: 112-120. https://doi.org/10.1016/j.prevetmed.2007.11.006

Cankaya S, Unalan A, Soydan E, 2011. Selection of a mathematical model to describe the lactation curves of Jersey cattle. Arch Tierz 54: 27-35. https://doi.org/10.5194/aab-54-27-2011

Dekkers JCM, Jamrozik J, Ten Hag JH, Schaeffer LR, Weersink A, 1996. Genetic and economic evaluation of persistency in dairy cattle. Interbull Bull 12: 97-102.

Dekkers JCM, Ten Hag JH, Weersink A, 1998. Economic aspects of persistency of lactation in dairy cattle. Livest Prod Sci 53: 237-252. https://doi.org/10.1016/S0301-6226(97)00124-3

de los Campos G, Gianola D, Heringstad B, 2006. A structural equation model for describing relationships between somatic cell score and milk yield in first-lactation dairy cows. J Dairy Sci 89: 4445-4455. https://doi.org/10.3168/jds.S0022-0302(06)72493-6

Dematawewa CMB, Berger PJ, 1997. Effect of dystocia on yield, fertility, and cow losses and an economic evaluation of dystocia scores for Holsteins. J Dairy Sci 80 (4): 754-761. https://doi.org/10.3168/jds.S0022-0302(97)75995-2

Dijkstra J, France J, Dhanoa MS, Maas JA, Hanigan MD, Rook AJ, Beever DE, 1997. A model to describe growth patterns of the mammary gland during pregnancy and lactation. J Dairy Sci 80: 2340-2354. https://doi.org/10.3168/jds.S0022-0302(97)76185-X

Djemali M, Freeman AE, Berger PJ, 1987. Reporting of dystocia scores and effects of dystocia on production, days open, and days dry from dairy herd improvement data. J Dairy Sci 70: 2127-2131. https://doi.org/10.3168/jds.S0022-0302(87)80263-1

Domecq JJ, Skidmore AL, Lloyd JW, Kaneene JB, 1997. Relationship between body condition scores and milk yield in a large dairy herd of high yielding Holstein cows. J Dairy Sci 80: 101-112. https://doi.org/10.3168/jds.S0022-0302(97)75917-4

Fricke PM, 2001. Review: Twinning in dairy cattle. Prof Anim Sci 17: 61-67. https://doi.org/10.15232/S1080-7446(15)31599-0

Gaafar HMA, Shamiah ShM, Abu El-Hamd MA, Shitta AA, Tag El-Din MA, 2011. Dystocia in Friesian cows and its effects on postpartum reproductive performance and milk production. Trop Anim Health Prod 43: 229-234. https://doi.org/10.1007/s11250-010-9682-3

Gengler N, 1996. Persistency of lactation yields: A review. Interbull Bull 12: 87-96.

Ghavi Hossein-Zadeh N, 2013. Effects of main reproductive and health problems on the performance of dairy cows: A review. Span J Agric Res 11 (3): 718-735. https://doi.org/10.5424/sjar/2013113-4140

Ghavi Hossein-Zadeh N, 2014a. Comparison of non-linear models to describe the lactation curves of milk yield and composition in Iranian Holsteins. J Agr Sci 152: 309-324. https://doi.org/10.1017/S0021859613000415

Ghavi Hossein-Zadeh N, 2014b. Study on the effect of dystocia on the productive performance and calf stillbirth in Iranian Holsteins. J Agric Sci Technol 16: 69-78.

Ghavi Hossein-Zadeh N, 2016. Effect of dystocia on subsequent reproductive performance and functional longevity in Holstein cows. J Anim Physiol Anim Nutr 100: 860-867. https://doi.org/10.1111/jpn.12460

Ghavi Hossein-Zadeh N, Nejati-Javaremi A, Miraei-Ashtiani SR, Kohram H, 2008. An observational analysis of twin births, calf stillbirth, calf sex ratio, and abortion in Iranian Holsteins. J Dairy Sci 91: 4198-4205. https://doi.org/10.3168/jds.2008-1079

Johansson I, Hansson A, 1940. Causes of variation in milk and butterfat yield of dairy cows. Kungliga Lantbruksakademiens Tidskrift 79: 1-127.

Kaya I, Uzmay C, Ayyilmaz T, 2015. Effects of dystocia on milk production and reproduction in subsequent lactation in a Turkish Holstein herd. Turk J Vet Anim Sci 39: 87-95. https://doi.org/10.3906/vet-1404-13

Lombard JE, Garry FB, Tomlinson SM, Garber LP, 2007. Impacts of dystocia on health and survival of dairy calves. J Dairy Sci 90 (4): 1751-1760. https://doi.org/10.3168/jds.2006-295

Lopez de Maturana E, Legarra A, Varona L, Ugarte E, 2007. Analysis of fertility and dystocia in Holsteins using recursive models to handle censored and categorical data. J Dairy Sci 90 (4): 2012-2024. https://doi.org/10.3168/jds.2005-442

McGuirk BJ, Forsyth R, Dobson H, 2007. Economic cost of difficult calvings in the United Kingdom dairy herd. Vet Rec 161: 685-687. https://doi.org/10.1136/vr.161.20.685

Mee JF, 2008. Prevalence and risk factors for dystocia in dairy cattle: A review. Vet J 176 (1): 93-101. https://doi.org/10.1016/j.tvjl.2007.12.032

Pérochon L, Coulon JB, Lescourret F, 1996. Modelling lactation curves of dairy cows with emphasis on individual variability. Anim Prod 63: 189-200.

Rajala PJ, Gröhn YT, 1998. Effects of dystocia, retained placenta, and metritis on milk yield in dairy cows. J Dairy Sci 81: 3172-3181. https://doi.org/10.3168/jds.S0022-0302(98)75883-7

Rook AJ, France J, Dhanoa MS, 1993. On the mathematical description of lactation curves. J Agr Sci 121: 97-102. https://doi.org/10.1017/S002185960007684X

SAS Institute, 2002. SAS User's guide v. 9.1: Statistics. SAS Institute Inc., Cary, NC, USA.

Sewalem A, Miglior F, Kistemaker GJ, Sullivan P, van Doormaal BJ, 2008. Relationship between reproduction traits and functional longevity in Canadian dairy cattle. J Dairy Sci 91: 1660-1668. https://doi.org/10.3168/jds.2007-0178

Tekerli M, Akinci Z, Dogan I, Akcan A, 2000. Factors affecting the shape of lactation curves of Holstein cows from the Balikesir Province of Turkey. J Dairy Sci 83: 1381-1386. https://doi.org/10.3168/jds.S0022-0302(00)75006-5

Tenhagen BA, Helmbold A, Heuwiser W, 2007. Effect of various degrees of dystocia in dairy cattle on calf viability, milk production, fertility and culling. J Vet Med A 54: 98-102. https://doi.org/10.1111/j.1439-0442.2007.00850.x

Thompson JR, Pollak EJ, Pelissier CL, 1983. Interrelationships of parturition problems, production of subsequent lactation, reproduction, and age at first calving. J Dairy Sci 66: 1119-1127. https://doi.org/10.3168/jds.S0022-0302(83)81909-2

Wood PDP, 1967. Algebraic models of the lactation curves in cattle. Nature 216: 164-165. https://doi.org/10.1038/216164a0