Iranian Journal of Applied Animal Science

Lactation Curves for Milk Yield and Composition of Moroccan Holstein Dairy Cows

Research Article

I. Boujenane[1*] and E. Elouaddi[1]

[1] Department of Animal Production and Biotechnology, Hassan II Agronomy and Veterinary Medicine Institute, Madinate Al Irfane, 10 101, Rabat, Morocco

Received on: 25 Oct 2020
Revised on: 25 Mar 2021
Accepted on: 1 May 2021
Online Published on: Dec 2021

*Correspondence E-mail: i.boujenane@iav.ac.ma

Online version is available on: www.ijas.ir

ABSTRACT

The objectives of this study were to describe lactation curves for milk yield and composition using the Wood's model and to estimate lactation curve characteristics. Data including 202 283 test-day records belonging to 27 108 first three lactations of Holstein cows recorded from 2012 to 2016 in a total of 193 herds were analyzed for milk yield, fat, protein, lactose, total solids (TS) and solids not fat (SNF) contents, as well as milk urea nitrogen (MUN) concentration and somatic cell score (SCS). The lactation curve and lactation parameters of interest were intercept (a) and curve shape (b and c) of the lactation curves, as well as the peak production (y_m), the day at peak (t_m) and persistency. The test-day averages milk yield, fat, protein, lactose, TS and SNF contents, as well as MUN and SCS were 24.4 ± 7.87 kg/day, 3.57 ± 0.78%, 3.04 ± 0.35%, 4.88 ± 0.26%, 12.2 ± 1.02%, 8.73 ± 0.39%, 15.8 ± 7.12 mg/dL and 4.37 ± 1.84 units, respectively. Standard lactation curve was the most frequent shape for milk yield (63.9%), lactose content (46.7%) and MUN (42.4%), while reversed standard was the most common shape for fat, protein, TS and SNF contents (59.4, 57.3, 57.8 and 54.0%, respectively) and for SCS (43.2%). The milk yield increased from calving to peak production of 28.2 kg/day that occurred 61 days from parturition and then decreased regularly to dry-off with a persistency of 6.87. The peak for lactose content and MUN concentration of 4.95% and 17.3 mg/dL, respectively was reached at lactation days 105 and 115 post-calving, respectively. Estimated minimum for fat, protein, TS, SNF percentages and SCS was attained at lactation days 100, 69, 83, 68 and 95, respectively with values 3.26%, 2.78%, 11.7%, 8.16% and 3.92, respectively. It was concluded that the knowledge of lactation curves for studied traits will help to improve herd management and to increase production.

KEY WORDS milk constituent, peak yield, persistency, test-day, Wood's model.

INTRODUCTION

Lactation curves describe milk yield and composition during lactation. Their accurate description is necessary for decisions on herd management and selection strategies since lactation curves provide information on problems of feeding, health status and fertility (Swalve, 2000). They also facilitate the prediction of the 305-d lactation yield from partial yield, which helps in early animal culling and selection (Macciotta *et al.* 2005). Numerous models were designed to explain the shape of the lactation curve in dairy cattle (Wood, 1967; Ali and Schaeffer, 1987; Wilmink, 1987; Naeemipour Younesi *et al.* 2019; Ghavi Hossein-Zadeh *et al.* 2020), but the most popular model, owing to its simplicity and accuracy of the lactation curve description (Boujenane, 2013), is the Wood incomplete gamma function (Wood, 1967). The parameters of Wood's function such as peak production, time to peak and persistency can be found directly from the lactation curve models (Kopec *et al.* 2013). Knowledge of these parameters provides valuable information useful for feed management decisions, health monitoring, replacement strategies and genetic evaluation (Naderi, 2018).

Although records of dairy cows on milk yield, milk constituents, somatic cell count (SCC) and milk urea nitrogen (MUN) can be modeled to obtain lactation curves, most research has been for milk yield (Tekerli *et al.* 2000; Macciotta *et al.* 2005), and rather less for milk composition (Wood, 1976; Stanton *et al.* 1992; Olori *et al.* 1997; Garcia and Holmes, 2001; Rodriguez-Zas *et al.* 2000; Pollot, 2004; Silvestre *et al.* 2009). There is accord in the literature about the expected allure of the lactation curve for milk yield. It increases from calving, reaches the peak yield between 4 and 8 weeks after calving, and then decreases progressively after peak yield until the cow is dried off (Swalve, 2000; Macciotta *et al.* 2005). For milk fat and protein percentage curves, some divergence has been reported. According to some authors (Wood, 1976; Schutz *et al.* 1990; Stanton *et al.* 1992; Silvestre *et al.* 2009), fat and protein curves follow the inverse of the lactation curve for milk yield; they tend to decrease rapidly post calving, reach a trough early in lactation at week 8 and 11, respectively and then increase slowly until the end of lactation. However, for Pollot (2004), fat and protein curves follow the so-called standard shape for milk yield. Contradictory to this latter finding, the minimum point on the fat percentage occurs approximately three weeks behind milk yield peak, whereas in the case of protein, it is reached at approximately the same time as the milk yield peak (Schutz *et al.* 1990; Stanton *et al.* 1992; Quinn *et al.* 2006), indicating that instead of being independent, curves for milk yield and constituents seem to be linked, since milk is a mixture of fat, protein, lactose, vitamins and minerals, either dissolved or suspended in water (Silvestre *et al.* 2009). In addition, the lactose content is highest at the start of the lactation and decreases linearly during the remainder of the lactation (Waite *et al.* 1956), and it is generally highest when the protein content is lowest, and vice versa (Legates, 1960). Moreover, the contents of total solids (TS), solids not fat (SNF) and protein drop rather sharply after the first test for the lactation, reaching a low value by the second month in lactation (Legates, 1960). The most important breed of dairy cattle in Morocco is the Holstein breed, which is responsible for providing more than 80% the country's annual cattle milk production. However, its lactation milk curve was fewly studied (Boujenane and Hilal, 2012; Boujenane, 2013), whereas those for milk constituents were never studied. Moreover, no Moroccan study was published that investigated the major milk constituents across the entire lactation. Instead, the protein and fat contents of milk, which are particularly important variables for the dairy industry, serve as significant markers for identifying certain important nutrition and herd management problems, as well as for providing information about the level of success of nutritional regimens introduced to the dairy cattle (Cardak, 2016). Also, MUN, which is an indicator of the relation between feed protein content and energy level, also reveals information about the utilization of crude protein in the feed (Cardak, 2016).

The objectives of this study were to describe the lactation curves for milk yield, milk constituents as well as MUN and somatic cell score (SCS) of Moroccan Holstein cows using the Wood's function.

MATERIALS AND METHODS

Environment and animal management

Test-day data used in this study were obtained from the database of Coopérative Souss d'Amélioration Génétique Bovine, Taroudant, Morocco (COPAG). Herds of COPAG are raised in the Souss-Massa region positioned in South-West of Morocco. The climate of the region is semiarid with the average highest temperature 27 ˚C in the summer and the average lowest temperature 19 ˚C during winter months.

The annual rainfall varied from 180 to 280 mm generally received between November and April. Herds are composed by cows born locally or imported either from Europe or North America. Cows were raised under an intensive production system. They received feed composed of corn silage, forages (fresh or hay), in addition to a concentrate mixture provided to meet the cows' nutritional requirements. The ration varied according to body condition, milk production and stage of lactation of cows. Cows were milked two times daily using machine milking. Fresh water was available all the time.

Data

The data consisted of test-day records on daily milk yield (kg), fat, protein, lactose, TS and SNF contents (%), as well as MUN (mg/dL) and SCC (1000 cells mL^{-1}) from the first three lactations of Holstein cows calved from 2012 to 2016. Individual milk yields were recorded once a month, according to the official A4 protocol, as the sum of the morning and evening milking. Individual milk samples were collected from each cow at each milking and stored at 4 ˚C. Composition was determined by using a MilkoScan FT+ (FOSS, Hilleroed Denmark).

Cows with missed birth date, calving date, parity number, herd number or presenting unlikely ages for a given lactation (age at calving different from 21 to 38, 34 to 52 and 46 to 68 months for lactations 1, 2 and 3, respectively) were discarded.

Moreover, test-day records from days in milk (DIM) lower than 5 and greater than 305 days were excluded, and lactations for which the first test-day was greater than 75 DIM were eliminated. Records showing milk yield and milk constituents above or below the population average plus or minus 3 standard deviations or cows with less than six test-day records during lactation were deleted from the data file. Herds not practicing two milking daily or those with less than 5 cows per herd in calving year were eliminated. The SCC was transformed to somatic cell score (SCS) using the formula (Shook, 1982):

$$SCS = \log2(SCC/100000) + 3$$

Finally, the data set included 202 283, 199 511, 189 698, 189 707, 188 533, 189 372, 163 508 and 177 528 test-day records belonging to 27 108, 27 057, 26 878, 26 878, 26 874, 26 878, 26 569 and 26 811 lactations for milk yield, fat, protein, lactose, TS, SNF, MUN and SCS, respectively of 11912 cows raised in 193 herds. The data for milk yield included 45.9%, 31.7% and 22.4% records from parities 1, 2 and 3, respectively.

Statistical analyses

The incomplete gamma function of Wood (1967) was used to fit lactation curve for milk yield and milk constituents and to estimate their parameters (Wood, 1976; Silvestre *et al.* 2009). The Wood's mathematical model was as follows:

$$y_t = at^b \exp^{-ct}$$

Where:

y_t: milk yield, milk constituent content, MUN or SCS at time t of lactation.

a, b and c: estimated parameters of the function.

t: test-day.

exp: exponential term.

A two-step procedure was applied to estimate parameters a, b and c of studied trait curves. In the first step, Wood's function was transformed logarithmically into a linear form (Tekerli *et al.* 2000) as: $\ln(y_t) = \ln(a) + b\ln(t) - ct$ and parameters a, b and c (intercept and curve shape) were estimated on the whole data set by multiple linear regression using PROC REG (SAS, 2002). Several authors (Wood, 1976; Macciotta *et al.* 2005; Silvestre *et al.* 2009) reported that depending on signs of parameters b and c, model of Wood can fit curves with four various shapes, parameter a is always positive. On the basis of parameters obtained for each individual's curve, curves were discarded following the most frequent results of Golebiewski *et al.* (2011); for milk yield, lactose content and MUN, eliminated curves were those with $b \leq 0$ or $c \leq 0$, whereas for fat, protein, TS, SNF and SCS, discarded curves were those with $b \geq 0$ or $c \geq 0$. On the basis of this approach, the frequency of eliminated curves was 36.1, 40.6, 42.7, 53.3, 42.2, 46.0, 57.6 and 56.8% for milk yield, fat, protein, lactose, TS, SNF, MUN and SCS, respectively. Thus, the final analyses were carried out on 17 315, 16 080, 15 398, 12 559, 15 522, 14 514, 11 260 and 11 588 lactations, respectively.

In the second step, the Wood's function parameters were estimated for the remaining curves only by the non-linear regression using PROC NLIN and Marquardt iterative method (SAS, 2002). Starting values of the iteration process in non-linear regression were Wood's parameters obtained in the first step. The main curve's characteristics, which are the time at peak (maximum or minimum point) (t_m), peak production (y_m) and persistency (s), were calculated using parameter combinations (a, b, and c) of the Wood's model as follows:

$$t_m = b / c$$
$$y_m = a (b/c)^b \exp^{-b}$$
$$s = -(b+1)\ln(c)$$

Higher value of this measure is favorable.

RESULTS AND DISCUSSION

Descriptive statistics of the studied traits are listed in Table 1. The test-day averages milk yield, fat, protein, lactose, TS and SNF contents, as well as MUN concentration and SCS were 24.4 ± 7.87 kg/day, 3.57 ± 0.78%, 3.04 ± 0.35%, 4.88 ± 0.26%, 12.2 ± 1.02%, 8.73 ± 0.39%, 15.8 ± 7.12 mg/dL and 4.37 ± 1.84 units (corresponding to 258 471±44 751 cells/mL), respectively.

These values are in general within the ranges reported in the literature; 22.0-29.6 kg/day for milk yield, 3.51-4.48% for fat content, 3.01-3.41% for protein content, 4.55-4.94% for lactose content, 12.26-13.76% for TS content, 8.86% for SNF content, 11.00-25.10 mg/dL for MUN concentration and 2.88-4.42 for SCS (Tyler, 1958; Rajala-Schultz and Saville, 2003; Wood *et al.* 2003; Miglior *et al.* 2006; Bastin *et al.* 2009; Cao *et al.* 2010; Golebiewski *et al.* 2011; Bertocchi *et al.* 2014; Henao-Velasquez *et al.* 2014; Zhang *et al.* 2018). Dissimilarities may be due to differences in the genetic backgrounds or to herd management, especially feeds and sources of feeding. Further, the lowest coefficients of variation were those of SNF and lactose contents and the highest were those of MUN concentration and SCS (Table 1). Moreover, coefficient of variation for protein percentage was much lower than those for milk yield and fat content.

Table 1 Numbers of test-day records, arithmetic means, standard deviations and coefficients of variation for milk yield, fat, protein, lactose, total solids (TS), solids not fat (SNF) contents, milk urea nitrogen (MUN) concentration and somatic cell score somatic cell score (SCS) of Holstein cows

Trait	Number	Arithmetic mean	Standard deviation	Coefficient of variation (%)
Milk yield (kg/d)	202 283	24.4	7.87	32.3
Fat (%)	199 511	3.57	0.78	21.8
Protein (%)	189 698	3.04	0.35	11.5
Lactose (%)	189 797	4.88	0.26	5.32
TS (%)	188 533	12.2	1.02	8.35
SNF (%)	189 372	8.73	0.39	4.46
MUN (mg/dL)	163 508	15.8	7.12	45.1
SCS	177 528	4.37	1.84	42.1

The analyses of complete dataset (before elimination) showed that curves for milk yield and contents of fat, protein, lactose, TS and SNF, as well as MUN concentration and SCS were distributed according to C1 (standard), C2 (continuously increasing), C3 (continuously decreasing) and C4 (reversed standard) shapes (Wood, 1976; Macciotta *et al.* 2005). Standard lactation curve (C1) was the most common shape for milk yield (63.9%), lactose content (46.7%) and MUN concentration (42.4%), while reversed standard (C4) was the most frequent shape for fat, protein, TS and SNF contents (59.4, 57.3, 57.8 and 54.0, respectively) and for SCS (43.2%) (Table 2).

For any trait, C1 and C4 shapes were the most frequent, whilst the remaining two shapes (C2 and C3) appeared very rarely. The most common shapes; standard lactation curve shape (C1) for milk yield and the reversed standard shape (C4) for fat and protein contents were in agreement with previous works (Schutz *et al.* 1990; Stanton *et al.* 1992; Silvestre *et al.* 2009; Golebiewski *et al.* 2011). C1 curves represented 76.6, 58.5 and 66.3% for milk yield, lactose content and MUN concentration, respectively, while 68.9, 65.7 and 49.6% of fat content, protein content and SCS, respectively curves showed C4 shape in Polish Holstein-Friesian and Montbéliard cows (Golebiewski *et al.* 2011). The standard lactation curve (C1) was the most common shape for milk yield (75.4%), followed by C3 shape, whereas curves for fat and protein percentage showed the reversed standard shape (C4) in 62.4 and 66.4% of the lactations, respectively, followed by C1 shape (23.7 and 19.4%, respectively) (Silvestre *et al.* 2009). Depending on the trait, the atypical curves were those of cows with problems due to management issues, incorrect data or lack of information.

Rekik and Ben Gara (2004) reported that the appearance of atypical curves is mainly due to physiological and health problems related to difficult environmental conditions, as well as frequent changes in the quantity and quality of the ration. Torshizi (2016) mentioned that other factors leading to atypical lactation curves are inadequate distribution of measurements due to time of sampling, missing measurements for lactation curve phases and few numbers of measurements for estimation of model parameters.

Estimated parameters of Wood's model (a, b and c) for milk yield, fat, protein, lactose, TS, SNF contents, as well as MUN concentration and SCS curves for Holstein dairy cows are shown in Table 3. The initial lactation value (a=16.0) for milk yield was lower than those reported by Quinn *et al.* (2005) in Ireland (25.20), Boujenane and Hilal (2012) in Morocco (17.0) and Rekik and Ben Gara (2004) in Tunisia (16.57), but it was higher than the value indicated by Chegini *et al.* (2015) in Iran (15.08). The values for b and c (0.1822 and 0.0030, respectively) were within reports of several authors (Tekerli *et al.* 2000; Rekik and Ben Gara, 2004; Macciotta *et al.* 2005; Dematawewa *et al.* 2007; Golebiewski *et al.* 2011; Boujenane and Hilal, 2012; Chegini *et al.* 2015; Khalifa *et al.* 2018). Differences observed in a, b and c values might be attributed to differences in genetic groups, herd management, environmental conditions or their combinations. Ural and Koskan (2014) reported that the lactation curve for more milk production requested a high value of a and b parameters and low value of c parameter. Parameters of Wood's function (a, b and c) for lactose content curve were 4.41, 0.0316 and 0.0003, respectively. Golebiewski *et al.* (2011) determined values of 4.90, 0.03 and 0.01, respectively for the Polish Holstein-Friesian breed. Estimates of lactation curve parameters (a, b and c) for MUN concentration curve were 7.30, 0.2300 and 0.0020, respectively. Values of 22.08, 0.39 and 0.08, respectively were estimated by Golebiewski *et al.* (2011) who concluded that MUN curve is not precisely explained by Wood’s model.

Estimated Wood’s model parameters (a, b and c) were 6.70, -0.2000 and -0.0020, respectively for fat content curve and 4.34, -0.1381 and -0.0020, respectively for protein content.

Silvestre *et al.* (2009) studied different lactation combinations of lactation curves and reported for combinations 1, 2 and 3 of fat % and protein % values of parameter a varying from 7.29 to 11.51 and from 5.20 to 6.02, respectively, parameter b values from -0.358 to -0.220 and from -0.211 to -0.161, respectively and parameter c values from -0.0041 to -0.0030 and from -0.0027 to -0.0024, respectively.

Table 2 Relative frequencies of individual curve shapes classified according to the four shapes detected by the Wood model for the different traits*

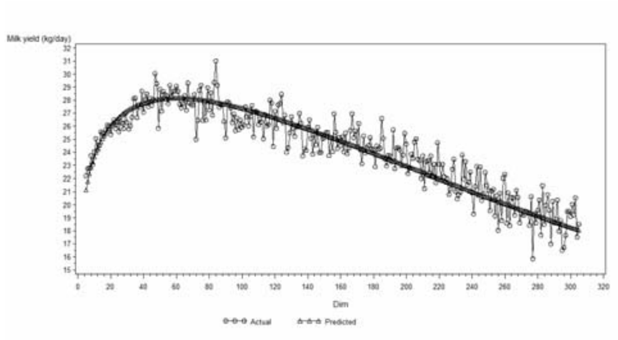
Shape	Trait[2]							SCS
	Milk yield	Fat	Protein	Lactose	TS	SNF	MUN	
C1	**63.9**	20.4	21.3	**46.7**	20.5	22.7	**42.4**	33.4
C2	9.76	15.1	18.2	15.6	17.2	18.9	15.9	16.9
C3	12.4	5.08	3.35	8.56	4.55	4.41	7.70	6.43
C4	13.9	**59.4**	**57.3**	29.1	**57.8**	**54.0**	34.0	**43.2**
Total	27 108	27 057	26 678	26 878	26 874	26 878	26 569	26 811

* Highest frequency for each trait is in bold.
C1: standard curve; C2: continuously increasing; C3: continuously decreasing curve and C4: reversed standard.
TS: total solids; SNF: solids not fat; MUN: milk urea nitrogen and SCS: somatic cell score.

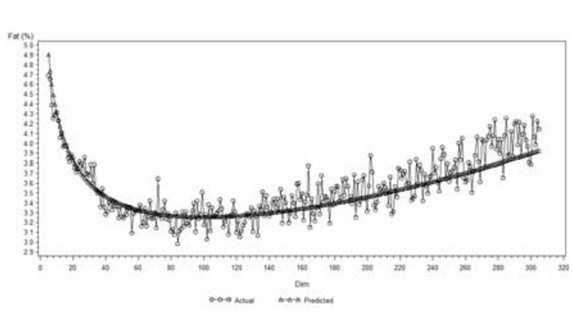
Quinn *et al.* (2006) estimated parameters a, b and c for fat content 4.72, 0.13 and -0.01, respectively and for protein content 3.55, 0.05 and -0.01, respectively. Estimates of lactation curve parameters (a, b and c) were 4.59, -0.19 and -0.04, respectively for fat content and 3.05, -0.07 and -0.04, respectively for protein content (Golebiewski *et al.* 2011). Values of parameter a of Wood's model for TS and SNF content curves were assessed 15.5 and 9.69, respectively, the b parameter values were calculated -0.0829 and -0.0409, respectively and the c parameter values were estimated -0.0010 and -0.0006, respectively. Parameters (a, b and c) of Wood's model for SCS were estimated to 7.70, -0.1900 and -0.0020, respectively. Golebiewski *et al.* (2011) determined parameters for SCC of 471 040 cells/mL, -0.05 and -0.06, respectively. They also mentioned that since SCC is affected by many factors (mainly environmental), SCC curves were very unstable and difficult to predict by any mathematical model. Parameter estimates of Wood's model for SCS curves for the first-, second- and third-parity dairy cows varied from 3.3 to 4.0 for a, from 0.15 to -0.05 for b and -0.002 for c (Ghavi Hossein-Zadeh, 2014). Studying several milk traits, Golebiewski *et al.* (2011) concluded that a different mathematical model should be used for each analyzed trait within a breed since a single mathematical model, even if effective for particular traits, showed various accuracies for others even within one breed.

The daily milk yield followed the standard lactation curve (Figure 1). It increased from calving to peak production of 28.2 kg/day that occurred 61 days from parturition and then decreased regularly to dry off with a persistency of 6.87 (Table 3). This tendency, that milk yield increases as the lactation period progresses, has been confirmed by various researchers (Boujenane and Hilal, 2012; Ghavi Hossein-Zadeh, 2014). The peak milk yield assessed in this study was low compared to those by Olori *et al.* (1999) (32.3 kg), Tekerli *et al.* (2000) (29.2 kg), Chegini *et al.* (2015) (34.5 kg) and Torshizi (2016) (33.1 kg), but high compared to previous works on Holstein cows [Boujenane and Hilal, (2012), (23.6 kg); Khalifa *et al.* (2018), (23.2 kg)].

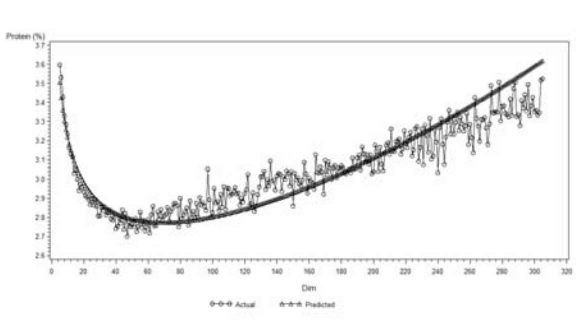
The time at the peak after calving (61 days) was lower than that reported by Chegini *et al.* (2015), Torshizi (2016) and Khalifa *et al.* (2018) (91.6, 76 and 84.9 days, respectively), and higher than those found by Stanton *et al.* (1992) (45 days), Tekerli *et al.* (2000) (48.8 days) and Boujenane and Hilal (2012) (41.4 days). The persistency of lactation found in the present study (6.87) was higher than those observed for Holstein cattle (Tekerli *et al.* (2000), 6.70; Boujenane and Hilal, (2012), 6.56), but lower than those reported by Chegini *et al.* (2015) (7.71) and Khalifa *et al.* (2018) (7.35). The lactose and MUN showed shapes similar to the standard curve for milk yield (Figure 1). They increased just after calving, reached peak yield of 4.95% and 17.3 mg/dL, respectively at lactation days 105 and 115 post calving, respectively and declined gradually with a persistency higher for lactose (8.37) than for MUN (7.64). From calving to time of peak, milk yield, lactose content and MUN concentration increased by 76.2, 12.2 and 137%, respectively. Miglior *et al.* (2006) observed a similar shape for lactose percentage; an increase after calving, a peak in the first 30 to 60 DIM and a constant decrease over the rest of the lactation. However, Henao-Velásquez *et al.* (2014) reported that the lactose curve exhibited a progressive decline as DIM advanced, with a maximum value at the beginning. Our results are in agreement with those of Cao *et al.* (2010) and Zhang *et al.* (2018) who reported that the MUN increased after calving, reached the highest at 90-120 DIM and then slowly decreased throughout the remaining lactation period. Spicer *et al.* (2000), cited by Wood *et al.* (2003), indicated that MUN increased during the first three weeks of lactation, then remained steady for the remainder of the lactation. Henao-Velásquez *et al.* (2014) reported that the average MUN in the first 115 DIM increased from 14.1 to 17.75 mg/dL, then decreased to 17.40 mg/dL on 195 DIM and increased to 18.50 mg/dL until 300 DIM. However, Wood *et al.* (2003) reported that the lactation curves for MUN were slightly high at the start of lactation, attaining to a nadir in early lactation (day 30 to 40), and then rising steadily to maximum values at the end of the lactation.



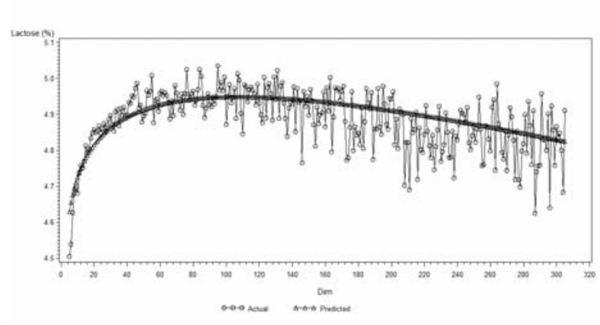
Milk yield



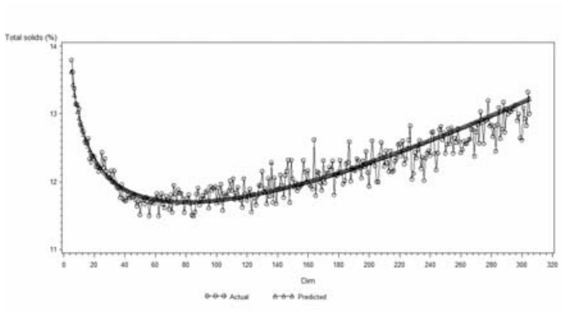
Fat



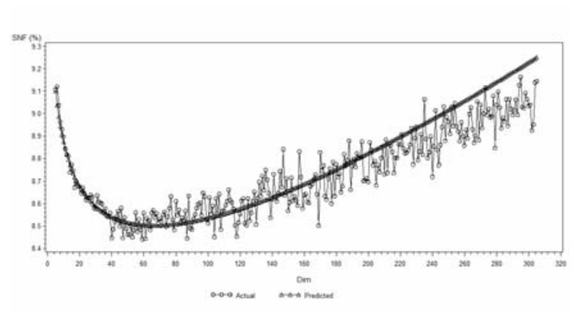
Protein



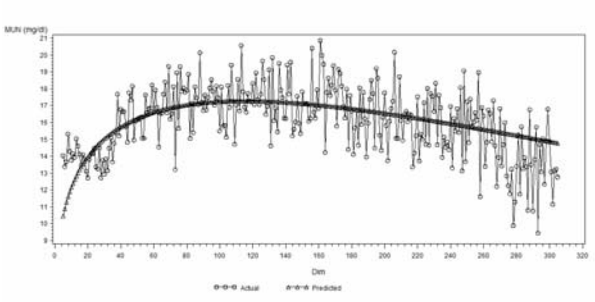
Lactose



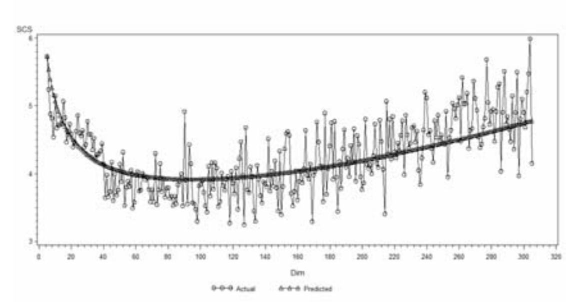
TS



SNF



MUN



SCS

Figure 1 The actual and predicted lactation curves fitted from Wood function for milk yield fat protein, lactose, total solids (TS), solids not fat (SNF), milk urea nitrogen (MUN) and somatic cell score (SCS) of Moroccan Holstein cows

Table 3 Estimated parameters of Wood's model (a, b and c) for milk yield, fat, protein, lactose, total solids (TS), solids not fat (SNF), milk urea nitrogen (MUN) and somatic cell score (SCS) curves

Trait	a	b	c	t_m (days)[1]	y_m[1]	s[1]
Milk yield	16.0	0.1822	0.0030	61	28.2 kg/day	6.87
Fat	6.70	-0.2000	-0.0020	100	3.26%	-
Protein	4.34	-0.1381	-0.0020	69	2.78%	-
Lactose	4.41	0.0316	0.0003	105	4.95%	8.37
TS	15.5	-0.0829	-0.0010	83	11.7%	-
SNF	9.69	-0.0409	-0.0006	68	8.16%	-
MUN	7.30	0.2300	0.0020	115	17.3 mg/dL	7.64
SCS	7.70	-0.1900	-0.0020	95	3.92	-

t_m: day at peak; y_m: peak production and s: persistency.

Zhang *et al.* (2018) explained the low concentration of MUN at the first month of lactation by the inability of cows to ingest sufficient feed in the early lactation period, which leads to relatively lower dry matter and protein intake, whereas Wood *et al.* (2003) argued that as milk production decreases throughout lactation, less protein is needed from the diet, thus greater proportions of urea in blood and milk were released. In any case, the feed management is an important source of variability in MUN. However, other researchers (Miglior *et al.* 2006; Bastin *et al.* 2009) reported that average lactation curve of MUN concentration was similar to lactation curves of percentages of fat and protein; it declined after calving and increased gradually at the end of the lactation. This trend might be due to the physiological changes and the evolution of the metabolic demands of milk production across lactation (Wood *et al.* 2003).

Fat, protein, TS and SNF percentages as well as SCS exhibited reversed standard curves opposite to the classical lactation shape for milk yield. They decreased at the beginning of lactation until a minimum point, and then increased progressively over the rest of lactation (Figure 1). Estimated minimum for fat, protein, TS, SNF percentages and SCS was attained at lactation days 100, 69, 83, 68 and 95, respectively with values 3.26%, 2.78%, 11.7%, 8.16% and 3.92, respectively.

From calving to minimum points, fat, protein, TS, SNF and SCS decreased by 105, 56.1, 32.5, 18.7 and 96.4%, respectively. Observed lactation patterns for fat content, protein content and SCS, i.e. a decrease from day 5 until minimum values sometime after that, and then an increase until day 305 post calving has been reported by several authors (Silvestre *et al.* 2009; Golebiewski *et al.* 2011; Jamrozik and Schaeffer, 2012; Ghavi Hossein-Zadeh, 2014).

Schutz *et al.* (1990) also indicated that curves for fat and protein contents were characterized by an early decline to a trough near 50 days' post calving followed by a stable increase to end of lactation, while that for SCS decreased to nadir before 90 days and increased during the remainder of lactation.

Moreover, they reported that for Holsteins, fat percentage declined faster than protein percentage through the first 20 DIM, which is in agreement with our finding. Points of minimum for fat and protein contents estimated in this study (3.26 and 2.78%, respectively) were lower than scores reported by Silvestre *et al.* (2009) (3.6 and 3.1%, respectively). Troughs for protein and fat percentages (days 69 and 100, respectively) were reached later compared to those of Silvestre *et al.* (2009) (days 65 and 70, respectively). With regard to SNF percentage, our results are in conformity with those of Waite *et al.* (1956) who observed a similar trend; it fell during the first seven weeks until a minimum point and then rose during the remainder of the lactation, slowly at first and then more rapidly as the end of lactation approached.

The peak occurrence for milk yield was earlier and that for MUN was later compared with those (points of maximum and minimum) for other studied traits. Moreover, the trough for protein content coincided with peak milk yield, while that for fat percentage corresponded to peak for lactose content but both of them were found to lag approximately 40 days behind the peaks for milk yield and lactose content. Several authors (Schutz *et al.* 1990; Stanton *et al.* 1992; Quinn *et al.* 2006) reported that the trough for fat percentage lags approximately three weeks behind the peak for milk yield, while that for protein content coincided with peak milk yield. Furthermore, Cardak (2016) found that milk fat content was found to reach the highest value in cases where the MUN was < 15 mg/dl, with the fat content decreasing in proportion to the increase in the MUN, indicating a negative correlation between MUN and fat content. Moreover, Henao-Velásquez *et al.* (2014) reported that the average MUN increased when lactose increased and vis-versa.

CONCLUSION

The main objective of this study was the determination of lactation curve parameters from test-day milk yield and components by Wood's model. Milk yield, lactose and

MUN followed the standard lactation curve, whereas fat, protein, TS, SNF and SCS exhibited reversed standard curves opposite to the classical lactation shape for milk yield. The peak occurrence for milk yield was earlier and that for MUN was later compared with those (points of maximum and minimum) for other studied traits. Moreover, the trough for protein content coincided with peak milk yield, while that for fat percentage corresponded to peak for lactose but both of them were found to lag approximately 40 days behind the peaks for milk yield and protein content. It was concluded that the knowledge of lactation curves for studied traits will help to improve herd management and to increase production.

ACKNOWLEDGEMENT

The authors thank the Coopérative Souss d'Amélioration Génétique Bovine, Taroudant, Morocco (COPAG) for providing the analyzed data.

REFERENCES

Ali T.E. and Schaeffer L.R. (1987). Accounting for covariance among test day milk yields in dairy cows. *Can. J. Anim. Sci.* **67,** 637-644.

Bastin C., Laloux L., Gillon A., Miglior F., Soyeurt H., Hammami H., Bertozzi C. and Gengler N. (2009). Modeling milk urea of Walloon dairy cows in management perspectives. *J. Dairy Sci.* **92,** 3529-3540.

Bertocchi L., Vitali A., Lacetera N., Nardone A., Varisco G. and Bernabucci U. (2014). Seasonal variations in the composition of Holstein cow's milk and temperature–humidity index relationship. *Animal*. **8(4),** 667-674.

Boujenane I. (2013). Comparison of different lactation curve models to describe lactation curve in Moroccan Holstein‐Friesian dairy cows. *Iranian J. Appl. Anim. Sci.* **3(4),** 817-822.

Boujenane I. and Hilal B. (2012). Genetic and non genetic effects for lactation curve traits in Holstein-Friesian cows. *Arch. Tierz.* **55(5),** 450-457.

Cao Z., Huang W., Wang T., Wang Y., Wen W., Ma M. and Li S. (2010). Effects of parity, days in milk, milk production and milk components on milk urea nitrogen in Chinese Holstein. *J. Anim. Vet. Adv.* **9(4),** 688-695.

Cardak A.D. (2016). Effects of somatic cell count, parity and lactation stage on yield and components of milk in Holstein-Friesian cows. *Harran Üniv. Vet. Fak. Derg*. **5(1),** 34-39.

Chegini A., Shadparvar A.A. and Ghavi Hossein‐Zadeh N. (2015). Genetic parameter estimates for lactation curve parameters, milk yield, age at first calving, calving interval and somatic cell count in Holstein cows. *Iranian J. Appl. Anim. Sci.* **5(1),** 61-67.

Dematawewa C.M.B., Pearson R.E. and VanRaden P.M. (2007). Modeling extended lactations of Holsteins. *J. Dairy Sci.* **90,** 3924-3936.

Garcia S.C. and Holmes C.W. (2001). Lactation curves of autumn- and spring calved cows in pasture-based dairy systems. *Livest. Prod. Sci.* **68,** 189-203.

Ghavi Hossein-Zadeh N. (2014). Comparison of non-linear models to describe the lactation curves of milk yield and composition in Iranian Holsteins. *J. Agric. Sci.* **152,** 309-324.

Ghavi Hossein-Zadeh N., Darmani Kuhi H., France J. and López S. (2020). Introducing a sinusoidal equation to describe lactation curves for cumulative milk yield and composition in Holstein cows. *J. Dairy Res.* **87(2),** 220-225.

Golebiewski M., Brzozowski P. and Golebiewski L. (2011). Analysis of lactation curves, milk constituents, somatic cell count and urea in milk of cows by the mathematical model of Wood. *Acta Vet. Brno* **80,** 73-80.

Henao-Velasquez A.F., Munera-Bedoya O.D., Herrera A.C., Agudelo-Trujillo J.H. and Ceron-Munoz M.F. (2014). Lactose and milk urea nitrogen: Fluctuations during lactation in Holstein cows. *Rev. Bras. Zootecn*. **43(9),** 479-484.

Jamrozik J. and Schaeffer L.R. (2012). Test-day somatic cell score, fat to-protein ratio and milk yield as indicator traits for subclinical mastitis in dairy cattle. *J. Anim. Breed. Genet.* **129(1),** 11-19.

Khalifa M., Hamrouni A. and Djemali M. (2018). The estimation of lactation curve parameters according to season of calving in Holstein cows under North Africa environmental conditions: The case of Tunisia. *J. New Sci.* **50(5),** 3048-3053.

Kopec T., Chladek G., Kucera J., Falta D., Hanus O. and Roubal P. (2013). The effect of the calving season on the Wood's model parameters and characteristics of the lactation curve in Czech Fleckvieh cows. *Arch. Tierz.* **56(80),** 808-815.

Legates J.E. (1960). Genetic and environmental factors affecting the solids-not-fat composition of milk. *J. Dairy Sci.* **43(10),** 1527-1532.

Macciotta N.P.P., Vicario D. and Cappio-Borlino A. (2005). Detection of different shapes of lactation curve for milk yield in dairy cattle by empirical mathematical models. *J. Dairy Sci.* **88,** 1178-1191.

Miglior F., Sewalem A., Jamrozik J., Lefebvre D.M. and Moore R.K. (2006). Analysis of milk urea nitrogen and lactose and their effect on longevity in Canadian dairy cattle. *J. Dairy Sci.* **89,** 4886-4894.

Naderi Y. (2018). Appropriate mathematical models to describe the lactation curves of milk production traits of Iranian Holstein dairy cattle. *Acta Sci. Anim. Sci.* **40,** e37895.

Naeemipour Younesi H., Shariati M.M., Zerehdaran S., Jabbari Nooghabi M. and Løvendahl P. (2019). Using quantile regression for fitting lactation curve in dairy cows. *J. Dairy Res.* **86(1),** 19-24.

Olori V.E., Brotherstone S., Hill W.G. and McGuirk B.J. (1997). Effect of gestation stage on milk yield and composition in Holstein-Friesian dairy cattle. *Livest. Prod. Sci.* **52,** 167-176.

Olori V.E., Brotherstone S., Hill W.G. and McGuirk B.J. (1999). Fit of standard models of the lactation curve to weekly records of milk production of cows in a single herd. *Livest. Prod. Sci.* **58,** 55-63.

Pollot G.E. (2004). Deconstructing milk yield and composition during lactation using biologically based lactation models. *J. Dairy Sci.* **87,** 2375-2387.

Quinn N., Killen L. and Buckley F. (2006). Modelling fat and protein concentration curves for Irish dairy cows. *Irish J. Agric. Food Res.* **45,** 13-23.

Rajala-Schultz P.J. and Saville W.J.A. (2003). Sources of variation in milk urea nitrogen in Ohio dairy herds. *J. Dairy Sci.* **86,** 1653-1661.

Rekik B. and Ben Gara A. (2004). Factors affecting the occurrence of atypical lactations for Holstein-Friesian cows. *Livest. Prod. Sci.* **87,** 245-250.

Rodriguez-Zas S.L., Gianola D. and Shook G.E. (2000). Evaluation of models for somatic cell score lactation patterns in Holsteins. *Livest. Prod. Sci.* **67,** 19-30.

SAS Institute. (2002). SAS®/STAT Software, Release 9.1. SAS Institute, Inc., Cary, NC. USA.

Schutz M.M., Hansen L.B. and Steuernagel G.R. (1990). Variation of milk, fat, protein and somatic cells for dairy cattle. *J. Dairy Sci.* **73,** 484-493.

Shook G.E. (1982). Approaches to summarizing somatic cell counts which improve interpretability. Pp. 150-166 in Proc. Natl. Mastitis Council., Arlington, Virginia.

Silvestre A.M., Martins A.M., Santos V.A., Ginja M.M. and Colaco J.A. (2009). Lactation curves for milk, fat and protein in dairy cows: a full approach. *Livest. Sci.* **122,** 308-313.

Spicer L.J., Francisco C.C., Jones D. and Waldner D.N. (2000). Changes in milk urea nitrogen during early lactation in Holstein cows. *Anim. Sci. Res. Rep*. **2000,** 169-171.

Stanton T.L., Jones L.R., Everett R.W. and Kachman S.D. (1992). Estimating milk, fat and protein lactation curves with a test day model. *J. Dairy Sci.* **75,** 1691-1700.

Swalve H.H. (2000). Theoretical basis and computational methods for different test-day genetic evaluation methods. *J. Dairy Sci.* **83(5),** 1115-1124.

Tekerli M., Akinci Z., Dogan I. and 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.

Torshizi M.E. (2016). Effects of season and age at first calving on genetic and phenotypic characteristics of lactation curve parameters in Holstein cows. *J. Anim. Sci. Technol.* **58,** 8-18.

Tyler W.J. (1958). Genetic aspects of solids-not-fat and its components. *J. Dairy Sci.* **41,** 447-449.

Ural D.A. and Koskan O. (2014). The estimation of lactation curve parameters from testday milk yield in Holstein-Friesian cows in Bozdogan province in Turkey. *Res. J. Agric. Environ. Manage.* **3(2),** 145-150.

Waite R., Wrote J.C.D. and Robertson A. (1956). Variations in the chemical composition of milk with particular reference to the solids-not-fat. I. The effect of stage of lactation, season of year, and age of cow. *J. Dairy Res.* **23,** 65-76.

Wilmink J.B.M. (1987). Adjustment of test day milk, fat and protein yield for age, season and stage of lactation. *Livest. Prod. Sci.* **16,** 335-348.

Wood G.M., Boettcher P.J., Jamrozik J., Jansen G.B. and Kelton D.F. (2003). Estimation of genetic parameters for concentrations of milk urea nitrogen. *J. Dairy Sci.* **86,** 2462-2469.

Wood P.D.P. (1967). Algebraic model of the lactation curve in cattle. *Nature*. **216,** 164-165.

Wood P.D.P. (1976). Algebraic models of the lactation curves for milk, fat and protein production, with estimates of seasonal variation. *Anim. Prod.* **22,** 35-40.

Zhang H., Wang M., Jiang H., Cui Y., Xia H., Ni W., Li M., Karrow N.A., Yang Z. and Mao Y. (2018). Factors affecting the milk urea nitrogen concentration in Chinese Holstein cows. *Anim. Biol.* **68,** 193-211.