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Comparisons of different models for lactation curves of fat to protein ratio and somatic cell score of Holstein cows in Iran

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Abstract A total of 989,582 test-day records of 160,243 first-parity cows collected from 131 herds of Iranian Holstein dairy cows from 1995 to 2014 by the Animal Breeding and Improvement Centre of Iran, were used to determine the best model for lactation curves of fat to protein ratio (FPR) and somatic cell scores (SCS) in the first lactation. Several mathematical models including the Wood (WD), Wilmink (WL), Rook (RK), Dijkstra (DJ), Narushin-Takma (NT) and Ali and Schaeffer (AS) functions were fitted and compared by four comparison measures; adjusted coefficient of determination (R^2_{adj}), residual standard deviation (RSD), Akaike's information criterion (AIC) and Durbin-Watson statistic (DW). The NT function was the best model for describing the lactation curves of FPR and SCS in terms of higher R^2_{adj} and lower RSD and AIC. The calculated values of DW for FPR and SCS under NT function were 1.99 and 1.86, respectively; implying that the existence of positive autocorrelation between residuals was not important for these traits. The Pearson's correlation coefficients between the actual and predicted records of SCS and FPR values were 0.98 and 0.99 ($P < 0.01$), respectively by fitting NT function.

Keywords: non-linear models, goodness of fit, milk constituents, Holsteins

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Introduction

Selection for milk production traits has traditionally been received more emphasis in breeding programs and selection indexes of dairy cows (Oltenacu and Broom, 2010). Dairy farm husbandry including the health, feeding and breeding practices affects daily milk production and its constituents. Therefore, by applying accurate tools such as mathematical models when determining changes in milk production, the degree of the impact of the influencing factors may better identified (Ehrlich, 2011). Making appropriate management and breeding decisions requires accurate models for describing the lactation curves (Cobuci and Costa, 2012). Graphical representation of the dairy cow's milk production and its constituents against time throughout the lactation period is called the lactation curve (Sherchand et al., 1995). For example, arrangement of feeding programs might be managed according to the shape of the lactation curve (Kocak and Ekiz, 2008), while the ascending part of the curve suggests that a higher plane of nutrition should be supplied to cows; the descending part is suggestive of a lower plane of nutrition (Sherchand et al., 1995; Tekerli et al., 2000).

At the beginning of the lactation period cows with severe energy deficiency are metabolically more stressed and show greater occurrence of diseases such as mastitis (Jamrozik and Schaeffer, 2012). Measurement of milk components can be easily achieved at routine milk performance testing without any extra costs (Nishiura et al., 2015). Fat to protein ratio (FPR) is considered an appropriate indicator trait as a measure of energy balance (Buttchereit et al., 2010; Nishiura et al., 2015) and a risk factor for many diseases, including mastitis (Heuer et al., 1999).

Windig et al. (2005) documented that both increased and decreased FPR led to the increased risk of mastitis; cows with short and intensive peaks of somatic cell scores (SCS) related to infections with environmental pathogens showed an increase in FPR, whereas infections caused by contagious pathogens resulted in decreased FPR. Jamrozik and Schaeffer (2012) pointed out that patterns of changes in FPR and SCS during lactation can potentially be applied to detect mastitis in dairy cows. They also showed that FPR may be a potential and easily measurable trait to differentiate between cows that can or cannot adapt to the energy related challenge of early lactation.

Namjo et al. (2016) evaluated the effects of several environmental factors such as lactation stage, production season, age at first calving, somatic cell count in milk yield, province and calving year on the occurrence of negative energy balance in Iranian dairy cows and concluded that all considered factors, except age of cow at first calving, had significant effects on the occurrence of negative energy balance. They considered fat to protein ratio as a measure of energy balance. In a previous study, Pakdel et al. (2010) fitted six non-linear models including the Wood, Wilmink, Ali and Schaeffer, Rook, Nedler and Morant for describing the somatic cell score curves in the first four lactations of Iranian Holstein cows. Ghavi Hossein-Zadeh (2016) compared seven mathematical models including Brody, Wood, Dhanoa, Sikka, Nelder, Rook and Dijkstra for describing the lactation curves for fat to protein ratio in the first three lactation periods of Iranian Holstein cows and determined Dijkstra function as the best fitted model during the first three lactations.

Patterns of changes in test day FPR and SCS throughout the lactation period can be used to identify the dairy cows with mastitis (Jamrozik and Schaeffer, 2012). In the present study, test-day records on both FPR and SCS of the same individuals were considered. Therefore, the objective of the present study was to compare six mathematical models fitted on FPR and SCS lactation curves in first-parity Iranian Holsteins and to determine the most appropriate model for describing phenotypic changes of these traits in the lactation period.

Materials and methods

Data and editing protocol

Data included 989,582 test-day records of 160,243 cows collected from 131 herds of Iranian Holstein dairy cows during 1995 to 2014 by the Animal Breeding and Improvement Centre of Iran**.** Age of cows at first calving was restricted to be ranged from 20 to 38 months. Test-day records were limited to cows for which the first milk recording had been measured between 5 days in milk (DIM) and 60 DIM, consecutive sampling intervals of 25-35 days and lactation length was not greater than 305 days**.** Test-day somatic cell counts (SCC) were transformed into SCS applying Box-Cox transformation as the following, achieving a normal distribution:

$$SCS = \frac{SCC^{\lambda}-1}{\lambda} \tag{1}$$

in which, $\boldsymbol{\lambda}$ was determined as -0.237 applying R software (R Development Core Team, 2016).

Fitting lactation curves

Data were analyzed using NLIN procedure and Newton-Gauss iterative method applying SAS software (SAS, 2004). The considered mathematical models were shown in Table 1, which included the Wood function (Wood, 1967), Wilmink function (Wilmink, 1987), Rook function (Rook et al., 1993), Dijkstra function (Dijkstra et al., 1997), Narushin-Takma function (Narushin and Takma, 2003) and Ali and Schaeffer (Ali and Schaeffer, 1987).

Comparison criteria

For comparing the fitted models four criteria were used including adjusted coefficient of determination (R^2_{adj}), residual standard deviation (RSD), Akaike's information

Table 1. Models used to describe fat to protein ratio and somatic cell score curves of Iranian Holsteins

Model[1]	Formula[2]	No. of parameters
WD	$y_t = a\, b\, e^{-ct}$	3
WL	$y_t = a + bt + ce^{-0.5t}$	3
RK	$y_t = a\,(1 - b_1\, e^{-\mathbf{b_2 t}})e^{-ct}$	4
NT	$y_t = \left(a\, t^3 + b\, t^2 + ct + d\right)/(t+f)$	5
DJ	$y_t = a\, e(b(1 - e^{-ct})/\, c - dt)$	4
AS	$y_t = a + b\left(\frac{t}{305}\right) + c\left(\frac{t}{305}\right)^2 + d\ln\left(\frac{305}{t}\right) + k\left(\ln\left(\frac{305}{t}\right)\right)^2$	5

[1]WD: Wood function, WL: Wilmink function, RK: Rook function, NT: Narushin-Takma function, DJ: Dijkstra function, AS: Ali and Schaeffer

[2]y_t: Fat to protein ratio and / or somatic cell score at time t; t: time of measurement; a, b, c, d, t and f are parameters that define the scale and shape of the curve in the model; e: Napierian figure which is equal to 2.71 with 2 decimals; ln: Napierian logarithm

criterion (AIC) and Durbin-Watson statistic (DW).

The first criterion, adjusted coefficient of determination or adjusted square of correlation coefficient between the actual and predicted values of FPR and/or SCS was computed as:

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

The model with the highest adjusted R^2 is the most appropriate model among the tested models.

The second criterion, residual standard deviation was computed as follows:

$$RSD=\frac{\sqrt{SS_e}}{\sqrt{n-p}} \quad (3)$$

The model with the lowest RSD is the most appropriate model among the tested models. The third criterion was Akaike's information criterion and was computed as follows:

$$AIC=n\log\left(\frac{SSe}{n}\right)+2p \quad (4)$$

The model with the lowest AIC is the most appropriate model among the tested models.

In the above mentioned comparison criteria, *n* is the number of observations, *p* is the number of model parameters and SS_e is the residual sum of squares.

The fourth criterion for comparing the tested models was Durbin-Watson statistic which was calculated using the following formula (Durbin, 1970):

$$\mathrm{DW}=\frac{\sum_{i=2}^{n}(e_t-e_{t-1})^2}{\sum_{t=1}^{n}e_t^{\,2}} \quad (5)$$

where e_t is the residual at time *t*, and e_{t-1} is the residual at time t-1. The presence of autocorrelation in the residuals from the regression analysis may be assessed applying DW. Such autocorrelation implies that the function may be inappropriate for fitting on the data. The Durbin-Watson statistic ranges from 0 to 4. A value near 2 denotes a non-autocorrelation, a value toward 0 denotes a positive autocorrelation and a value toward 4 denotes a negative autocorrelation.

Results and discussion

The results of model fitting for FPR under the tested models applying the considered comparison criteria are presented in Table 2. Among the tested models, NT showed better fitting in terms of the highest R^2_{adj} and the lowest RSD and AIC. The values of DW varied from 0.069 (RK) to 1.990 (NT) across the considered models; implying positive autocorrelation between residuals under the tested models expect for NT.

The observed and predicted FPR curves based on NT function are presented in Figure 1. A statistically significant Pearson's correlation coefficient of 0.99 was observed between the actual and predicted milk FPR values (P <0.01). In the present study, a polynomial regression with R^2 equal to 0.86 was fitted properly for FPR curve. The maximum value for FPR was 1.17 on 5 DIM; FPR values gradually decreased afterwards until 170 DIM which reached its minimum value (1.03). From 170 DIM, milk FPR slightly increased and reached a value of 1.05 at 305 DIM. Jamrozik and Schaeffer (2012) pointed out that FPR in first-parity cows peaked soon after parturition. Nishiura et al. (2015) reported that FPR values increased in the first few days of the lactation and reached to its peak on days 10 to 20 of the lactation period in Japanese Holstein dairy cows and decreased afterwards until 120 DIM.

Negussie et al. (2013) reported that the phenotypic value of FPR increased from 1.32 at 8 DIM to 1.42 at 40 DIM in the first lactation of Nordic Red cattle, then decreased and stabilized at the approximately value of 1.3 from 100 to 200 DIM but it increased afterwards slightly. In early lactation, the peak of milk FPR could be ascribed to the negative energy balance and in conse-

Table 2. Model comparisons for milk fat to protein ratio in Iranian Holsteins

Model*	Comparison measures**			
	R^2_{adj}	RSD	AIC	DW
WD	0.894	0.012	-369.254	0.674
WL	0.837	0.014	-343.096	0.355
RK	0.315	0.030	-255.565	0.069
NT	**0.982**	**0.005**	**-477.780**	**1.990**
DJ	0.182	0.033	-244.736	0.267
AS	0.689	0.020	-303.654	0.474

*WD: Wood function, WL: Wilmink function, RK: Rook function, NT: Narushin-Takma function, DJ: Dijkstra function, AS: Ali and Schaeffer

**R^2_{adj}: Adjusted coefficient of determination, RSD: Residual standard deviation, AIC: Akaike's information criterion, DW: Durbin-Watson statistic.

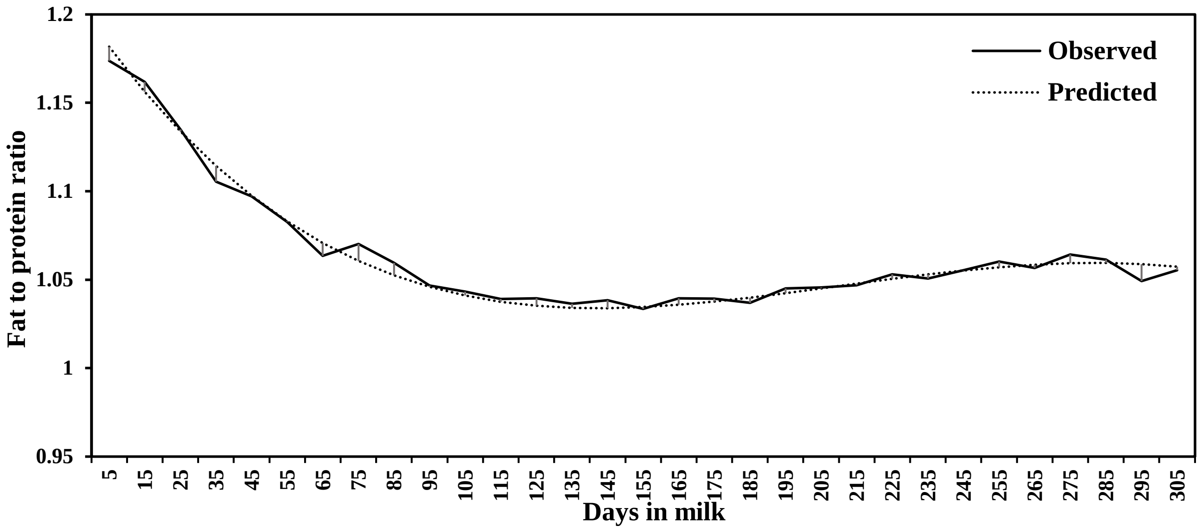

Figure 1. Observed and predicted milk fat to protein ratio curves in Iranian Holsteins

quence tissue mobilization associated with stresses of calving and peak milk production (Buttchereit et al. 2010, Toni et al. 2011, Jamrozik and Schaeffer 2012). Negussie et al. (2013) pointed out that increasing trend of milk FPR after reaching the minimum value could be explained by increased energy requirements of pregnant cows to support milk production and fetal growth. A little increase in milk FPR toward the end of the lactation period in German Holstein cows has been reported by Buttchereit et al. (2010).

Energy deficiency leads to increased lipolysis and uptake of fatty acids mobilized from body fat. Therefore, the synthesis of fat in the udder is increased (Buttchereit et al., 2010). Simultaneously, insufficient intake of fermentable, energy-spending carbohydrates can result in inadequate synthesis of protein by ruminal bacteria and the flow of amino acids to the udder is compromised and milk protein content reduces (Buttchereit et al., 2010), consequently FPR would be increased. A value of FPR which is higher than 1.5 denotes abnormally high lipolysis and may be a suitable index of diseases such as mastitis in dairy cows (Heuer et al., 1999). Greater values of FPR are associated with decrease in dry matter intake and increase in fat mobilization over negative energy balance phase after calving (Eicher, 2004). Milk FPR may be considered as a practical criterion to differentiate between cows that can or cannot prevail the metabolically challenges associated with early lactation (Jamrozik and Schaeffer, 2012). Similar behavior to that of observed in the present study for milk FPR changes over the lactation period was documented in the previous studies (Buttchereit et al. 2010, Jamrozik and Schaeffer, 2012). For modeling milk FPR in German Holsteins, five lactation curve models including Ali and Schaeffer, Guo and Swalve, Wilmink, Legendre polynomials of third and fourth degree were fitted for milk FPR by Buttchereit et al. (2010). They reported that function of Ali and Schaeffer described changes of milk FPR more appropriately than the other considered functions.

The results of model fitting for SCS in the present study under the tested models, applying the considered comparison criteria are presented in Table 3. Among the tested models, NT showed better fitting in terms of the

Table 3. Model comparisons for somatic cell score in Iranian Holsteins

Model*	Comparison measure**			
	R^2_{adj}	RSD	AIC	DW
WD	0.939	0.012	-367.953	1.090
WL	0.949	0.011	-378.540	1.424
RK	0.595	0.030	-252.553	0.558
NT	**0.962**	**0.009**	**-397.537**	**1. 863**
DJ	0.255	0.041	-215.332	1.035
AS	0.939	0.012	-367.953	0.986

*WD: Wood function, WL: Wilmink function, RK: Rook function, NT: Narushin-Takma function, DJ: Dijkstra function, AS: Ali and Schaeffer

**R^2_{adj}: Adjusted coefficient of determination, RSD: Residual standard deviation, AIC: Akaike's information criterion, DW: Durbin-Watson statistic.

highest R^2_{adj} and the lowest RSD and AIC relative to the other considered models. The values of DW varied from 0.558 (under RK model) to 1.863 (under NT model) across the models. These values indicated positive autocorrelation between residuals with the highest for RK and the lowest for NT function. Pakdel et al (2010) fitted six non-linear models including the Wood, Wilmink, Ali and Schaeffer, Rook, Nedler and Morant for describing the changes of somatic cell scores in Iranian Holstein cows and concluded that Ali and Schaeffer model fitted more appropriately than the other considered models.

Observed and predicted SCS curves based on NT function are presented in Figure 2. In the present study, a statistically significant Pearson's correlation coefficient of 0.98 was observed between the actual and predicted SCS values (P <0.01). A polynomial regression with R^2 equal to 0.55 was fitted properly. The value of SCS was 2.77 on 5 DIM and gradually decreased afterwards until 55 DIM of the lactation period at which it reached its minimum value (2.53). From 55 DIM, SCS gradually increased and reached a value of 2.66 at 305 DIM. Data on health traits of dairy cows are not routinely recorded in dairy herds of Iran. Philipsson et al. (1995) pointed out that somatic cell count may be considered as a selection criterion for mastitis resistance in dairy cattle. Therefore, indirect selection against mastitis considers mainly somatic cell scores (SCS) as an appropriate correlated trait (Jamrozik and Schaeffer, 2012).

Pattern of changes in somatic cell count values during the lactation period is opposite to that of milk yield. Somatic cell count value is in maximum value at the beginning of the lactation period and gradually decreases until approximately 50-70 days of lactation (reaches the minimum value) afterwards it increases toward the end of lactation period (Rodriguez-Zas et al., 2000). In the present study, lactation curve for FPR (Figure 1) was generally of a similar shape to lactation curve of SCS (Figure 2), maximum values in milk attained on days in milk immediately after calving, decreased towards the peak of lactation and steadily but slow increased toward the end of period. Such observed pattern was in agreement with the one observed by Jamrozik and Schaeffer (2012) in first-lactation Canadian Holstein cows.

Conclusion

Different mathematical models were investigated for determining the best fitted model for FPR and SCS changes during first lactation of Iranian Holsteins. Narushin and Takma (NT) model provided the best fit for the lactation curves of FPR and SCS in first lactations of Iranian Holstein cows. The appropriate mathematical modeling for describing lactation curves of FPR and SCS could provide the possibility of selection on the level of the lactation curve for individual animals and is a pre-requisite to develop an optimal strategy to obtain a desired shape of lactation curve through modifying the parameters of models.

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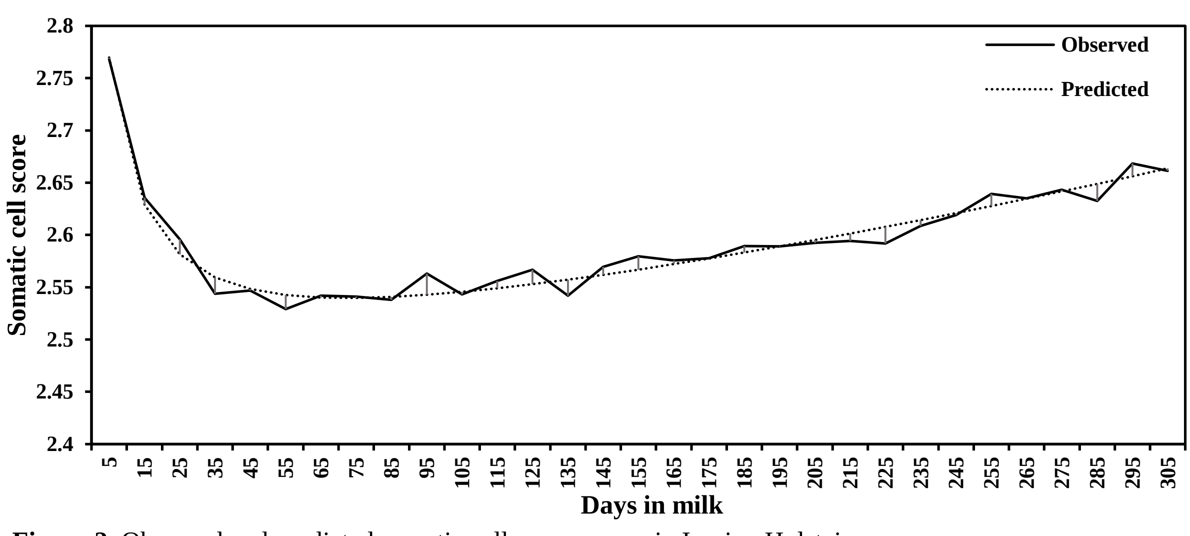

Figure 2. Observed and predicted somatic cell score curves in Iranian Holsteins

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مقایسه مدل‌های مختلف منحنی نسبت چربی به پروتئین و نمره سلول‌های سوماتیک شیر در گاوهای هلشتاین ایران

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چکیده در پژوهش کنونی از ۹۸۹۵۸۲ رکورد روز آزمون مربوط به ۱۶۰۲۴۳ گاو هلشتاین استفاده شدکه در طی سال‌های ۱۳۸۴ تا ۱۳۹۳ توسط مرکز اصلاح نژاد و بهبود تولیدات دامی ایران در ۱۳۱ گله تحت پوشش جمع آوری شدند. هدف از این پژوهش تعیین مدل مناسب منحنی نسبت چربی به پروتئین و نمره سلول‌های سوماتیک بود. مدل‌های ریاضی وود، ویلمینک، روک، دایجکسترا ، نارشین– تاکما و علی و شفر با استفاده از چهار معیار ضریب تعیین تصحیح شده، انحراف معیار باقی مانده، معیار اطلاع آکائیک و آماره دوربین – واتسون مقایسه شدند. نتایج به دست آمده نشان دادند که از بین توابع مقایسه شده، تابع نارشین– تاکما برای توصیف منحنی های نسبت چربی به پروتئین و نمره سلول‌های سوماتیک در نخستین شیردهی گاوهای هلشتاین ایران به دلیل بیشتر بودن ضریب تعیین تصحیح شده و کمتر بودن انحراف معیار باقی مانده و معیار اطلاع آکائیک مناسبترین بود. مقادیر به دست آمده آماره دوربین – واتسون برای نسبت چربی به پروتئین و نمره سلول‌های سوماتیک تحت تابع نارشین – تاکما به ترتیب ۱/۹۹ و ۱/۸۶ بودند که نشان می دهد خود همبستگی مثبت بین باقی مانده ها برای این دو صفت مهم نیست. ضرائب همبستگی پیرسون بین مقادیر مشاهده شده و پیش بینی شده نسبت چربی به پروتئین و نمره سلول‌های سوماتیک تحت تابع نارشین – تاکما به ترتیب به ترتیب ۰/۹۹ و ۰/۹۸ به دست آمدند.