Study of non-genetic factors on the shape of lactation curves for milk yield, fat and protein percents of Holstein-Friesian cows under hot Mediterranean climate

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SUMMARY

This investigation was done to study the effect of non-genetic factors on the lactation curve of Holstein-Friesian cows reared under hot Mediterranean climate. The shape of the lactation curve of 5649 Tunisian Holstein-Friesian cows were estimated by fitting the Wilmink model to 259,776 test-day records for milk traits. Analyses were conducted for six groups edited according to the calving age of cows associated with their parity, three herd groups were formed according to the level of average milk yield from calving years and four seasons were also used. All sources of variation were significant, except the calving age-parity was not significant (P>0.05) for b and c both for fat and protein percents. The herd-calving year effect was independent of persistency for all milk traits and not significant for b (fat percent) and for b and c (protein percent). The calving season was not significant for fat persistency. Peak and lactation yield were the highest for cows calving at 4-5 years (77% in the third parity). Peak fat and protein percentage occurred at the beginning or/and at the end of lactation. Cows in different herd-calving year groups presented almost the same persistency for all Milk traits but recorded different yields at 305-days of lactation. The lactation curve of cows with the lowest initial level and a rapid decrease to the nadir point (the minimum point) presented a very high inflection especially around the nadir point resulting in an almost linear increase of the fat or protein percent to the end of lactation. This shape resulted to produce the lowest 305-day fat and protein yields. The highest peak and lactation milk yields were reached by cows that calved in winter and fall. Cows calved in the summer and spring presented a different shape of lactation curve but produced almost the same 305-day milk yield. In summer,

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cows showed an atypical shape of the lactation curve for fat percent. The highest correlation was found between a, and peak yield or nadir level.

Keywords: calving age-parity, Holstein-Friesian, lactation curve, peak yield, test day, Wilmink model

INTRODUCTION

The shape of the lactation curve of milk and its composition in dairy cattle is affected by a large number of environmental factors, such as herd, calving year, parity, age at calving, month of calving, days in milk and calving season (e.g. Wilmink, 1978, Tekerli et al., 2000, Atashi et al., 2009). Yet, only calving season and year are environmental factors strictly speaking, the others being characteristics of the recorded animal. Some of them are related to physiological aspects, such age parity and pregnancy effects, others, such as length of dry period and age at calving, are more linked with management practices (Leclerc et al., 2008). In the lactation curve studies, calving age is usually used as a variation factor than the age of animal. Moreover, age at calving has two advantages over age at TD (test day) in that age at calving needs to be calculated only once per lactation and has been reported to explain more of the variation in TD yield than has age at TD (Stanton el al. 1992). The parity was reported to be a significant source of variation and lactation curves are usually developed using the average test day data on milk yield within parity groups (1^{st}, 2^{nd} and ≥ 3^{rd}) and the third group always includes animal with the third and later lactation without considering the effect of calving age. This consideration may be limited some practical usefulness of the lactation curve, especially in management and feed practice. For the example illustrated (Figure 1) with the data used in the current study, cows with the same parity didn’t always get the same shape of the lactation curve at different calving age. Schutz et al. (1990) reported that milk, fat and protein yields for Holstein differ according to the age at calving for the same parity and Holsteins in 2^{nd} parity had highest yield calving at 37 to 40 months. However, Fitting lactation curves with cows’ group according to physiological stage (such as parity, calving age or their interaction) present an interest to help farmer in order to optimize animal performances. Proposed calving age within parity effects are intended to consider the difference in calving age effect from year to year.

The herd effect can be thought of as an effect that considers management practices and other environmental conditions that are possible to vary from herd to herd. Chauhan (1987) found that the herd effect accounted for about 30% of the total variance in milk and fat yield. The interaction herd-calving year makes it possible to take account of the difference related to the system in control of breeding and in particular to the food. The season at calving has also a significant effect on the shape of the lactation curve (Tekerli et al., 2000). Seasons are usually formed by grouping months with similar production means together, and cows are assigned to a particular season due to their calving date. Therefore, cows have to be grouped according to the shape of lactation curve when employing test-day models (Ptak and Scheffer, 1993) for the genetic evaluation and management purpose. Some advantages of test day-models include the ability to model the trajectory of the lactation for individual genotypes or groups of animals (Jensen, 2000) and the shape of the lactation curve to be fitted with subsequently more precise.

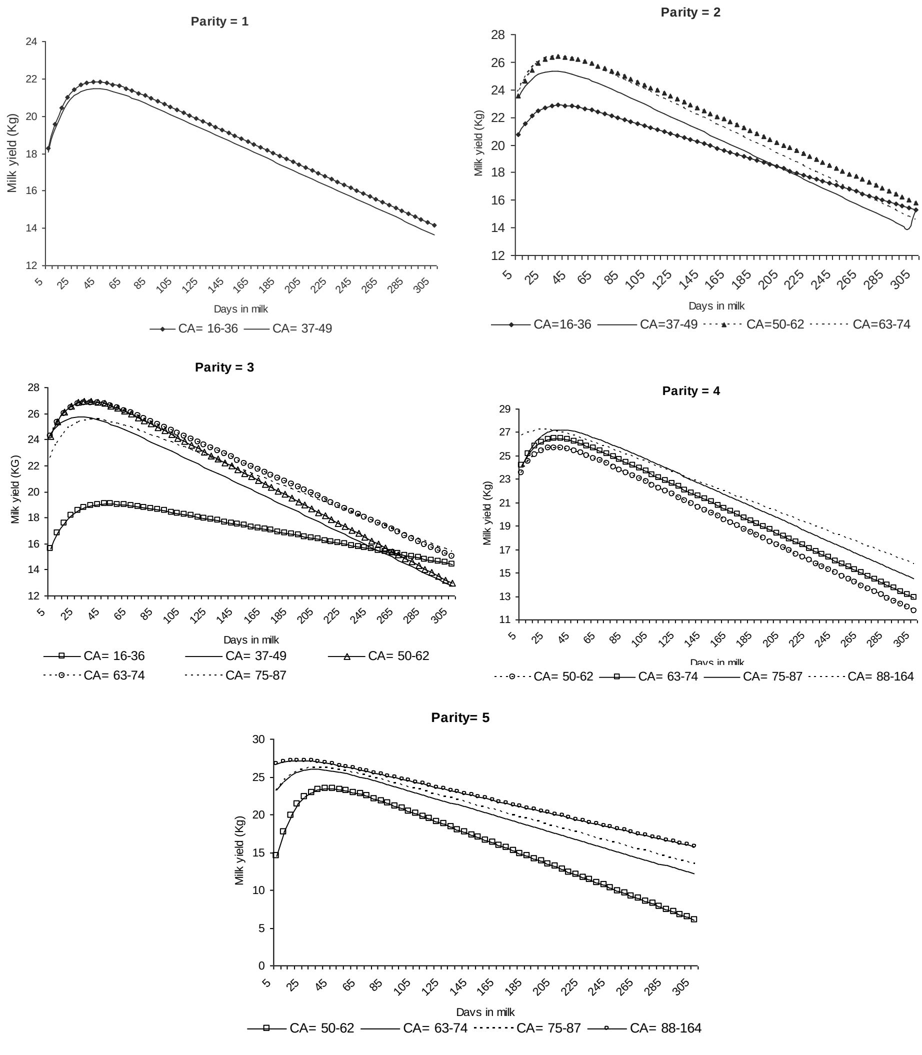


Figure 1. Examples of lactation curve for milk yield fitted for calving age classes by parity

Different mathematical models have been evaluated for their ability to describe lactation patterns of milk yield. Non-linear parametric models have represented the preferred tools for fitting average curves of homogeneous groups of animals (Macciotta et al., 2011). The Wilmink model (WIL) (Wilmink, 1987) is one among several models reported in the literature to describe the lactation curve of dairy cows. In this form, it is considered the best three parameters of lactation curve for milk yield (Olori et al., 1999) and for fat and protein concentration (Quinn et al., 2006). Thus, WIL model was used in some studies detecting the effect of environmental factors on the shape of the lactation curve (Macciotta et al., 2005, Roshanfekr et al., 2010). This model is specifically conceived to model the lactation curve and WIL parameters can also be easily related to the characteristics of the lactation curve shape (Macciotta et al., 2005). Although most research of lactation curves has been for milk yield, several investigators have looked at constituent traits. Silvestre et al. (2009) studied lactation curve shape of different milk production traits.

Tunisia has a Mediterranean climate characterized by high ambient temperatures for a long period. Thus, one of the challenges to dairy producers is heat stress. Summer heat stress prevails in Tunisia for four to five months going from May to September. Milk yield per cow was dropped by about 10% between March and August (Ben Salem and Bouraoui, 2009).

The main objective of the present investigation was to analyse some environmental factors that affect the shape of lactation curves and yield traits for milk, fat and protein percents of Tunisian Holstein-Friesian cows.

MATERIAL AND METHODS

The study was conducted by using 259,776 monthly test-day records of 5649 Holstein-Friesian cows obtained from the National Centre for Genetic Improvement of Tunisia (CNAG: Sidi Thabet, Tunis). The data concerned 188 herds during the years 1994 to 2002. Data were firstly edited to eliminate duplicate records. Lactation records with less than 10 consecutive test-days were eliminated and biologically unacceptable fat or protein yields and a very low milk yield (< 3 Kg) were omitted. The WIL model (Wilmink, 1987) was used to fit individual lactation curves for milk, fat and protein percents ($Y_t = a + b\ e^{-kt} + ct$).Where *a*, is a coefficient represents yield at the beginning of lactation; *b* and *c* are the coefficients that define shape of the curve before and after peak. Curves were fitted using the Levenberg-Marquardt's iterative method via the NLIN procedure of SAS [SAS, 2001]. The parameter K is connected to the time of the peak lactation and usually assumes as a fixed value derived from a preliminary analysis made on average production (Wilmink, 1987). In the present study, the estimated value of K parameter was 0.65 for milk yield (similar value was obtained by Silvestre et al., 2006) and 0.10 for fat and protein percents (is the same one proposed by Quinn et al., 2006). The peak yield (Peak) and the time when this maximum is observed (DIMP) were calculated as follows: $DIMP = 1/k \log(c/kb)$ and $Peak = a + c/k\,(1 + \log(bk/c))$

Persistency for milk, fat and protein percents was calculated by the report of the one month production has that of the previous month. Goodness of fit was assessed by the coefficient of determination (1- the ratio of the residual sum of squares to the total sum of squares) and the residual (RES), defined as the absolute values of the difference between the predicted and real yields. In addition to the evaluation of the goodness of fit, individual curves in each environmental effect group were grouped according to the different combinations of parameter signs in order to detect the frequencies of atypical lactation curves. It is recognized that Wilmink's model can fit curves for milk yield with four different shapes (Macciotta et al., 2005). Knowing that parameter *a* is always positive, the first type (b<0 and c<0) represents the standard form of the lactation curve, the second with the combination b>0 and c<0 expresses the continuously decreasing curve called (atypical curve), the third type is defines as reversed standard (b and c were positive) and the fourth type illustrate the continuously increasing (b<0 and c>0).Whereas, fat and protein percents have reversed standard shape. In this investigation, the atypical curve for FP and PP were detected when b<0 and c>0.

In order to fit and study factors which affect the shape of individual lactation curve of milk traits, the data were grouped according to some environmental factors which have a possible relation between them. Indeed, six calving age-parity groups included in the analysis were edited according to calving age of cows in associate with their parity.

Table 1 summarized the description of the data used in this work and the definition of calving age-parity groups presented with the average milk yield (MY), fat percent (FP) and protein percent (PP).

Three herd production groups were defined as the level of average milk yields from calving years. And four Season groups were defined as three month intervals, winter (December to February), spring (Mars to May), summer (June to August), and fall (September to November). The effects of these factors and the first test-day date on MY, FP and PP and lactation curves traits were analysed by a general linear model:

$$Y_{ijkn} = \mu + CAP_i + HCY_j + CS_k + \beta\ JC_{ijkn} + e_{ijkn}$$

Where: Y_{ijkn} is a lactation curve trait on MY, or FP or PP based on observation *n* in calving age-parity groups (CAP_i); i=1,2,3,4,5,6, belonging to group of herd-calving year (HCY_j); j=1,2,3 and has calving season (CS_k) ;

k=1,2,3,4, μ = overall mean; β = regression coefficient, JC = is the effect of DIM at first test day includes in the model as a co-variable and e= random residual with an expected value of zero and a variance of σ_e^2 .

Table 1. Means and standard deviation for milk yield, fat percentage and protein percentage by groups of age at calving associated with parity (CAP)

Groups	N	Calving age	Parity	[a] P (%)	Mean		
					Milk (Kg)	Fat (%)	Protein (%)
CAP1	78,459	16-36	1	97.09	18.61 (6.62)	3.40 (0.86)	3.06 (0.41)
	2,298		2	2.84	18.36 (6.83)	3.46 (0.91)	3.18 (0.41)
	52		3	0.06	16.95 (5.05)	3.27 (0.77)	3.18 (0.41)
CAP2	3,728	37-49	1	6.27	18.17 (6.83)	3.40 (0.86)	3.07 (0.4)
	52,456		2	88.24	20.43 (7.62)	3.46 (0.90)	3.16 (0.41)
	3,264		3	5.49	20.20 (7.93)	3.51 (0.93)	3.15 (0.44)
CAP3	216	50-62	1	0.49	19.06 (7.29)	3.71 (0.83)	3.19 (0.41)
	6,518		2	14.74	21.04 (8.24)	3.45 (0.89)	3.13 (0.43)
	33,942		3	76.76	21.07 (8.04)	3.50 (0.90)	3.13 (0.41)
	3,531		4	7.99	19.88 (7.79)	3.47 (0.95)	3.13 (0.41)
	9		5	0.02	17.08 (8.71)	3.37 (0.67)	2.63 (0.28)
CAP4	252	63-74	2	0.89	21.53 (8.71)	3.51 (0.93)	3.19 (0.40)
	6,062		3	21.31	21.20 (8.34)	3.47 (0.93)	3.12 (0.41)
	19,841		4	69.73	20.48 (7.98)	3.47 (0.89)	3.13 (0.41)
	2,268		5	7.97	19.81 (7.70)	3.46 (0.89)	3.16 (0.41)
	29		6	0.10	27.16 (7.04)	2.75 (0.78)	3.08 (0.44)
CAP5	398	75-87	3	1.80	20.29 (7.77)	3.55 (0.96)	3.16 (0.38)
	5,242		4	23.77	21.58 (8.51)	3.45 (0.92)	3.10 (0.41)
	14,493		5	65.72	20.23 (7.82)	3.48 (0.86)	3.11 (0.40)
	1,911		6	8.67	19.65 (7.76)	3.48 (0.89)	3.11 (0.42)
	9		7	0.04	27.04 (6.43)	3.11 (1.12)	2.68 (0.33)
CAP6	302	88-164	4	1.22	22.25 (8.30)	3.34 (0.78)	3.04 (0.39)
	3,704		5	14.99	21.50 (8.53)	3.46 (0.88)	3.11 (0.40)
	10,745		6	43.49	20.04 (7.97)	3.49 (0.87)	3.12 (0.41)
	6,376		7	25.81	19.36 (7.87)	3.48 (0.86)	3.10 (0.41)
	2,545		8	10.30	18.84 (7.40)	3.42 (0.87)	3.07 (0.41)
	781		9	3.16	18.01 (6.91)	3.46 (0.92)	3.09 (0.37)
	236		10	0.96	16.16 (6.26)	3.52 (0.92)	3.06 (0.33)
	19		11	0.08	15.05 (4.71)	3.47 (0.6)	3.26 (0.29)

() Standard deviation, [a] P= percentage following the parity and CAP= the calving age-parity groups.

RESULTS AND DISCUSSION

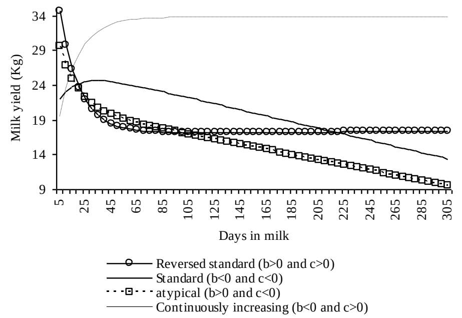
The Goodness of fit of the WIL model was satisfactory to fit individual lactation curves (table 2) assembled according to environmental effects. However, the coefficient of determination (R^2) ranged from 97 to 98% for MY; 97% for FP and 98% for PP. Thus, the WIL model was able to predict daily yield and its compositions within mean absolute error (RES) ranged from 1.68 to 2.34 Kg for MY; 0.37 to 0.41% for FP and from 0.16 to 0.17% for PP.

Table 2. Goodness of fit and relative frequencies (%) of atypical curves for Wilmink model according to various environmental factors

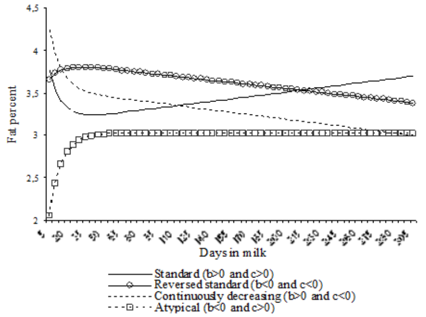
Effects	Milk yield			Fat percent			Protein percent		
	Goodness of fit			Goodness of fit			Goodness of fit		
	RES	R^2	%AC	RES	R^2	%AC	RES	R^2	%AC
CAP1	1.68 (1.64)	0.98 (0.01)	17.04	0.39 (0.4)	0.97 (0.02)	18.07	0.16 (0.17)	0.98 (0.007)	13.40
CAP2	1.80 (1.75)	0.98 (0.01)	18.64	0.41 (0.42)	0.97 (0.02)	18.80	0.17 (0.18)	0.98 (0.006)	14.04
CAP3	1.90 (1.86)	0.98 (0.01)	18.45	0.41 (0.41)	0.97 (0.02)	19.49	0.17 (0.18)	0.98 (0.006)	15.71
CAP4	1.86 (1.79)	0.98 (0.01)	18.68	0.40 (0.41)	0.97 (0.02)	20.38	0.16 (0.17)	0.98 (0.006)	16.53
CAP5	1.89 (1.81)	0.98 (0.01)	19.63	0.40 (0.40)	0.97 (0.02)	22.14	0.17 (0.18)	0.98 (0.006)	15.81
CAP6	2.34 (2.22)	0.97 (0.02)	20.60	0.40 (0.40)	0.97 (0.02)	21.54	0.16 (0.18)	0.98 (0.006)	16.87
HCY1	1.93 (1.82)	0.98 (0.01)	18.36	0.37 (0.43)	0.97 (0.02)	20.74	0.17 (0.21)	0.98 (0.009)	14.75
HCY2	2.14 (2.09)	0.97 (0.01)	18.29	0.39 (0.39)	0.97 (0.02)	20.12	0.16 (0.17)	0.98 (0.006)	14.54
HCY3	2.20 (2.16)	0.97 (0.02)	18.50	0.41 (0.41)	0.97 (0.02)	18.56	0.17 (0.17)	0.98 (0.006)	20.80
Winter	2.21 (2.12)	0.97 (0.01)	18.83	0.41 (0.41)	0.97 (0.02)	16.74	0.17 (0.18)	0.98 (0.006)	13.89
Spring	2.18 (2.07)	0.97 (0.01)	19.28	0.41 (0.41)	0.97 (0.02)	20.39	0.17 (0.18)	0.98 (0.007)	12.74
Summer	2.34 (2.24)	0.97 (0.02)	17.90	0.39 (0.41)	0.97 (0.02)	22.31	0.16 (0.18)	0.98 (0.006)	16.72
Fall	2.25 (2.15)	0.97 (0.02)	17.79	0.40 (0.40)	0.97 (0.02)	18.41	0.16 (0.17)	0.98 (0.006)	15.60

() Standard deviation, CAP= calving age parity, HCY= herd-calving year,
AC= atypical curve, RES= the residual and R^2= the coefficient of determination

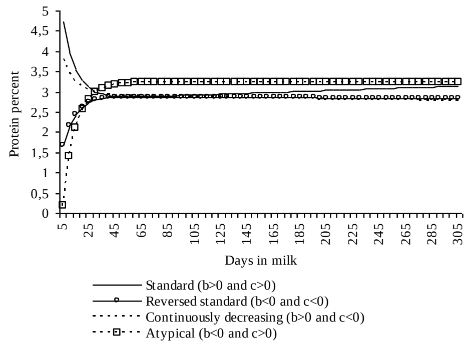
Several shapes of lactation curve were detected when data of milk traits were fitted and some of them consist of a slight modification of the standard curves. The shapes of the typical and atypical curves for all milk traits are illustrated in figure 2. Indeed The frequency of atypical curves ranged from 17.04% in the first calving age-parity group (CAP1) to 20.6% in CAP6 for MY. These frequencies are comparable to those reported by Soysal et al. (2005) and Cilek et al. (2009). For FP 18.07% of atypical curves were observed in CAP1 group and 22.31% in the summer season. And for PP this frequency ranged from 13.40% in CAP1 group to 20.80% in the third herd-calving year group. These proportions for FP and PP are equivalent to those indicated by Silvestre et al. (2009). The standard deviations of the mean absolute error were uniformly smaller for PP than FP; similar results were noted by Schutz et al. (1990). Thus, WIL predicted PP with a lower residual than FP in all environmental factors and the percent of atypical curves was the lowest for PP, in agreement with the report of Silvestre et al. (2009)



(a) Milk yield



(b)Fat percent



(c) Protein percent

Figure 2. Examples of shapes of fitted lactation curves by Wilmink model for milk yield (a), fat percent (b) and protein percent (c)

The ANOVA mean squares of calving age-parity (CAP), herd-calving year (HCY), calving season (CS) and DIM at first test-day (DIM1) on lactation curve traits are presented in table 3 and the least square means of level effects and the coefficient of regression on DIM1 are expressed by table 4 (for MY) and table 5 (for FP and PP).

The CAP effect was highly significant (P<0.01) for all lactation curve traits of MY. For FP and PP, this effect was not significant (P>0.05) for *b* and *c*, it was significant (P<0.05) for fat production peak and highly significant for other traits. The high significance of calving age parity is mainly explained by the effect of milk-secretory tissues that require more time for their peak activity in primiparous cows than in multiparous cows (Rao and Sundaresan, 1979) and consequently, this effect tends to cause both fat and protein to be decreased as the animal will become older. This significance of CAP can be also explained by the decrease in stress from milking through the increased lactations. Indeed, during the first lactation the animal encounters unfamiliar situations, including the atmosphere of the milking parlour; the presence of the dairy farmer; and the milking procedure. These factors trigger physiological reactions that interfere with milk production. Moreover, animals at higher lactations are more conditioned to milking and have higher digestive, respiratory and udder capacities (Glória et al., 2012).

Table 3. Mean squares of variable from the analysis of variance of lactation curve for MY, FP and PP

Trait	Variable	Lactation curve traits						
		a ($\times10^3$)	*b* ($\times10^3$)	*c*	[1]Peak or nadir ($\times10^3$)	DIMP ($\times10^3$)	Per ($\times10^3$)	Y_{305} ($\times10^6$)
MY	CAP	7.91**	13.78**	0.19**	4.22**	12.33**	4.81**	120.94**
	HCY	10.11**	13.89**	0.01**	5.30**	2.75**	1.47	538.93**
	CS	3.08**	26.41**	0.06**	1.02**	1.23*	4.83**	14.13*
	DIM1	1.38**	231.12**	0.04**	2.89**	505.70**	0.55	41.21**
FP	CAP	0.004**	1.49	0.00004	0.002*	1.34**	10.38**	0.21**
	HCY	0.031**	2.93	0.00038**	0.022**	3.53**	2.79	0.81**
	CS	0.085**	25.13**	0.0028**	0.040**	3.99**	2.01	0.01*
	DIM1	0.0005	10.22*	0.00008	0.079**	204.36**	0.01	0.005
PP	CAP	0.008*	2.98	0.00007	0.004**	18.52**	5.77**	0.16**
	HCY	0.025**	3.49	0.00006	0.008**	325.81**	0.15	0.59**
	CS	0.022**	8.65**	0.00062**	0.001**	38.74**	4*	0.024**
	DIM1	0.003	0.004	0.00005	0.004**	468.88**	0.17	0.003

* $P<0.05$ and ** $P<0.01$ DIMP= days in milk at peak production, Per= persistency, Y_{305} =Total milk or fat or protein yields in 305 DIM, DIM1=days in milk at first test day CAP= calving age parity, HCY= herd-calving year and CS= calving season, [1] peak for MY and nadir for FP and PP.

The effects of HCY were highly significant (P<0.01) for all lactation curve traits of milk yield except for persistency. Atashi et al. (2009) and Roshanfekr et al. (2010) noted a similar effect for Iranian Holstein dairy cattle for MY. However, this high significance can be explained by the difference in management between herds and also the diverse feeding level that changes according to the annual climate which frequently observed under the hot Mediterranean conditions. The parameter describing the ascending phase (*b*) of lactation curve and the persistency were not influenced by the HCY for FP and PP and the parameter *c*, primarily controls the rate of decline after peak production was also independent of HCY only for PP.

The effects of CS were highly significant for the lactation curve parameters describing the shape of the lactation curve (*a*, *b* and *c*) for all milk traits, not significant for persistency (FP), significant (P<0.05) for DIM1 (MY); Y_{305} (MY and FP) and persistency for PP and highly significant for the remaining lactation curve traits. The relationship between calving season and the lactation curve traits is explained by temperature and rain variations which affect fodder production, especially in summer under the Tunisian climate when feeding resources are limited and heat stress effect is important. Indeed, Bouraoui et al. (2002) reported that summer heat stress reduced milk yield and altered milk composition and affected the physiological functions of confined lactating Holstein cows managed under Mediterranean climatic conditions.

Table 4. Least squares means of grouped environmental effects included in the analysis and linear regression coefficient of individual lactation curves traits for milk yield.

Variable	N	Lactation curve traits						
		a	*B*	*c* ($\times10^{-2}$)	Peak	DIMP	Per	Y_{305}
Age-parity								
CAP1	80,809	24.81^{a} (0.21)	-7.73^{a} (1.46)	-3.32^{a} (0.0007)	23.65^{a} (0.21)	48.97^{a} (0.62)	94.36^{a} (0.81)	5899^{a} (44.89)
CAP2	59,448	27.86^{b} (0.22)	-2.74^{b} (1.35)	-4.59^{b} (0.0007)	26.45^{b} (0.23)	43.32^{b} (0.66)	92.58^{b} (0.83)	6315^{b} (46.52)
CAP3	44,216	29.35^{c} (0.22)	-5.11^{b} (1.40)	-5.32^{c} (0.0007)	27.48^{c} (0.23)	42.23^{bd} (0.68)	91.65^{bd} (0.86)	6395^{b} (48.05)
CAP4	28,452	28.70^{d} (0.24)	-1.30^{bc} (1.45)	-5.24^{cd} (0.0008)	26.91^{bd} (0.26)	43.27^{b} (0.75)	91.09^{bd} (0.93)	6297^{b} (51.95)
CAP5	22,608	28.82^{d} (0.25)	-4.19^{b} (1.57)	-5.44^{ce} (0.0008)	27.38^{cd} (0.26)	44.70^{be} (0.77)	90.67^{cd} (0.97)	6194^{c} (53.90)
CAP6	24,708	27.80^{b} (0.25)	-3.15^{b} (1.63)	-5.36^{c} (0.0008)	26.19^{be} (0.26)	44.89^{ce} (0.68)	91.62^{bd} (0.98)	5926^{a} (54.52)
Herd-calving year								
HCY1	55,484	26.14^{a} (0.17)	-2.44^{a} (1.10)	-4.67^{a} (0.0005)	24.70^{a} (0.17)	43.32^{a} (0.52)	91.57^{a} (0.65)	5753^{a} (36.47)
HCY2	82,920	28.28^{b} (0.14)	-3.79^{a} (0.95)	-4.90^{b} (0.0005)	26.86^{b} (0.15)	45.11^{b} (0.44)	91.89^{a} (0.56)	6287^{b} (31.39)
HCY3	121,837	29.26^{c} (0.14)	-5.88^{b} (1.20)	-5.07^{c} (0.0005)	27.47^{c} (0.16)	45.25^{b} (0.43)	92.64^{a} (0.51)	6473^{c} (30.52)
Calving season								
Winter	67,773	29.07^{a} (0.18)	-6.30^{a} (1.14)	-5.45^{a} (0.0006)	27.17^{a} (0.18)	44.10^{a} (0.52)	90.71^{a} (0.68)	6229^{a} (37.80)
Spring	54,319	27.43^{b} (0.19)	-0.009^{b} (1.25)	-4.81^{b} (0.0006)	25.89^{b} (0.20)	43.79^{a} (0.59)	91.94^{a} (0.74)	6124^{b} (41.38)
Summer	74,697	26^{c} (0.18)	-3.93^{c} (1.15)	-4.46^{c} (0.0006)	24.2^{c} (0.18)	45.03^{b} (0.53)	93.40^{b} (0.68)	6112^{b} (38.05)
Fall	63,452	28.03^{d} (0.17)	-5.92^{a} (1.12)	-4.81^{b} (0.0006)	26.50^{c} (0.18)	44.33^{b} (0.52)	91.92^{a} (0.69)	6220^{a} (36.01)

[a,b,c,d,e,f] Means of variable levels with different superscripts for each lactation curve trait are significantly different (P<0.05)

DIMP= days in milk at peak production, Per= persistency, Y_{305} =Total milk or fat or protein yields in 305 DIM, DIM1=days in milk at first test day CAP= calving age parity, and HCY= herd-calving year

() the standard error of mean

The level of peak yield for the first CAP cows (97% in their first parity and calved at 2-3 years) was the lowest and cows produced the lowest total yields (Y_{305}). Tekerli et al. (2000) observed reduced peak yields in primiparous cows. Highest peak production occurred in the third CAP group (calving age 4-5 years and 77% in the third parity), which also have the highest Y_{305}.

The highest peak and lactation milk yields were reached by cows that calved in winter and fall. Tekerli et al. (2000) reported similar results for Turkish Holstein cows. For the HCY effect, the highest peak yield occurred in HCY3 and the cows in this group recorded approximately 12% more than cows in HCY1.

The least squares means indicated that the day of peak milk yield was the earliest in the third CAP, in the first HCY and in spring. While, cows in the first CAP and in summer calving were observed to reach the day at peak yield in a longer period than others.

The rate of decline following peak trends to increase with the CAP of animals. Thus, the lactation curve of cows calved at 2 to 3 years (97% in their first parity) are characterized by the highest persistency. One explanation for the persistency of the first lactation cows is that they are undergoing a maturation process during their first lactation that counterbalances the normal decline in milk yield as the lactation progress (Stanton et al., 1992). The least square means of persistency estimates for FP and PP (table 5) presented the same general trend as MY which cows in CAP1 were more persistent.

Summer season is the most persistent for MY and PP. While for FP spring is the most persistent. Keown et al. (1986) reported that the months of freshening for the most persistent milk yield are July and August. Tekerli et al. (2000) indicated that persistency was higher for cows that calved during summer and fall. The high persistence of the summer season lactation can be explained by the fact that the declining phase of milk production of cows calving in summer (June to August) coincided with the rainy months (especially between the end of fall and at the beginning of winter) and reduction in the stress due to high temperature . Cows in different HCY groups present almost the same persistency for MY, FP and PP but recorded different yields at 305-days of lactation. For the majority of effects protein tends to be more persistent than fat, in agreement with Keown et al. (1986). This can be explained by the lower variation in PP than in FP and MY. This is supported by the results of the goodness of fit (Table 2).

The nadir point (Table 5) occurred between 7 to 9 weeks for FP and PP, and was earlier in lactation for FP than PP in the majority of cases. The level at the nadir point for primiparous cows (CAP1) was the lowest for FP and PP.

Table 5. Least squares means of grouped environmental effects included in the analysis and linear regression coefficient of individual lactation curves traits for fat and protein percentage.

Variable	N	Lactation curve traits *a*	*b*	*c* ($\times 10^{-3}$)	Nadir	DIMN	per	Y_{305}
Fat percentage								
Age-parity								
CAP1	80,809	3.09^{a} (0.027)	2.99^{a} (1.20)	2.01^{a} (0.0001)	3.15^{a} (0.27)	50.63^{a} (0.51)	96.88^{a} (1.24)	197^{a} (1.80)
CAP2	59,448	3.14^{b} (0.028)	1.83^{a} (1.25)	2.20^{a} (0.0001)	3.23^{b} (0.28)	52.08^{a} (0.53)	92.70^{b} (1.29)	215^{b} (1.86)
CAP3	44,216	3.25^{b} (0.029)	1.15^{a} (1.29)	2.12^{ab} (0.0001)	3.29^{b} (0.29)	51.79^{a} (0.55)	92.37^{b} (1.33)	220^{c} (1.92)
CAP4	28,452	3.26^{b} (0.032)	1.31^{a} (1.39)	1.80^{a} (0.0001)	3.27^{ab} (0.32)	53.36^{b} (0.59)	93.08^{b} (1.44)	215^{b} (2.08)
CAP5	22,608	3.28^{b}	1.27^{a} (1.44)	1.63^{ac} (0.0001)	3.30^{b} (0.33)	51.92^{b} (0.62)	92.09^{b} (1.49)	209^{d} (2.16)
CAP6	24,708	3.17^{b} (0.033)	1.19^{a} (1.42)	2.34^{a} (0.0001)	3.23^{ab} (0.35)	51^{b} (0.67)	92.01^{b} (1.48)	201^{e} (2.18)
Herd-calving year								
HCY1	55,484	3.07^{a} (0.022)	1.87^{a} (0.98)	2.53^{a} (0.0001)	3.13^{a} (0.41)	50.47^{a} (0.41)	92.26^{a} (1.01)	192^{a} (1.46)
HCY2	82,920	3.32^{b} (0.019)	2.20^{a} (0.84)	1.67^{b} (0.0001)	3.35^{b} (0.36)	52.66^{b} (0.36)	93.38^{a} (0.87)	217^{b} (1.25)
HCY3	121,837	3.21^{b} (0.017)	0.81^{a} (1.87)	1.85^{b} (0.0001)	3.26^{b} (0.33)	52.26^{b} (0.34)	93.92^{a} (1.02)	220^{b} (1.27)
Calving season								
Winter	67,773	3.10^{a} (0.023)	4.70^{a} (1.01)	2.12^{a} (0.0001)	3.16^{a} (0.42)	54.19^{a} (0.42)	92.23^{a} (1.04)	211^{a} (1.51)
Spring	54,319	3^{b} (0.025)	2.66^{a} (1.10)	3.12^{b} (0.0001)	3.09^{b} (0.47)	50.53^{b} (0.47)	94.10^{a} (1.14)	208^{b} (1.65)
Summer	74,697	3.25^{c} (0.023)	-1.03^{b} (1.02)	2.14^{a} (0.0001)	3.32^{c} (0.43)	50.02^{b} (0.43)	93.09^{a} (1.05)	208^{b} (1.52)
Fall	63,452	3.44^{d} (0.022)	0.18^{b} (1.03)	0.83^{c} (0.0001)	3.41^{d} (0.45)	52.44^{c} (0.45)	93.33^{a} (1.13)	212^{a} (1.52)
Protein percentage								
Age-parity								
CAP1	80,809	2.87^{a} (0.016)	1.53^{a} (1.11)	16^{a} (0.0008)	2.84^{a} (0.59)	53.40^{a} (0.016)	95.94^{a} (1.03)	180^{a} (1.69)
CAP2	59,448	3^{b} (0.016)	-0.007^{ac} (1.13)	12^{bc} (0.0008)	2.99^{b} (0.60)	53.62^{a} (0.016)	95.13^{a} (1.05)	198^{b} (1.73)
CAP3	44,216	2.95^{c} (0.017)	0.38^{a} (1.17)	16.6^{ad} (0.0008)	2.94^{c} (0.62)	52.87^{a} (0.017)	92.91^{b} (1.08)	198^{b} (1.77)
CAP4	28,452	2.93^{c} (0.018)	0.60^{a} (1.27)	15.6^{ad} (0.0008)	2.92^{c} (0.68)	55.74^{a} (0.018)	92.28^{b} (1.17)	195^{b} (1.93)
CAP5	22,608	2.94^{c} (0.019)	0.65^{a} (1.36)	15.2^{cd} (0.0001)	2.94^{c} (0.73)	59.40^{b} (0.020)	92.19^{b} (1.26)	189^{c} (2.07)
CAP6	24,708	2.94^{c} (0.019)	-1.99^{bc} (1.38)	13.3^{cd} (0.0001)	2.92^{c} (0.75)	61.29^{b} (0.016)	92.56^{b} (1.30)	180^{a} (2.12)
Herd-calving year								
HCY1	55,484	2.84^{a}	0.56^{a}	15.3^{a}	2.89^{a}	49.54^{a}	93.71^{a}	176^{a}

		(0.012)	(0.88)	(0.0006)	(0.46)	(0.012)	(0.81)	(1.33)
HCY2	82,920	2.81[a]	0.81[a]	15.6[a]	2.94[b]	67.77[b]	93.28[a]	191[b]
		(0.011)	(0.77)	(0.0006)	(0.41)	(0.011)	(0.72)	(1.18)
HCY3	121,83	2.95[b]	-0.78[b]	13.4[a]	2.99[c]	50.84[a]	93.52[a]	202[c]
	7	(0.012)	(0.79)	(0.0006)	(0.42)	(0.010)	(0.73)	(1.22)
Calving season								
Winter	67,773	2.88[a]	1.97[ac]	13.5[a]	2.93[a]	52.01[a]	92.41[a]	193[a]
		(0.013)	(0.92)	(0.0007)	(0.49)	(0.013)	(0.85)	(1.42)
Spring	54,319	2.74[b]	0.38[ac]	21[b]	2.91[ac]	61.33[b]	93.31[a]	189[bc]
		(0.014)	(1.02)	(0.0007)	(0.54)	(0.015)	(0.95)	(1.56)
Summer	74,697	2.90[a]	-1.91[b]	14.9[a]	2.95[ad]	57.31[c]	95.02[b]	186[b]
		(0.013)	(0.93)	(0.0007)	(0.50)	(0.014)	(0.86)	(1.42)
Fall	63,452	2.94[a]	0.32[c]	9.8[c]	2.97[bd]	53.55[a]	93.27[a]	191[ac]
		(0.013)	(0.95)	(0.0007)	(0.52)	(0.014)	(0.88)	(1.43)

[a,b,c,d,e,f] Means of variable levels with different superscripts for each lactation curve trait are significantly different (P<0.05)

DIMN= days in milk at nadir point, Per= persistency, Y_{305} =Total milk or fat or protein yields in 305 DIM, DIM1=days in milk at first test day CAP= calving age parity, and HCY= herd-calving year

() the standard error of mean

While, the highest level were observed in CAP5 (66% of the cows in the fourth parity) for FP and in CAP2 for PP. Cows in the first HCY produced less FP and PP at the nadir point which was reached earlier than other cow groups. The level of FP and PP at the nadir point was higher for cows that calved in fall than other seasons. The DIM at nadir were the earliest in summer for FP and in winter for PP.

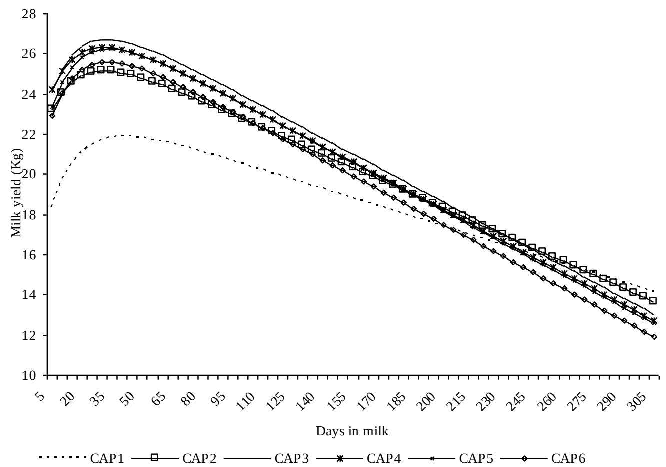
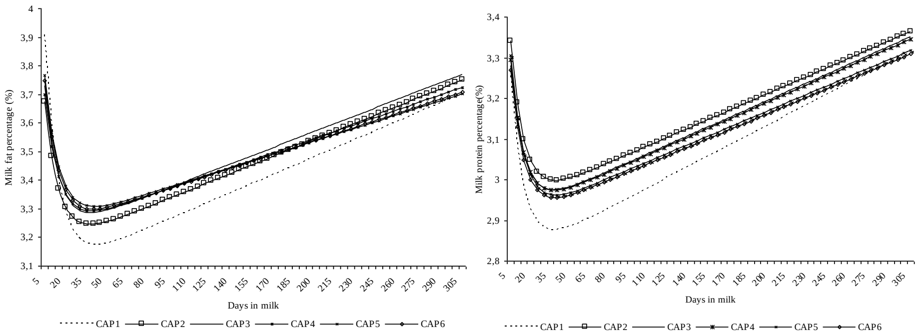


Figure 3. The shape of the lactation curve for milk yield according to calving age-parity (CAP) effects.

Lactation curves fitted for MY, FP and PP in various environmental factors, are presented in figures 3 to 8. Lactation curve of cows calved at 2 to 3 years

(CAP1) differ from those of older animals (Figure 3), their peak yield was reached at approximately 6 to 7 weeks with a long ascendant phase compared to other cows' group, these trends in the shape result that the cows' group were more persistent and presented the flattest curve. This result corresponds with the finding of Tekerli et al. (2000) and related results were observed by Cismas et al. (2012) for Romanian Black and White cows. The initial milk yield was similar for cows in the third and the fourth calving age-parity groups with the highest level (24-25 Kg). While cows in CAP2, 5 and 6 started their lactations by approximately the same level but with a low yield (22-23 Kg). Glória et al. (2012) reported that early yield increased with lactation number. The level of production after calving depend of the calving age-parity of the animal but also can be explained by the body condition of the animal and feeding level before and at calving. However, Under-nutrition in the first part of lactation generally results in low and delayed peaks of milk yield or the absence of the lactation peak (continuously declining curves)

The rate of increase until the peak yield was enough moderate for the third CAP group and that of decrease in the second phase of lactation increases as a calving age-parity increase. However, Milk production for cows in the second and the third calving age-parity group decreases with a moderate rate than those in the fourth, fifth and sixth groups. And cows in CAP6 (43% of cows are more than the sixth parity) presented the highest rate of decline from peak yield to the end of lactation. The rate of decrease was accelerated at 230-270 DIM with the higher rate for CAP5 and CAP6 than the younger cows' group. This decline is explained by an increase in the influence of pregnancy depression at 7 to 8 months in gestation which its effect influences the production of animal with a different level according to parity and calving age. Similar results were reported by Stanton et al. (1992).



(a) Fat percent (b) Protein percent

Figure 4. The shape of the lactation for fat percent (a) and protein percent (b) according to calving age-parity (CAP) effects

Figure 4 presented the lactation curves fitted in different CAP effects for FP (a) and PP (b). The general occurrence observed of change in milk content during lactation is the decrease of MY accompanied by an increase in fat and protein content. Similar findings were reported in earlier research (Schutz et al. (1990) and Cismas et al. (2012)). Curves for FP and PP in all CAP groups were characterized by an early decline until to around 35 to 50 DIM post calving followed by a steady increase to end of lactation. Peak fat percentage occurred at the beginning (5 DIM) of lactation in the first CAP group, but was at the end (305 DIM) of lactation for other groups and for all cows' group for PP. Stanton et al. (1992) reported that peak fat percentage occurred at 8 days of lactation for Holsteins but was at the end (308 days) for other breeds. However, Peak for FP and PP is related to enzyme activity for milk fat and protein synthesis, such that peak enzyme activity occurs nearer to parturition.

The shape of the lactation curve of the first CAP group for FP (figure 4-a) and PP (4-b) are distinguished clearly from other groups. However, cows in CAP1 started their lactation with the highest level for FP (3.9%) but with the lowest level for PP (3.25%). The nadir point was the lowest (3.17% and 2.87%, for FP and PP, respectively) in CAP1, which was reached very early in all groups (35 to 50 DIM). The first CAP presented a higher inflexion around the nadir point for FP and PP than those in CAP2 and the other groups. These results were opposite to the findings of Stanton et al. (1992) that fat and protein percentage lactation curves did not change substantially with change in parity. This may be explained by the fact that the lactation curve in the current study was not fitted only according to the parity, but also consider the calving age effect.

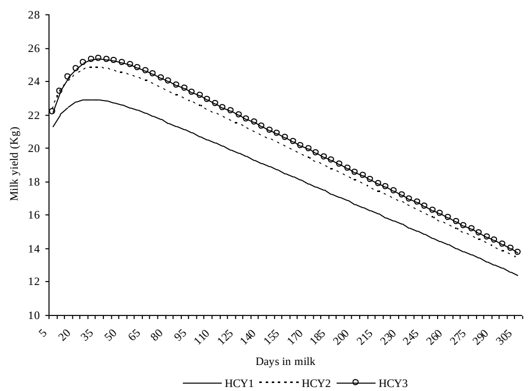
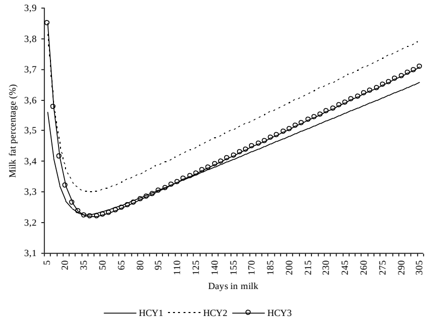
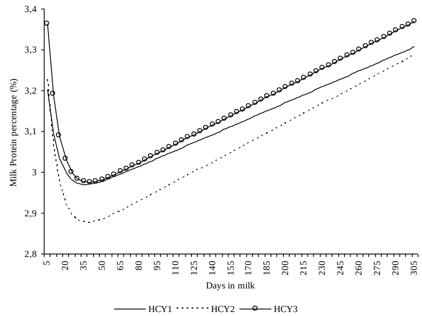


Figure 5. The shape of the lactation curve for milk yield according to herd-calving year (HCY) effects

The patterns of lactation in the different HCY studied are presented in Figure 5 for MY and Figure 6 for FP and PP. Cows belonging in HCY3 presented a more typical lactation curve than HCY 1 and 2 so, this group produced the highest level of total milk yield. The shape of the lactation curves in different herd-calving year groups confirm the result of the ANOVA mean squares.



(a) Fat percent



(b) Protein percent

Figure 6. The shape of the lactation for fat percent (a) and protein percent (b) according to herd-calving year (HCY) effects

For FP and PP, Cows with the lowest initial level and a rapid decrease to the nadir point showed a very high inflection especially around the nadir point which resulted in an almost linear increase of the FP or PP to the end of lactation. This shape was observed for the first HCY and had as consequence to produce the lowest 305-day fat and protein yields. This graphic illustration (figure 6) is supported by the result of the Least squares means (table 5). Herd with a higher production may have a higher percentage of complete confinement and feed more uniform throughout the year.

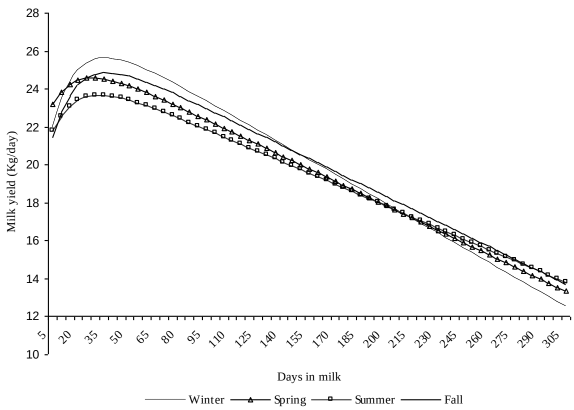
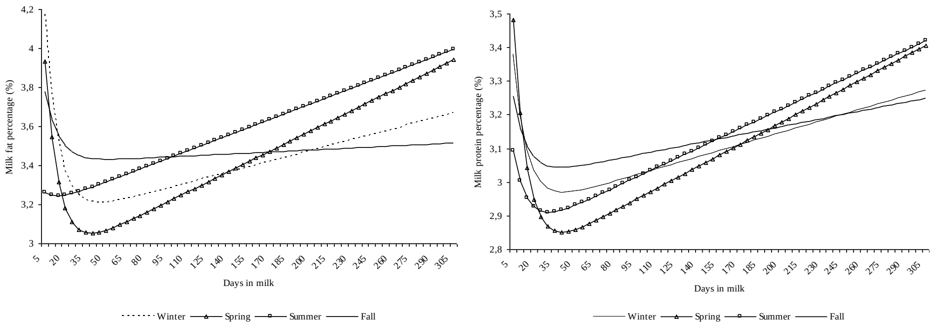


Figure 7. The shape of the lactation curve for milk yield according to season effects

The lactation curves for the different seasons are presented in Figure 7 for MY and figure 8 for FP and PP. Cows calving in winter had the highest peak production and MY decreased slowly as lactation length increases; they become less persistent (from 200 DIM to the end of lactation) and those calved in summer (the lowest peak) become more persistent at about 270 DIM. However, those cows finish their lactation during winter and acquire an added increase in total production. As consequence of these variations, cows calving in summer and spring presented a different shape of lactation curve (figure 7) but produce almost the same 305-day milk yield (Table 4). However, these results draw that attention which we must carefully consider the relationships between persistency and yield especially in selection. Macciotta et al. (2002) observed at the same level of production different shape of the lactation curves.



(a) Fat percent (b) Protein percent

Figure 8. The shape of the lactation for fat percent (a) and protein percent (b) according to season effects

Cows freshening in the fall had the intermediate shape and the level of peak yield between the four season groups and become more persistent in the last 150 DIM of lactation which this period coincide with warmer months between winter and the beginning of spring.

For FP and PP, results show that the calving season affected the shape of FP and PP curves more than MY.

The FP and PP nadir point for all season was reached at 35 to 50 DIM, except for summer which is early in lactation at 10 DIM for FP and 25 DIM for PP and cows showed an atypical shape of the lactation curve for FP, the initial level being the lowest with an almost linear increase of the FP from beginning (15 DIM) to end of lactation. For PP cows started with also the lowest level but as lactation length increases, they become more persistent and presented the highest level from 160 DIM to end of lactation. This can be explained by the effect of the heat stress due to the hot temperature always observed in summer in Tunisian climate.

Pearson phenotypic correlation among the lactation curve parameters and production characteristics are given in table 6. For MY, The highest correlation found was between *a* and peak yield (r=+0.98) followed by that between *a* and Y_{305} (r=+0.76). These higher and positive correlations suggest that cows with a higher initial level show a high peak yield and recorded the biggest total yield (Y_{305}). These results are connected to the Least squares means (Table 4) and support the results obtained for the third CAP, for HCY3 and in winter.

Table 6. Pearson phenotypic correlation between individual lactation Curve traits for MY, FP and PP

Trait	Variable	Lactation curve traits					
		b	*c*	Y_{305}	[1] Peak or nadir	DIMP	Per
MY	*a*	-0.29**	-0.80**	0.76**	0.98**	-0.27**	-0.088**
	b		0.29**	0.17**	-0.26**	-0.26**	0.032**
	c			-0.30**	-0.73**	0.18**	0.16**
	Y_{305}				0.85**	-0.025**	0.011**
	Peak					-0.10**	-0.25**
	DIMP						0.19**
FP	*a*	-0.23**	-0.84**	0.10**	0.98**	0.15**	-0.11**
	b		0.20**	0.13**	-0.21**	0.039**	0.023**
	c			- 0.05**	-0.76**	-0.21**	0.12**
	Y_{305}				0.57**	-0.036**	0.0025
	Peak				0.13**	0.082**	0.015**
	DIMN						-0.020**
PP	*a*	-0.17**	-0.83**	0.086**	0.98**	0.21**	-0.078**
	b		0.15**	0.073**	-0.15**	-0.008**	0.008**
	b			0.021**	-0.76**	-0.25**	0.081**
	Y_{305}				0.12**	0.11**	0.011**
	Peak					0.22**	-0.069**
	DIMN						-0.026**

[1] peak for MY and nadir for FP and PP, DIMP= days in milk at peak production, DIMN= days in milk at nadir points
Per= persistency, Y_{305} =Total milk or fat or protein yields in 305 DIM, MY= milk yield,
FP= fat percent and PP= protein percent

Negative correlations among *a* and *b*; *a* and *c*; peak and *b*; peak and *c* and Y_{305} and *c* indicate that a low initial yield is associated with a high rate of increase and decrease before and after reaching the peak production and milk production at peak was low. These results are confirmed by the shape of the lactation curve in the first CAP cows' group where 97% are primiparous. Moreover, peak yield seems to be more important in determining total lactation yield (r=+0.85). For FP and PP the highest correlation between *a* and nadir confirm the results of the least squares means obtained in table 5 where cows with a high initial level presented the highest concentration of FP and PP at nadir point.

The high and negative correlation between *a* and *c* for all milk traits implies that a high initial yield or concentration is associated with a low rate of decrease after peak yield for MY or of increase of FP and PP after the nadir point.

CONCLUSIONS

The Wilmink model showed a satisfactory fit to the data and the curves developed from the Wilmink model were influenced by the various factors conducted in groups of cows in the present study which suggest that the nature of the curves can provide a basis for planning and adjustment in the management of herds. Moreover, the association of environmental factors in the groups of animals makes it possible to take account differences related to the interaction between factors such as herd and calving years, which affect the food. In addition to some physiological aspects related to age of animal and the parity.

The highest peak and lactation yields were associated with cows that calved in fall and winter for MY, in fall for FP and PP and also with cows that calved at 50 to 62 months, where 77 % are in the third parity. Cows calving in summer and spring season showed different shapes of the lactation curve but produced almost the same 305-days milk yield. Thus, the cows in different herd-calving year groups presented almost the same persistency for MY, FP and PP but recorded different yields at 305-days of lactation.

Generally, protein percent variation during lactation was lower than those of milk yield and fat percent. And protein percent tends to be more persistent than fat percent for all environmental effects.

The correlation between peak yield and lactation yield was higher than that observed between persistency and lactation yield. Peak yield seems to be more important in determining the total lactation yield than persistency but more persistent lactation may be desirable when we consider the relationship between this trait and reproduction efficiency, health status and feed costs.

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