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Review

Characteristics of lactation curves in ewes and factors influencing their variation: A review

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Abstract:

Dairy sheep breed genetic improvement programs have responded to the increasing market demand and popularity, especially for cheeses made from sheep's milk. These milk derivatives are an important source of bioactive substances for human health. Therefore, it is very important to learn about milk production (MPROD) and the factors that influence its variation. The typical pattern of MPROD during the period when an ewe is lactating is known as the lactation curve (LC), and this can be typical (TLC) or atypical (ACL). TLCs are characterized by reaching a maximum MPROD (lactation peak, LP) within a few days after parturition, and then gradually decreasing until the end of lactation, or lactation drying, is reached. ALCs are those that show some deviation from the normal pattern. It is important to know the graphical representation of lactation behavior, as, in addition to predicting MPROD, it makes it possible to identify health and feeding issues, as well as to select females that will excel in MPROD. Persistence of lactation (PER) has been defined as the rate of decline in MPROD after the LP was reached, and it is highly desirable for ewes to have a high PER. Mathematical models have been developed for the study of LCs and PER. There are genetic and environmental factors that influence LCs.

Keywords: Milk production, Peak lactation, Persistence, Typical curves, Sheep breeds.

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Introduction

Over the last 150 yr, genetic selection and improvements in management have led to improved breeds of sheep for milk production (MPROD), responding to growing market demand and popularity, especially for cheeses made from sheep's milk(1). There are currently an estimated 1 billion sheep in the world(2); the main breeding areas are located within latitudes 35-55 degrees north in Europe and Asia, as well as between 30 and 45 degrees south in South America, Australia and New Zealand(3). Products derived from sheep's milk, such as cheese, cottage cheese, yogurt, etc., constitute the typical diet of sheep farmers(4) and are an important source of bioactive substances that benefit human health(5). About 1,500 sheep breeds have been described; of these, only 180 are identified as milking breeds because of their zootechnical purpose (milk), although many are local breeds used for meat, wool, and milk production where milk is not the main product of interest(6). Some of the most important breeds of dairy sheep in the world are East Friesian(7), Lacaune(8), Chios(9), Sarda(10), and Manchega(11).

The productive level of the ewe is the most important economic characteristic in the flock, as it provides information used in the estimation of biological indexes that facilitate selection decisions in genetic improvement programs(12). Therefore, one of the most important criteria for evaluating female productivity is MPROD, since it directly affects the efficiency of the production system and has very important effects on farm profitability(13). Therefore, knowledge of the behavior of the lactation curve (LC) is very important, since it will allow adequate planning of general management and genetic improvement programs. The objective of this review is to describe the main characteristics of LCs and to enumerate the factors that influence their variation. This review has included studies conducted in sheep; however, the vast majority of studies in the scientific literature that address this topic are focused on describing LCs in dairy cattle.

Definition of lactation curve

MPROD during the lactation period in mammals and domestic ruminants is the result of physiological processes developed by specialized cells of the mammary gland, which synthesize and secrete organic and inorganic compounds through active and passive blood filtration[(14)]. MPROD begins when gestation is nearing completion through expansion of the mammary gland tissue, and ends when the mammary gland volume decreases, due to secretory regression that ends with the cessation of lactation, or drying[(15)]. All these physiological mechanisms result in a typical pattern of MPROD over time known as the "lactation curve" (LC), which can be defined as the graphical representation of the time period in which MPROD occurs, although it is also expressed as a continuous physiological function describing milk secretion over time[(16)]. According to the criteria of certain authors[(17)], and taking Assaf dairy ewes as an example, lactation can be divided into three periods: early lactation, which considers the period from lambing until month 2, mid lactation, which covers months 3 to 7, and late lactation, from month 8 to dry-off.

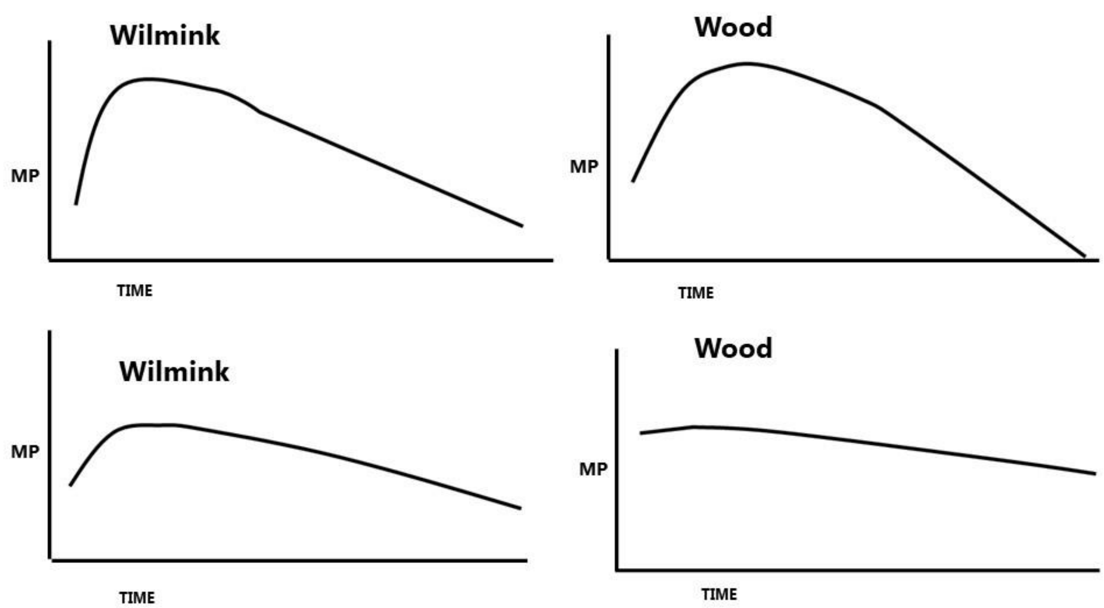
Importance of knowing lactation curves

Knowledge of a LC allows prediction of the total milk production[(18)], the characteristics of the curve (discussed below), and, finally, the future performance of the breeding animals (cattle, sheep, goats) or their progeny[(19)]. In addition, by understanding the behavior of the LC's shape, it is possible to make decisions regarding such aspects as nutrition, health, and management of the herd. Above all, knowledge of these curves is useful for identifying and selecting superior ewes for MPROD and, therefore, valuable for the producers[(20)].

Lactation curve types

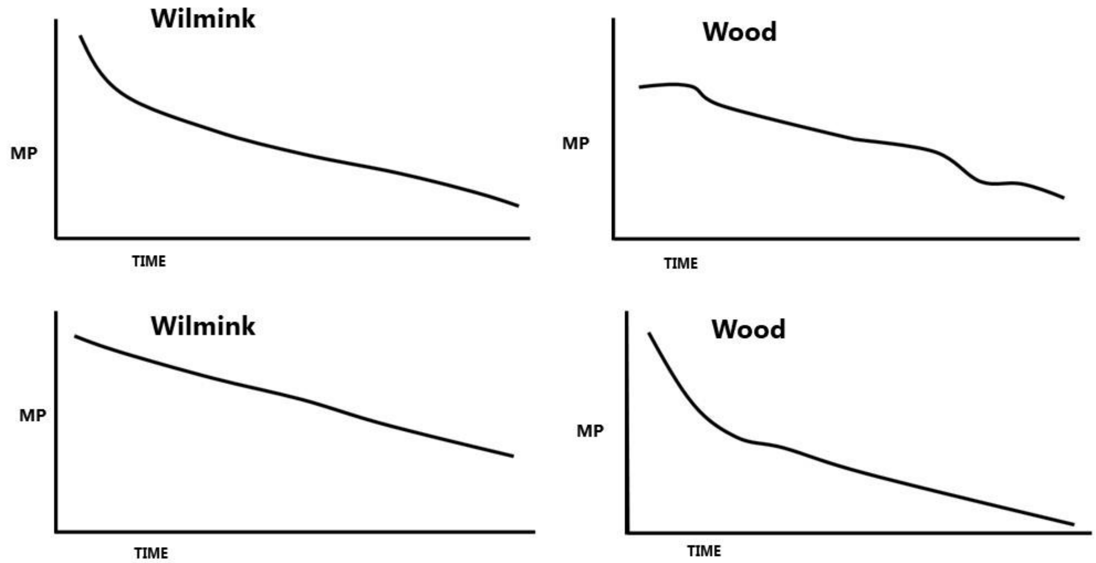
According to their shape, there are two types of LCs: typical (TLC) and atypical[(21)] (ALC). A TLC reaches its maximum milk production (peak production, lactation peak, LP) a few days after lambing (2-6 weeks), and thereafter shows a steady decline until it reaches the drying stage, or end of lactation(22). The typical pattern of a LC (Figure 1) is regular and continuous, and constitutes the expression of physiological mechanisms from the onset of MPROD(23). An ALC is one represented by slight deviations from the TLC due, for example, to the presence or absence of an inflection point in the decreasing lactation; others decline steadily and lack the LP(24), as shown in Figure 2; they are represented by deviations from the regular pattern, which can be attributed to various factors such as nutrition, health status of the animal, and environmental disturbances(23). For example, in Wood's model(25), a characteristic that differentiates TLCs from ALCs is that the "b" and "c" parameters are positive in TLCs, and negative in ALCs(26).

Figure 1: Schematization of typical lactation curves, according to Wilmink's and Wood's models



Adapted from Palacios Espinosa *et al*(21)

Figure 2: Schematization of atypical lactation curves, according to Wilmink and Wood's models



Adapted from Palacios Espinosa *et al*[21]

Stages (phases) of a lactation curve

The typical stages of a LC are: an initial gradual increase from lambing until reaching a point of maximum milk production that represents the LP is reached, which occurs within the first days after lambing (or days in milk), generally in the range between 2 and 6 wk, and which is also a criterion used in the selection of breeding females[28]. Subsequently, the decreasing phase begins until the MPROD ceases, or until the drying of the animal, when the MPROD is minimal. Drying, in dairy sheep breeds such as the East Friesian, generally takes between 180 and 210 d, and, in exceptional cases, it can take up to 260 d[29]. Great care must be taken with the method used to dry the animal, due to the possibility of infections in the mammary gland, such as mastitis[30,31]. Drying can be abrupt: stopping milking on a given day, or gradual, with a reduction of the frequency of milking over days or weeks[32]. In dairy cows, some management practices have been recommended to carry out the drying process[33,34], which could also be put into practice with sheep. At the end it has a CL that graphically represents the total MPROD, which can be estimated based on the area under the curve, defined as the total amount of milk produced during the whole lactation and determined by the shape of the curve[35].

Lactation curve models

The first mathematical models to characterize LCs were developed in studies of dairy cows; however, several of these have also been used to characterize LCs of sheep and goats. These models are classified as a) empirical and b) mechanistic. In relation to lactation, empirical models are based on actual MPROD data; e.g., test day records, whereas mechanistic models are based on the biology of lactation; e.g., mammary gland growth and regression, or nutrient flux(36). In other words, the theory of the empirical model refers to the level of reality in which the phenomenon under consideration is expressed, while the mechanistic one is characterized by a deeper theoretical assumption(37). Describing and discussing these models is not an objective of this review. Therefore, and for illustrative purposes only, Tables 1 and 2 show examples of empirical and mechanistic models, respectively.

Table 1: Examples of empirical models and their parameters used in sheep lactation curves, expressed as a function of t

Model	Parameters	Author(s)
$Y = ae^{-bt}$	2	Brody *et al.* (1923)
$Y_t = at^b \exp(-ct)$	3	Wood (1967)
$Y_t = a - bt - a \exp(-ct)$	3	Cobby & Le Du (1978)
$Y_t = at^{bc} \exp(-ct)$	3	Dhanoa (1981)
$Y_t = a + bt + c \exp(-wt)$	4	Wilmink (1987)
$Y_t = a_0 + a_1 t + a_2 t^2 + a_3 \log(1/t) + a_4 \log(1/t)^2$	5	Ali & Schaeffer (1987)
$Y_t = \sum\left[a_1 b_1 [1 - tanh^2(b_1(t - c_1))]\right]$	3 per phase	Grossman & Koops (1988)
$Y_t = \exp(a + bt + ct^2 + d/t)$	4	Morant & Gnanasakthy (1989)
$Yt = a_1 b_1 (tanh^2(b_1(t - c_1))) + a_2 b_2 (1 - tanh^2(b_2(t - c_2)))$	6	Gipson & Grossman (1989)

$Y_t = at^{bexp(-ct)}$	3	Cappio-Borlino *et al.* (1995)
$Y_t = {}^{t}/_{a} + bt + ct^2$	3	Nelder (1996)
$Y_t = \sum_{i=1}^{n} \alpha_1 P_j$	5	Brotherstone *et al.* (2000)

Adapted from Bilgin et al.[38] and Macciotta et al.[37]

Table 2: Examples of mechanistic models and their parameters used in sheep lactation curves

Model	**Parameters**	**Author(s)**
$\int_0^{t_L} R_M(t)dt.$	14	Neal & Thornley (1983)
$dY/dt = a\{ \exp[-\exp(G_0 - bt)]\} [\exp(-ct)]$	4	Emmans & Fisher (1986)
$Y_t = a \exp^{[b(1-\exp-ct)/c - dt]}$	4	Dijkstra *et al*. (1997)
$Y_t=a\{1/[1+(1-b)/b \exp^{-cn}]-1/[1+(1-d)/d \exp^{-gn}]\}$	5	Pollot (2000)
$I = SE^L(de^{-k_2 t} + l_6 e^{w_6 t} + l_7 e^{w_7 t})$	8	Vetharaniam *et al.* (2003)

Source: Neal & Thornley[39], Friggens *et al*[40], Adediran *et al*[41], Vetharaniam *et al*[42].

In order to carry out genetic improvement programs for CL, it is necessary to know the magnitude of the additive genetic variance of CL parameters. Based on the above, some studies have been carried out in sheep to estimate the heritability (h^2) of CL parameters. Pollot and Gootwine[43] found in improved Awassi ewes low values of the additive genetic variance for LP and day on which the LP occurs (DPL), resulting in h^2 values of 0.11 for PL and 0.032 for DPL, explaining that these results indicate that environmental factors exert a greater effect on the manifestation of these parameters. In the USA, a group of researchers(20) analyzed first lactations of Dorset, Romanov, Targhee, Rideau Arcott, Polypay, Booroola Merino, Suffolk, Rambouillet, Finnsheep and East Friesian ewe crosses to investigate genetic variation in CL parameters using a Bayesian analysis of Wood's model[25]. The h^2 values obtained for parameters “a”, “b”, and “c” were 0.35, 0.35, and 0.27, respectively, so these authors concluded that part of the variation in lactation curves among ewes is heritable. In another study on Yankasa sheep[44], and also with Wood’s model[25], h^2 values of 1.4, 0.3, and 0.2 were found for parameters “a”, “b”, and “c”, respectively. With respect to the irregular value of the parameter "a", these authors explained that this value could be subject to large sampling errors and, moreover, overestimated, due to the participation of non-additive genetic effects. Reviewing the magnitude of the h^2 estimators in the previous studies, it is inferred that, by virtue of being in the low-medium range, a positive response to CL selection in ewes could be expected.

Lactation persistence

A phase of lactation closely related to CL is what is known as "lactation persistency" (or milk production, PER), which was initially defined as "the rate of milk secretion indicating the initial value at parturition and its change with advancing lactation"(45), and whose first numerical measure was given, in cattle, as a percentage of the MPROD in the previous month. Subsequently, it was defined as(46) "a function of CL flattening"; i.e., a female has a higher PER the more flattened her CL is. One year later another definition was published in the literature(47): "the ability to maintain the level of MPROD during lactation" and that it can be extended to milk components, including fat and protein. Finally, with a different approach(48), PER was said to be: "the rate of decrease in MPROD after reaching the LP".

Most of the information on lactation PER, especially mathematical models, comes from larger species, particularly dairy livestock(37). However, in studies with dairy sheep, PER has been studied with the same approach as dairy livestock(49,50). Under this scenario, PER has an important impact on dairy cattle, which has benefits both in feed costs(51), as well as reproductive aspects(52). Therefore, the current trend in MPROD in cattle is to improve the PER and extend it, rather than to increase MPROD in the LP(53), which also applies to sheep and goats.

Lactation persistence models

Different criteria have been proposed to measure the PER(35) which involve the use of different mathematical models. However, as in the case of the LC models, describing and discussing PER models is not an objective of this review. Therefore, for illustrative purposes, Table 3 shows some mathematical models that have been proposed for cattle, according to the definition of PER.

Table 3: Some mathematical models and their parameters for measuring lactation persistence in dairy cows

Persistence model	**Reference**
$P = (3+4+5th\ months\ yield) - (7+8+9th\ months\ yield)/12$ $P = Total\ yield\ (sum\ of\ 7\ months)/milk\ yield\ of\ last\ 3\ months$	Ludwin (1942)
$P = \sum (\gamma_i - S_i) \times (d_i - d_0)$	Cole & VanRaden (2006)
$P = EBV_{290} - EBV_{90}$	Cobuci *et al*. (2007)
$P = \sum_{i=61}^{300} EBV - 240 \times EBV_{60}$	Harder *et al*. (2006)
$P = \sum_{i=61}^{305} EBV - 245 \times EBV_{60}$ $P = (milk_{270}\ /\ milk_{90}) \times 100$	DeRoos *et al*. (2001)
$P = (milk_{225}\ /\ milk_{45}) \times 100$ $P = (\sum_{i=1}^{150} milk\ /maximum\ milk\ yield) \times 100$	Weller *et al*. (2006)
$P = 305\ day\ milk\ yield\ /\ the\ first\ 50\ day\ milk\ yield$	Yilmaz & Koc (2013)
$P = maximum\ milk\ yield\ /\ average\ milk\ yield$	Atashi *et al*. (2006)
$P = EBV_{280}\ /\ EBV_{65}$ $P = \sum_{i=66}^{280} EBV\ /\ \sum_{i=5}^{65} EBV$	Togashi & Lin (2004)
$P = (((EBV_{280} - EBV_{60}) + Y_{280})/\ Y_{60}) * 100$	Mostert *et al*. (2008)
$P = \sum_{i=61}^{280} milk_{280} - milk_{60}$	Jamrozik *et al*. (1997)
$P = {}^{1}/_{55} \sum_{i=255}^{i=350} milk\ yield\ i - {}^{1}/_{21} \sum_{i=50}^{i=70} milk\ yield\ i$	Kistemaker (2003)

$P = \sum_{i=101}^{200} milk \,/ \sum_{i=1}^{100} milk \quad P = \sum_{i=201}^{305} milk \,/ \sum_{i=1}^{100} milk$ $P = \sum_{i=1}^{100} milk \,/ \,(MAX \sum_{i=1}^{100} milk \times 200)$	Johansson & Hansson (1940)
$P = \sum_{DIM=60}^{279} D_{DIM} - D_{280} \qquad P = EBV_{280} - EBV_{60}$	Jakobsen *et al*. (2002)
$P = -(b+1)1n\ c$	Wood (1970)
$P = 100\ (1 + 2\gamma_i)$	Kamidi (2005)

Source: Torshizi *et al*[54]

As in the case of LCs, studies have also been carried out in sheep to estimate the h^2 of PER, although for this parameter, in smaller numbers compared to dairy cows. In order to estimate the h^2 of PER, a group of researchers in Greece[55] used Sfakia dairy ewes using MMP2:MMPP1 (MPROD month 2:MPROD month 1), MMP3: MMP1 (MPROD month 3:MPROD month 1), MMP4: MMP1 (MPROD month 4: MPROD month 1), MPR (measure of the reduction in an ewe's MPROD relative to MPROD level in early lactation, in percent), and VC (measure associated with the variation in an ewe's MPRODs on the test day, in percent), with results, respectively, of 0. 26, 0.16, 0.14, 0.24, y 0.28. In a study with improved Awassi ewes[43] the h^2 of PER was estimated, measured as the daily loss of MPROD between DPL and the end of lactation, thus obtaining a value of 0.11. Kominakis *et al*[56] estimated the h^2 of PER in Boutsiko dairy ewes from Greece, for which they used three measures of PER: $\hat{\beta}$ (measures the rate of decline of MPROD following an ewe's LP, in kg/day), in addition to the MPR and VC measures (already described), having obtained values of 0.15, 0.10, and 0.13, for the $\hat{\beta}$, MPR, and VC measures, respectively. As with LCs, h^2 estimators of PER are in the low-medium range, which is encouraging for use in selection programs to improve PER in ewes.

Factors affecting the lactation curve

Genetic

Lactation behavior is largely determined by the genotype of the individual; i.e., the shape of the CL is genetically determined[57]. A group of researchers[58] used a mechanistic mathematical model of the milk secretion process, based on the physiological theory of the mammary gland, where the model output can be a monoexponential or biexponential function. Using 64 Sarda dairy ewes, the biexponential function fitted regular LCs (R^2=0.87), while the monoexponential fitted decayed LCs (R^2=0.80). The authors concluded that LC dimorphism was not due to environmental factors (production level, type of birth, and udder health status), but did have a genetic influence.

A study using crosses between several dairy sheep breeds researched genetic variation in LC traits(20) using a three-stage Bayesian hierarchy: 1) Wood's model was utilized, 2) inter-sheep variation was described, and 3) *a priori* distributions of all unknown parameters were included. The results showed that some of the variation in LCs between ewes is heritable. On the other hand, genetic correlations were negligible, suggesting that there is sufficient scope for modifying LCs genetically.

The MPRODs of Araucana and Romney Marsh ewes were tested(59), also characterizing their LCs and relating MPROD to the growth of their lambs. The LCs in both breeds were typical; however, the MPROD of Araucana ewes was characterized by an ascending phase until d 30, with a maximum production of 2.18 L d^{-1}, while Romney Marsh ewes reached the LP on day 20 of lactation, with a maximum MPROD of 2.47 L d^{-1}.

Komprej *et al*(60) analyzed the LCs for daily MPROD, fat, and protein content in Bovec, improved Bovec, and Istrian Pramenka dairy ewes, estimated with a repeatability animal model that included records of the test days. The shape of the LCs for the daily milk production of Bovec and improved Bovec ewes was a good fit (51.35 %) for the general lactation curve of dairy ewes. In Istrian Pramenka ewes, the shape of the LCs was more or less atypical, with a lower peak production and a decreasing daily MPROD during almost the whole lactation. The shapes of the LCs for fat and protein contents were opposite to those of the LCs for daily MPROD in all three breeds.

In order to determine the MPROD and the LC characteristics, 863 weekly MPROD records from 70 lactations were analyzed(61) in six genetic groups of ewes: East Friesian (EF), Criollo (Cr), ½ EF x ½ Cr, ¾ EF x ¼ Cr, ½ Suffolk x ½ Cr, and Corriedale (C). Wood's function (WF) was used to calculate the total observed MPROD (TLP^{obs}) and the estimated 180-d MPROD (TLP^{180}), the peak lactation (PL), the time to peak lactation (TPL), and the PER. The genetic group significantly (P<0.05) influenced the TLP^{obs}, TLP^{180}, LP, and parameter “b” of Wood's model, with higher values in ½ EF x ½ Cr ewes. In all cases, the LCs were typical, although with varying degrees of PER. The authors concluded that differences in productive performance due to the genetic group may be associated with the adaptability of EF ewes to local climatic conditions.

Environmental

Before addressing the results found in the literature concerning this type of factors, a group of researchers[37] in dairy cattle pointed out that linear mixed models are an adequate mathematical tool for the evaluation of environmental effects, as they can take into account factors that could affect each test-day record differently. These authors presented the basic structure of these models as follows: y = HTD + F + DIM + L + e; where y= daily MPROD; HTD= interaction between herd and test date taking into account the peculiar effects of a specific date; F= fixed factor (lambing season, production region, lambing number); DIM= fixed effect of days on MPROD groups, whose least squares solutions allow generating lactation curves corrected for other effects included in the model; L= individual random effect of the cow (ewe, goat) associated with a variance component (σ^2L); e= residual random effect associated with the variance component σ^2_L.

In a study on Sarda dairy ewes[62], LCs were estimated and predicted LCs by age at lambing, in addition to seasonal effects for milk, fat, and protein yields. Trends in seasonal effects showed a spring peak for MPROD, milk, fat, and protein yields. The seasonal effects on fat content were very irregular, while in the case of the protein content they were small and constant over time. The predicted LCs showed an increasing effect of age at lambing on all variables. From these results, the authors concluded that the trend of seasonal effects on milk yields within herd-years could be an important tool for improving management techniques.

Using Sarda dairy ewes with different levels of milk production (in grams), lambing type, and udder health, a modified nonlinear version[63] of Wood’s model ($y=at^{b}\exp(-ct)$) was tested The results showed that the modified version (“a”=702.3 + 56.2, “b”=1.29 ± 0.09, “c”=0.133 ± 0.013) of the model fitted the LC very well (R^2= 0.905; residual standard deviation= 145.3) with few iterations required for convergence (<5). Milk yield, production level, and lambing type influenced all the parameters, while udder health only influenced parameter “a”.

In a study on Comisana dairy ewes[64], MPROD data were fitted with Wood's model, and the effect of environmental factors on the LC was assessed. The interaction between the lambing number and the lambing season had a strong influence on the lactation parameters. The LCs for winter-lambing ewes had a higher LP than for those for fall-lambing ewes. The lambing number correlated positively with the peak milk production and negatively with the milk production decrease (MPD) and PER. The lambing type did not significantly influence the shape of the LC.

In the case of Valle del Belice dairy ewes[65], test-day models were used to estimate the LC and assess the influence of environmental factors on MPROD and fat and protein percentages. Three flocks were analyzed. In each flock, two groups of ewes were formed;

one group received no feed supplement, while the other group received 500 g d^{-1} of a commercial concentrate. The lambing number affected the LC for MPROD, which was lower and flatter for first-time ewes; the effects on the fat and protein contents were smaller. The time of the lambing affected all variables. Seasonal productivity had the greatest effect on the milk composition, resulting in an imbalance between fat and protein percentages. Herd and dietary supplementation effects affected only the LC for MPROD.

A study was conducted in Mexico(66) with crossbred dairy ewes from four commercial farms to research those environmental factors that influence LC parameters using Pollot's 5-parameter additive model. The crossbred ewes were the progeny of East Friesian as the paternal line, and Suffolk, Pelibuey, Blackbelly, and Hampshire as the maternal line. The parameters estimated were the maximum milk secretion potential (MSmax), the relative rate of decline in cell number (DR), and the proportion of dead parenchyma cells at delivery. The effects of birth type, lambing number, herd, and lambing season on the total milk yield (TMY), lactation length, and estimated parameters of the Pollot model were analyzed. The herd had a significant effect ($P<0.05$) on most of the analyzed variables; the TMY was higher ($P<0.05$) in double lambing lactations than in those of single lambing. First-lambing ewes had a lower TMY than fourth-lambing ewes ($P<0.01$).

Likewise, in order to characterize the LC of ewes from the Bulgarian synthetic dairy population, taking into account the MPROD of the test day and the number of lambing, the following MPROD records of the Agricultural Institute-Shumen during the 2009-2019 period herd were analyzed(67). For this purpose, a linear mixed model was used where the analytical hypothesis included the effects of year and month of lactation, lambing number, lambing type, test day (related to the LC), lactation period, permanent effect of environmental changes, genetic value of the animal, and residual environmental effects. A typical, relatively flat curve was found, which varied according to the day of the test and the number of births.

Climatic factors such as temperature, humidity, wind speed, and radiation are environmental elements that influence animal welfare and stress(68) and can affect various productive aspects such as growth, reproduction, and MPROD in ruminants(69). In a study with Churra dairy ewes(70), these same factors, in addition to precipitation, affected the total milk production and milk quality, which exerted a direct influence on the LC.

A study was carried out in the Mediterranean region(71) to investigate the effect of heat stress on the MPROD of Valle del Belice sheep. The results indicated that there was an antagonistic effect between MPROD and heat stress, as the selection to increase the MPROD reduced the heat tolerance.

Similar results to the previous study were found in dairy cows from two regions of the USA(72), given that the selection to increase the MPROD remained constant up to a certain point (threshold) and then exhibited a linear decreasing behavior as the value of the temperature-humidity index (THI), designed to measure heat stress, increased.

Cold stress has also been found to have a significant effect on the MPROD. In a study with Mediterranean Manchega dairy ewes(73) the effect of the exposure to adverse climate conditions (exposure to heat and cold) on MPROD was analyzed to measure the thermotolerance capacity of the sheep, as well as the degree of decrease in MPROD outside the thermal comfort zone. The results showed that cold stress had a greater negative effect on MPROD than heat stress.

Conclusions and implications

A lactation curve is the graphical representation of the behavior of the level of milk production of an individual, or a group of individuals, throughout lactation. The knowledge of a lactation curve is of utmost importance since it allows predicting the total milk production and making decisions on nutrition, health, and farm management, but, above all, it allows identifying the superior females in terms of milk production to be used in the herd as breeders. According to their shape, lactation curves can be typical (normal) and atypical. Lactation persistency is a phase closely linked to the lactation curve and represents the rate of decline in milk production after the peak lactation has been reached. Mathematical models have been developed to characterize lactation curves and study lactation persistence, mostly in cattle, although several have also been used in sheep. For selection purposes, both for the lactation curve and persistence, the heritability estimates reported in sheep show values that are in the low-medium range, which gives the confidence to expect positive responses in genetic improvement programs; these should be designed with clear, well-defined objectives, in addition to using the appropriate program methodology, based on the characteristics of the variables to be measured, the animal population, and the environment, and, finally, they should consider the potential influence of genetic and environmental factors in the response of the sheep to lactation curves. The scarcity of information on the lactation curves in ewes indicates the need to carry out more research on this species —not only on ewes of dairy breeds, but also on ewes of meat-producing breeds—, since the maternal ability to produce milk significantly influences the pre-weaning growth and survival of the offspring and impacts the profitability of the production system directly.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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