

# Estimation of lactation persistency in a population of Rambouillet ewes utilizing five mathematical methods

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## ABSTRACT

**Objective:** The aim of the study was to estimate the lactation persistency (LP) of Rambouillet ewes using five mathematical methods.

**Design/methodology/approach:** Production records of 45 Rambouillet ewes were used, with an average live weight of  $65 \pm 7.1$  kg, from one to three lambings, with one and two lambs, which were weaned at six and eight weeks of age. To estimate the LP, the following five mathematical methods were used:  $P_1$  (regression of the rate of decline in milk production after reaching peak production, in  $\text{mL d}^{-1}$ ),  $P_2$  [ $-(\mathbf{b} + 1)\ln \mathbf{c}$ ], where  $\mathbf{b}$  and  $\mathbf{c}$  are parameters of the Wood model ( $Y_t = \mathbf{a}t^{\mathbf{b}} e^{-\mathbf{c}t} + \varepsilon_i$ , without units),  $P_3$  (the ratio between milk production in the second third of lactation and the first third, in %),  $P_4$  (the ratio between milk production in the last third of lactation, and that of the first third, in %), and  $P_5$  (milk production between the lactation peak and the end of lactation, in %).

**Results:** Results of the five methods to estimate the LP were:  $P_1 = -6.3 \pm 0.4$  mL,  $P_2 = 4.8 \pm 0.1$ ,  $P_3 = 108.9 \pm 3.7\%$ ,  $P_4 = 72.0 \pm 3.2\%$ , and  $P_5 = 11.1 \pm 12.7\%$ .

**Limitations on study/implications:** All the methods generated estimators whose magnitude was not satisfactory compared to other studies in the literature, because the comparisons were made mainly with studies on dairy ewes and cows. In the  $P_5$  method, a standard error greater than that of the estimator itself was obtained.

**Findings/conclusions:** The most reliable methods to estimate the LP in this population of Rambouillet ewes were  $P_1$ ,  $P_2$ , and  $P_4$ .

**Keywords:** Milk production, lactation curve, production systems.

## INTRODUCTION

Sheep milk production has lower participation worldwide compared to cow's milk; however, in countries such as Spain, sheep milk production systems represent a model

of great economic importance and even constitute an alternative kind of livestock production for disadvantaged rural areas (García-Díaz *et al.*, 2012). In Mexico, information about the production and composition of milk from non-dairy ewes is very limited, as is the case of Rambouillet sheep (Ochoa-Cordero *et al.*, 2002) and Katahdin sheep (Chay-Canul *et al.*, 2020). However, milk production systems with dairy sheep breeds are relatively recent, due to the introduction of germplasm from dairy breeds, such as East Friesian, Awassi, Lacaune, and Assaf; therefore, information on production rates and lactation characteristics is limited (Ángeles-Hernández *et al.*, 2018; Velarde-Guillén *et al.*, 2022).

A lactation curve (LC) describes the amount of milk produced during the lactation period. A critical phase of the LC is lactation persistency (LP), which refers to the ability of a cow, ewe, or goat to maintain milk production after reaching its peak production (Swalve and Gengler, 1999; Cobuci *et al.*, 2003). LP is of great importance in dairy cattle, since it benefits both in the reduction of feed costs (Dekkers *et al.*, 1998), and in some reproductive aspects (Dobson *et al.*, 2007). Therefore, in dairy cattle it has been preferred to prolong the LP, instead of increasing production at peak lactation (Schutz *et al.*, 1990), which is also applicable to ewes and goats. To estimate the LP, different mathematical methods have been used that are based on different criteria such as: multiple linear regression (Louda and Doney, 1976; Kominakis *et al.*, 2002), using the Wood method  $[S = -(\mathbf{b} + 1) \ln \mathbf{c}]$ , where parameters  $\mathbf{b}$  and  $\mathbf{c}$  must be estimated from the Wood model ( $Y_t = \mathbf{a} t^{\mathbf{b}} e^{-\mathbf{c}t} + \varepsilon_i$ , Nezamidoust *et al.*, 2013), due to the relationship between milk production in advanced stages of lactation in relation to initial stages, or else, using information on genetic values (Torshizi *et al.*, 2019), and others.

In Mexican Rambouillet sheep, a wool-producing breed, Ochoa-Alfaro *et al.* (2009) measured milk components and found contents similar to those of some dairy breeds, particularly in the total solids content (mean:  $16.8 \pm 12.6\%$ ). This suggests a possible shift in the production system, focusing it on cheese production, since current wool production is not profitable for Rambouillet sheep breeders due to competition from synthetic fibers in the international market. This has encouraged continued research in this breed on aspects such as LC (currently under study) and, especially, LP, with the purpose of using this information in genetic improvement programs by selecting ewes with outstanding performance in this characteristic. The objective of the present study was to use the same database of this population (Ochoa-Alfaro *et al.*, 2009) to estimate the LP of Rambouillet ewes by comparing five methods reported in scientific literature. Most studies on this topic have been conducted with dairy cows, so information on ewes and goats is very limited. The study's hypothesis was that there are differences in the results from the five methods used to estimate lactation persistency in Rambouillet ewes.

## MATERIALS AND METHODS

### Animals and management

The study was conducted using milk production records of 45 Rambouillet ewes with a live weight of  $65 \pm 7.1$  kg, from one to three lambings, with one and two offspring

weaned at six and eight weeks, belonging to the sheep flock of the School of Agronomy, Autonomous University of San Luis Potosí, at 1835 m above sea level (22° 09' 10" N and 100° 58' 41" W). The climate is cold and dry, with an average temperature of 17.8 °C and annual rainfall of 271 mm (García, 2004). The ewes were confined and fed daily with 3.5 kg fresh alfalfa and 1.7 kg of a commercial feed that had 14% crude protein and 2.96 Mcal kg<sup>-1</sup> of digestible energy. The ewes received similar amounts of the diet in the morning and afternoon (08:00 h and 13:00 h). Ewes were hand-milked twice daily (08:00 h and 13:00 h), starting on the first week post-lambing, without using any stimulus to allow milk let-down. During the lactation period, ewes were milked every seven days, with the lambs being separated from their dams at 16:00 h the day before milking. Additional management details are given in Ochoa-Alfaro *et al.* (2009).

### Statistical Analysis

To estimate the LP of sheep, the following five mathematical methods were used:

Method 1 - (Kominakis *et al.*, 2002):

$$P_1 = \hat{\beta}_k = \frac{\sum_{i=1}^n X_{ik} Y_{ik} - n \bar{X}_k \bar{Y}_k}{\sum_{i=1}^n X_{ik}^2 - n (\bar{X}_k)^2}$$

Where:  $\hat{\beta}_k$ : slope of the regression line of the  $k$ -th ewe, expressing the rate of decline in milk production after the peak performance of the  $k$ -th ewe ( $k=1, \dots, 45$ ).  $Y_{ik}$ : milk production of the  $k$ -th ewe on the  $i$ -th milk production day of the test day ( $i=1, \dots, 84$ ).  $\bar{Y}_k$ : average milk production on the test day in the  $k$ -th ewe.  $\bar{X}_k$ : average days of milk production in the  $k$ -th ewe.  $n_k$ : days of milk production of the  $k$ -th sheep.

Method 2 - (Wood, 1970):

$$P_2 = S = -(\mathbf{b} + 1) \ln \mathbf{c}$$

Where:  $\mathbf{b}$  and  $\mathbf{c}$ : parameters to be estimated from the lactation curve.  $\ln$ : natural logarithm.

To obtain parameters  $\mathbf{b}$  and  $\mathbf{c}$  from this second method, it was necessary to start from the Wood model (1967), whose mathematical function is:  $Y_t = \mathbf{a} t^{\mathbf{b}} e^{-\mathbf{c}t} + \varepsilon_t$ , where  $Y_t$ : milk production obtained on day  $t$ ;  $\mathbf{a}$ : scale factor, or milk production at the beginning of lactation;  $\mathbf{b}$ : slope of the curve in the ascending phase;  $e$ : natural logarithm;  $\mathbf{c}$ : slope of the curve in the descending phase;  $\varepsilon_t$ : random error. By means of a logarithmic transformation, this model became:  $\ln(y_t) = \ln \mathbf{a} + \mathbf{b} \ln t - \mathbf{c}t$ , and when solving by linear regression, the final values of parameters  $\mathbf{a}$  and  $\mathbf{c}$  were 901.2 mL and  $-0.01299$ , respectively, values that were used in the estimation of Method 2.

Methods 3 and 4 - Johansson and Hansson (1940):

$P_3 = R_{2:1}$  rate between milk production in the second third of lactation after lambing and the first third (%)

$P_4 = R_{3:1}$  rate between milk production in the last third of lactation after lambing and the first third (%)

Method 5 - (Keskin and Dag, 2006):

$$P_5 = \frac{\sum_{i=1}^k (pi + 1) / pi}{k} \times 100$$

Where:  $pi$ : production of the  $i$ -th milk record starting at the time of maximum milk production (peak lactation).  $k$ : record number between the time of peak lactation until the end of lactation.

## RESULTS AND DISCUSSION

Table 1 presents the results of the persistency estimators, according to the five methods used in the study.

The literature on lactation persistency in non-dairy ewes is very limited. Therefore, information from dairy cows and ewes will be presented for illustrative purposes only. Readers are advised to interpret the results with great caution, especially those from dairy ewes, since, on the one hand, there are differences in the zootechnical function of the ewes (dairy *vs.* non-dairy), in addition to the differences in feeding and general management of these populations.

The average  $P_1$ , expressed as a regression coefficient, indicates that after milk production reached the peak of lactation, Rambouillet ewes lost on average,  $6.3 \text{ mL d}^{-1}$ , a value slightly higher than the average obtained by Kominakis *et al.* (2002) in Boutsico sheep from Greece ( $-3.3 \text{ mL d}^{-1}$ ), which are dairy ewes. This indicates that, using this method, the persistency of Rambouillet ewes is lower than that of Boutsico ewes.

**Table 1.** Averages and standard errors (SE) of the lactation persistency estimators in Rambouillet ewes, according to the methods used\*.

Persistency measures	Average	Standard error
$P_1 \text{ (mL d}^{-1}\text{)}$	-6.3	$\pm 0.4$
$P_2$	4.8	$\pm 0.1$
$P_3 \text{ (%)}$	108.9	$\pm 3.7$
$P_4 \text{ (%)}$	72.0%	$\pm 3.2$
$P_5 \text{ (%)}$	11.1%	$\pm 12.7$

\*: described in the Materials and Methods section.

The estimated average of  $P_2$  was slightly lower than that obtained by Franci *et al.* (1999) in Massese dairy ewes from Italy, who used the same method in 3 types of lactations, named: Type 1 (short lactation in the fall with a duration of 136 days), Type 2 (short lactation in the spring with a duration of 93.7 days), and Type 3 (long lactation with a duration of 204.8 days), having obtained averages of 5.32, 4.93, and 5.35, for Type 1, Type 2, and Type 3 lactations, respectively, noting that the average estimated in this study is very close to that obtained by these authors (Franci *et al.*, 1999) in Type 2 lactation. In Suffolk and Columbia ewes, meat and wool producers, mated with North Country Cheviot, Dorset, Finnsheep and Romney Marsh sires, Torres-Hernández and Hohenboken (1980) obtained an average of 5.1 in  $P_2$ , a slightly higher value than that of the present study. On the other hand, Nezamidoust *et al.* (2013) found an average of 6.9 in  $P_2$  in Makui ewes from Iran, which are used in that country for milk, meat and wool production. From the results of these studies (Torres-Hernández and Hohenboken, 1980; Franci *et al.*, 1999; Nezamidoust *et al.*, 2013), it is observed that, in all cases, the persistency averages were greater than the average persistency obtained in the Rambouillet ewes of this study, although the average of this study was further from the average of the studies that used dairy ewes.

Methods 3 and 4, which are persistency measures that use proportions (Johansson and Hansson, 1940), have been most widely used in dairy cows and, unlike the other methods, are measures that indicate the rate of decline in milk production (in %) relative to the production level at the beginning of lactation. The average  $P_3$  in this study was too large compared to the average obtained by Madsen (1975) in Red Danish dairy cows from Denmark using the same method, which was 87.62%. Using the same method, Pesántez *et al.* (2014) found an average  $P_3$  of 69.4% in Anglo Nubian  $\times$  Criolla goats from Ecuador. Also in goats, other averages of  $P_3$  obtained have been: 59.2% in Bornova goats from Turkey (Takma *et al.*, 2009), 64.2% in Dhofari goats from Egypt (El-Wakil and Fooda, 2013), and 60.2% in Beetal goats from Pakistan (Waheed and Kan, 2013). In the same population of Red Danish dairy cows, Madsen (1975) obtained an average of 75.9% of  $P_4$ , a value higher than the average obtained in this study. On the other hand, in Dairy-mead dairy sheep from New Zealand, Marshall *et al.* (2023) used a method similar to the  $P_4$  method developed by Madsen (1975) and interpreted as  $P_{3;1}$ , in which these authors (Marshall *et al.*, 2023) related the amount of milk produced in the last third of lactation with the amount of milk produced in the first third of lactation, expressed in %. Thus, the more persistent the curve, the closer its value will be to 100%; the average they found was 57.8%. In tropical dairy goats in Colombia, Henao *et al.* (2017) used the method where  $P = (\text{average milk production during lactation} / \text{peak production}) \times 100$ , proposed by Montaldo *et al.* (1997), and obtained a persistency rate of 64.3%. The results for  $P_3$  and  $P_4$  from previous studies also show higher persistency rates than those obtained in the Rambouillet sheep in the present study.

Regarding Method 5, Keskin and Dag (2006), calculated the value of  $P_5$  in native Akkaraman sheep from Turkey, using the models Wood ( $Y_t = \mathbf{a}t^{\mathbf{b}} e^{-\mathbf{c}t}$ ), quadratic ( $Y_t = \mathbf{a} + \mathbf{b}t + \mathbf{c}t^2$ ), and cubic ( $Y_t = \mathbf{a} + \mathbf{b}t + \mathbf{c}t^2 + \mathbf{d}t^3$ ), and having obtained averages of  $P_5$  of 86.8, 79.7, and 81.6%, for the Wood, quadratic, and cubic models, respectively. This

also means greater persistency rates than those of the Rambouillet sheep in this study. It is not advisable to use this  $P_5$  method because its standard error was greater than the value of the estimator, which could be attributed to the sample size used in the present study. In Mexico, Velarde-Guillén *et al.* (2022) estimated the LP in crosses of sheep, mainly East Friesian and Awassi, using the method where  $P = (Y_{150} - Y_{42}) / (150 - 42) \times 100$ , where:  $Y_{150}$  and  $Y_{42}$  represent milk production on days 150 and 42 of lactation, respectively. These authors (Velarde-Guillén *et al.*, 2022) explain that this definition of persistency indicates the slope of the regression line from day 42 to 150 of lactation, expressed in  $g\ d^{-1}$  and that, furthermore, the more negative its value, the lower the LP will be. Thus, the average obtained by the authors of this study was  $-3.5\ g\ d^{-1}$ .

After reviewing the previous studies in the literature carried out on ewes, goats and cows, it can be stated that the differences between the present study and the studies reviewed here can be attributed mainly to the fact that most of the reviewed studies to measure the LP have used animals specialized in milk production, and it must be taken into account that the zootechnical function of Rambouillet sheep in Mexico is for wool production. However, it is important to note that their average is comparable to the LP averages obtained by Madsen (1975) in Red Danish dairy cows using the  $P_4$  method, Torres-Hernández and Hohenboken (1980) in crosses of meat and wool sheep using the  $P_2$  method, and Kominakis *et al.* (2002) in Boutsiko dairy ewes using the  $P_1$  method.

## CONCLUSIONS

Sheep milk production systems in Mexico are recent, due to the introduction to the country of dairy sheep breeds such as East Friesian, Awassi, Lacaune, and Assaf. A lactation curve represents milk production during the lactation period, while lactation persistency describes the ability of a cow, ewe, or goat to maintain constant milk production after reaching peak milk production. A high persistency of the lactation curve is highly desirable due to the benefits in feed costs and some reproductive aspects. In the present study, lactation persistency was estimated using five methods ( $P_1$ ,  $P_2$ ,  $P_3$ ,  $P_4$ , and  $P_5$ ) reported in scientific literature. Based on the magnitude of the estimators obtained, the best methods to estimate lactation persistency in Rambouillet sheep were  $P_1$ ,  $P_2$ , and  $P_4$ .

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## REFERENCES

- Ángeles-Hernández, J.C., Guerrero-Loredo, A., Solís-Guzmán, D.A., Ramírez-Pérez, A.H., Ángeles-Campos, S., & González-Ronquillo, M. (2018). Efecto del grupo genético sobre características de la curva de lactación ovina. *Ecosistemas y Recursos Agropecuarios*. 5(14), 327-333. <https://doi.org/10.19136/era.a5n14.1425>
- Chay-Canul, A.J., Parra-Bracamonte, G.M., López-Villalobos, N., Herrera-Ojeda, J.B., Magaña-Monforte, J.G., Peniche-González, I.N., Herrera-Camacho, J., & García-Herrera, R. (2020). Milk yield and composition of Katahdin and Pelibuey ewes in tropical conditions. *Journal of Animal and Feed Sciences*. 29(4), 352-357. DOI: 10.22358/jafs/129966/2020

- Cobuci, J.A., Euclides, R.F., Pereira, C.S., de Almeida-Torres, R., Costa, C.N., & Lopes, P.S. (2003). Persistency in lactation – a review. *Archivos Latinoamericanos de Producción Animal*. 11(3), 163-173.
- Dekkers, J.C.M., Ten-Hag, J.H., & Weersink, A. (1998). Economic aspects of persistency of lactation in dairy cattle. *Livestock Production Science*. 53(3), 237-252. [https://doi.org/10.1016/S0301-6226\(97\)00124-3](https://doi.org/10.1016/S0301-6226(97)00124-3)
- Dobson, H., Smith, R.F., Royal, M.D., Knight, C.H., & Sheldon, I.M. (2007). The high producing dairy cow and its reproductive performance. *Reproduction in Domestic Animals*. 42(Suppl 2), 17-23. <https://doi.org/10.1111%2Fj.1439-0531.2007.00906.x>
- El-Wakil, S.I., & Fooda, T.A. (2013). The potentiality of milk production and lactation curve in Dhofari goat. *Egyptian Journal of Sheep and Goat Sciences*. 8(2), 21-31. DOI: <https://doi.org/10.21608/ejsgs.2013.26772>
- Franci, O., Pugliese, C., Acciaoli, A., Parisi, G., & Lucifero, M. (1999). Application of two models to the lactation curve of Massese ewes. *Small Ruminant Research*. 31(2), 91-96. [https://doi.org/10.1016/S0921-4488\(98\)00130-8](https://doi.org/10.1016/S0921-4488(98)00130-8)
- García, E. (2004). Modificaciones al Sistema de Clasificación Climática de Köppen. Quinta edición. Instituto de Geografía, UNAM. México.
- García-Díaz, L.K., Mantecón, A.R., Sepúlveda, W.S. & Maza, M.T. (2012). Producción de leche ovina como alternativa de negocio agropecuario: modelo de producción en Castilla y León (España). *Revista Mexicana de Agronegocios*. 31, 6-18. DOI: 10.22004/ag.econ.130890
- Henaó, K.T., Blandón, Y.A., González-Herrera, L.G., Cardona-Cadavid, H., Corrales, J.D., & Calvo, S.J. (2017). Efectos genéticos y ambientales sobre la curva de lactancia en cabras lecheras del trópico. *Livestock Research for Rural Development*. 29(97). <http://www.lrrd.org/lrrd29/5/hena29097.html>
- Johansson, I., & Hansson, A. (1940). Causes of variation in milk and butterfat yield of dairy cows. *Kungliga Lantbruksakademiens Handlingar*. 79(62), 1-127.
- Keskin, I., & Dag, B. (2006). Comparison of different mathematical models for describing the complete lactation of Akkaraman ewes in Turkey. *Asian-Australasian Journal of Animal Sciences*. 19(11), 1551-1555. DOI:10.5713/ajas.2006.1551
- Kominakis, A.P., Rogdakis, E., & Koutsotolis, K. (2002). Genetic aspects of persistency of milk yield in Boutsico dairy sheep. *Asian-Australasian Journal of Animal Sciences*. 15(3), 315-320. <https://doi.org/10.5713/ajas.2002.315>
- Madsen, O. (1975). A comparison of some suggested measures of persistency of milk yield in dairy cows. *Animal Science*. 20(2), 191-197. <https://doi.org/10.1017/S0003356100035182>
- Marshall, A.C., López-Villalobos, N., Loveday, S.M., Ellis, A., & McNabb, W. (2023). Modelling lactation curves for dairy sheep in a New Zealand flock. *Animals*. 13(3), 349. <https://doi.org/10.3390/ani13030349>
- Merchant, I., Orihuela, A., Vázquez, R., & Aguirre, V. (2021). Characterization of the lactation curve and milk quality in Santa Cruz sheep. *Revista Mexicana de Ciencias Pecuarias*. 12(2), 644-652. <https://doi.org/10.22319/rmcp.v12i2.5519>
- Montaldo, H., Almanza, A., & Juárez, A. (1997). Genetic group, age and season effects on lactation curve shape in goats. *Small Ruminant Research*. 24, 195-202. <http://www.sciencedirect.com/science/article/pii/S0921448896009467>
- Nezamidoust, M., Kominakis, A., & Safari, A. (2013). Use of Wood's model to analyze the effects of milking methods on lactation curve in sheep. *Small Ruminant Research*. 113(1), 195-204. <https://doi.org/10.1016/j.smallrumres.2013.01.019>
- Ochoa-Cordero, M. A., Torres-Hernández, G., Ochoa-Alfaro, A. E., Vega-Roque, L., & Mandeville, P. B. (2002). Milk yield and composition of Rambouillet ewes under intensive management. *Small Ruminant Research*, 43(3), 269-274. DOI: 10.1016/S0921-4488(02)00019-6
- Ochoa-Alfaro, A.E., Vega-Roque, L., Ochoa-Cordero, M.A., Mandeville, P.B., & Torres-Hernández, G. (2009). Características físico-químicas de la leche de ovejas Rambouillet bajo manejo intensivo. *Revista Científica, FCV-LUZ*. 19(2), 196-200. <https://www.redalyc.org/articulo.oa?id=95911642014>
- Pesántez, M., Hernández, A., & Fraga, L.M. (2014). Persistency of milk yield in Anglo Nubia × Criolla goats. *Cuban Journal of Agricultural Science*. 48(4), 337-342. <https://ejascience.com/index.php/CJAS/article/view/560>
- Rodríguez-Álvarez, H.A., Hinojosa-Cuéllar, J.A., González-Garduño, R., Gallegos-Sánchez, J., Rubio-Rubio, M., Aranda-Ibáñez, E.M., Oliva-Hernández, J., & Torres-Hernández, G. (2021). Lactation curve, milk production of Pelibuey ewes, and preweaning growth rate of the lambs. *Agro Productividad*. <https://doi.org/10.32854/agrop.v14i6.1850>
- Schutz, M.M., Hansen, L.B., Steuernagel, G.R., & Kuck, A.L. (1990). Variation of milk, fat, protein, and somatic cells for dairy cattle. *Journal of Dairy Science*. 73, 484-493. [https://doi.org/10.3168/jds.S0022-0302\(90\)78696-1](https://doi.org/10.3168/jds.S0022-0302(90)78696-1)

- Swalve, H.H., & Gengler, N. (1999). Genetics of lactation persistency. *BSAP Occasional Publication*. 24(1), 75-82. <https://doi.org/10.1017/S1463981500043090>
- Takma, C., Akbas, Y., & Taskin, T. (2009) Modeling lactation curves of Turkish Saanen and Bornova goats. *Asian Journal of Animal and Veterinary Advances*. 4(3), 122-129. DOI: 10.3923/ajava.2009.122.129
- Torres-Hernández, G., & Hohenboken, W.D. (1980). Biometric properties of lactation in ewes raising single or twin lambs. *Animal Production*. 30, 431-436. DOI: <https://doi.org/10.1017/S0003356100024260>
- Torshizi, M.E., Mashhadi, M.H., Farhangfar, H. 2019. Different aspects of lactation persistency in dairy cows. *Indian Journal of Animal Science*. 89(6), 607-614. <https://doi.org/10.56093/ijas.v89i6.91098>
- Velarde-Guillén, J., López-Villalobos, N., Sainz-Ramírez, A., González-Sánchez, M., Arriaga-Jordán, C. M., & Albarrán-Portillo, B. (2022). Factors affecting the lactation curve parameters of crossbred dairy ewes in a flock of the highlands of Mexico. *Tropical Animal Health and Production*. 54(6), 373. <https://doi.org/10.1007/s11250-022-03371-9>
- Waheed, A., & Khan, M.S. (2013). Lactation curve of Beetal goats in Pakistan. *Archives Animal Breeding*. 56, 89. <https://doi.org/10.7482/0003-9438-56-089>
- Wood, P.D.P. (1967). Algebraic model of the lactation curve in cattle. *Nature*. 216(5111), 164-165. <https://doi.org/10.1038/216164a0>
- Wood, P.D.P. (1970). A note on the repeatability of parameters of the lactation curve in cattle. *Animal Production*. 12(3), 535-538. <https://doi.org/10.1017/S0003356100029135>

