

Effect of Dietary Energy Level on Milk Production in New Zealand White and Californian Does

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Citation: Pérez-Cruz, K. U., Herrera-Haro, J. G., Crosby-Galván, M. M., Martínez-Aispuro, J. A., Sánchez-Ramírez, E., Luis-Chincoya, H., & Barreras-Serrano, A. (2026). Effect of Dietary Energy Level on Milk Production in New Zealand White and Californian Does. *Agro Productividad*. <https://doi.org/10.32854/kxbwj325>

Academic Editor: Jorge Cadena Iñiguez

Associate Editor: Dra. Lucero del Mar Ruiz Posadas

Guest Editor: Juan Francisco Aguirre Medina

Received: November 30, 2025.

Accepted: March 16, 2026.

Published on-line: April XX, 2026.

Agro Productividad, 19(3). March. 2026. pp: 135-145.

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ABSTRACT

Objective: To evaluate milk yield in New Zealand White and Californian rabbit does fed high-energy diets.

Methodology: Milk production was measured in 72 New Zealand White and Californian does from kindling to 35 days postpartum. Four high-energy diets were formulated using the same ingredients, maintaining 17% crude protein (CP) and 14% crude fiber (CF), with progressively higher digestible energy (DE; kcal kg⁻¹) achieved by adding soybean oil. Milk yield was estimated under a controlled suckling scheme across six consecutive 7-day periods. A 2×4 factorial arrangement (breed×diet) was implemented in a completely randomized design. Data were analyzed using the MIXED procedure in SAS (v. 9.4). Wood's lactation model was fitted to describe milk-production dynamics, estimate the day of peak yield, and assess lactation persistence.

Results: No differences in milk production were detected among treatments. The lactation curve showed an early peak (day 17) and moderate persistence (0.5). Average feed intake was similar across treatments, with no significant differences ($p > 0.05$).

Study limitations: The effects of high-energy diets were assessed in purebred animals; however, it would be pertinent to include both direct and reciprocal crosses in future studies.

Conclusions: Diets containing at least 17% crude protein and 2700 kcal DE·kg⁻¹ are recommended to sustain adequate milk production in New Zealand White and Californian rabbit does.

Keywords: Lactating doe, milk yield, digestible energy, Wood's model.

INTRODUCTION

In Mexico, small-scale rabbit production in family farms is based primarily on New Zealand White (NZW), Californian (CAL), and Chinchilla breeds, as well as



their crosses. The NZW and CAL breeds exhibit high prolificacy, with litter sizes of 8 to 10 live-born kits (Ponce *et al.*, 2003), dressing percentages ranging from 56 to 58% at the end of the fattening period (Pla *et al.*, 1998), and high growth rates that allow them to reach market weight at 10 to 12 weeks of age (Lounaouci *et al.*, 2008), with daily weight gains of 35-42 g/day and slaughter weights of 2.0-2.2 kg (Blumetto, 2007). Rabbit meat production is considered an alternative to meet future food needs in rural and peri-urban production units, where this species can provide substantial amounts of meat for household consumption with relatively low investment (Bronio & Guzmán, 2003; Murillo, 2016). One of the key biological components to monitor within the family rabbit production system (FRPS) is kit output and milk production (MP), as the latter plays a pivotal role in kit survival and optimal growth (Gómez, 2006; Gómez *et al.*, 2011). Ludwiczak *et al.* (2020) estimated milk production in rabbit does and reported total solids contents of 27.6-29.0%, protein at 8.4-11.6%, fat at 11.6-13.8%, lactose at 1.4-2.6%, and ash at 1.7-2.1%. In addition, gross energy content has been reported at 2,220 kcal kg⁻¹ (Rommers *et al.*, 1999). Maertens *et al.* (2006) noted that rabbit milk contains higher protein and fat concentrations than that of other species. This distinctive nutritional profile may help explain the rapid growth of kits from birth to weaning, as the elevated levels of these nutrients contribute to accelerated offspring development (Rommers *et al.*, 1999). Reproductive does frequently experience a negative energy balance due to the high nutrient demand associated with milk synthesis. These requirements are often not fully met by voluntary feed intake, leading to the mobilization of body reserves to compensate for the energetic deficit (Xiccato *et al.*, 1999). A common strategy to mitigate excessive mobilization of body reserves in does is to increase the dietary energy density during lactation through the inclusion of fat or highly digestible carbohydrates, such as starch (Cervera *et al.*, 1993; Fortun-Lamothe, 1997). Prasad and Karim (1998) compared three energy and protein levels in the performance of lactating-pregnant does, obtaining average MP values of 105.7 g day⁻¹. Similarly, Pascual *et al.* (1999) evaluated the effects of three dietary energy levels on milk yield and composition in NZW and CAL does, reporting increased milk volume with high-fat diets and improved litter survival. The working hypothesis was that consumption of diets with a high concentration of digestible energy would increase milk production in does without altering feed intake. Therefore, the aim of this study was to compare milk production and feed intake in New Zealand White and Californian rabbit does fed high-energy diets during the lactation period.

MATERIALS AND METHODS

All animal-handling procedures and analyses were conducted in accordance with the Animal Welfare Committee regulations of the Colegio de Postgraduados (COBIAN/025/25; COLPOS, 2016).

Study location

This study was carried out at the rabbit unit of the Colegio de Postgraduados, Montecillo Campus, located at 19° 27' 35" N and 98° 54' 16" W, at an altitude of 2,220 m above

sea level, with a mean annual temperature of 15.9 °C and mean annual precipitation of 686 mm (INEGI, 2025). A total of 36 New Zealand White (NZW) and 36 Californian (CAL) does were used. Animals were housed in individual Extrona cages (90×50×40 cm), each equipped with an automatic drinker and a feeder (20×20×20 cm). The study was conducted from June to August; during this period, the mean recorded temperature was 22.5 ± 2.1 °C. The experimental period comprised 35 days of evaluation.

Reproductive management

The does used in this study were second-parity females. Artificial insemination (AI) was performed in all breeding does. Semen collection and evaluation procedures followed Luis *et al.* (2020). Semen was obtained from adult males of the same breed, 18 months of age, previously trained for semen collection. Semen was diluted with 0.9% sodium chloride solution (PISA) to achieve a final concentration of 20×10^6 spermatozoa. New Zealand White and Californian does were inseminated with a 0.5 mL dose deposited into the reproductive tract using a QHWJ (China) insemination gun; immediately thereafter, 0.2 mL of the gonadotropin-releasing hormone (GnRH) analog buserelin (SANFER) was administered intramuscularly (Dimitrova *et al.*, 2009). Pregnancy diagnosis was performed 14 days post-insemination. On day 28 of gestation, a nest box containing wood shavings was placed in each doe's cage and completed with fur pulled by the doe. Within the first hours after kindling, litter size and litter weight were recorded. Subsequently, litters were standardized to eight kits per doe in both breeds to promote maximal milk production (Singh, 1996).

Treatments and experimental diets

All diets were formulated according to the nutritional requirements recommended by De Blas and Wiseman (2020) for lactating does, varying the energy content across treatments. The calculated composition and the ingredients used in diet preparation are presented in Table 1.

Four isoproteic diets (T1, T2, T3, T4) were formulated with increasing digestible energy (DE) in 100-unit increments: 2600, 2700, 2800, and 2900 kcal kg⁻¹, respectively. The increase in energy was achieved by raising the inclusion level of soybean oil, while maintaining protein (17%), neutral detergent fiber (NDF; >30%), acid detergent fiber (ADF; 20%), and other nutrients as recommended by De Blas and Wiseman (2020). Diets were then mixed and pelleted to a 3-mm diameter. Recently kindled does (36 NZW and 36 CAL) were randomly allocated to the four treatments, with nine replicates per breed.

Feed intake

A total of 1.00 kg of feed per doe per day was offered in the morning (08:00 h). Feed intake was determined by weighing feed refusals and calculated as the difference between the amount offered and the amount refused. Measurements were recorded across five 7-day periods until the end of lactation (35 days).

Table 1. Composition of high-energy diets for lactating rabbit does.

Ingredient	Diet 1 (%)	Diet 2 (%)	Diet 3 (%)	Diet 4 (%)
Ground alfalfa	40.93	42.02	43.18	44.44
Corn	20.00	20.00	20.00	20.00
Dried distillers grains	15.00	15.00	15.00	11.42
Wheat bran	9.40	5.82	1.98	0.00
Canola meal	7.00	7.00	7.00	7.00
Soybean oil	4.16	5.82	7.50	9.36
Soybean meal	1.88	2.71	3.60	5.89
Common salt (NaCl)	0.30	0.30	0.30	0.33
L-lysine HCl	0.26	0.25	0.24	0.21
Mineral premix	0.25	0.25	0.25	0.25
Yeast	0.20	0.20	0.20	0.20
DL-methionine	0.19	0.20	0.21	0.25
Orthophosphate	0.14	0.23	0.33	0.45
L-threonine	0.11	0.11	0.10	0.11
Coccidiostat (Robenidine)	0.10	0.10	0.10	0.10
Calcium carbonate	0.08	—	—	—
Calculated nutrient composition				
Nutrient	Diet 1 (%)	Diet 2 (%)	Diet 3 (%)	Diet 4 (%)
Digestible energy (DE; kcal kg ⁻¹)	2600	2700	2800	2900
Crude protein (CP; %)	17.00	17.00	17.00	17.00
Crude fiber (CF; %)	14.00	14.00	14.00	14.00
Dry matter (DM; %)	90.21	90.43	90.66	90.89
Ether extract (EE; %)	7.33	8.91	10.51	12.09
Ash (%)	7.16	7.18	7.29	7.48
Neutral detergent fiber (NDF; %)	33.26	32.48	31.64	30.32
Acid detergent fiber (ADF; %)	20.12	20.13	20.14	20.06
Lysine (Lys; %)	0.90	0.90	0.90	0.90
Methionine + cysteine (Met+Cys; %)	0.69	0.69	0.69	0.69
Threonine (Thr; %)	0.74	0.74	0.74	0.74
Tryptophan (Trp; %)	0.20	0.20	0.20	0.21
Calcium (Ca; %)	0.80	0.80	0.83	0.88
Phosphorus (P; %)	0.45	0.45	0.45	0.45

Abbreviations: DE, digestible energy; CP, crude protein; CF, crude fiber; DM, dry matter; EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber; Lys, lysine; Met+Cys, methionine + cysteine; Thr, threonine; Trp, tryptophan; Ca, calcium; P, phosphorus.

Milk production

Milk production (MP) was estimated throughout lactation using the controlled-lactation method described by Gómez *et al.* (2008), which consisted of recording kit body weight immediately before and after nursing. The resulting weight difference was attributed to the amount of milk produced by the doe (McNitt & Lukefahr, 1990; Gómez *et al.*, 2008).

Statistical analysis

The Shapiro-Wilk test was used to assess data normality. To compare the effects of treatment and period, as well as their interaction, a joint adjustment was performed by simultaneously incorporating the effects of breed and energy level, grouping treatments in a 2×4 factorial arrangement (two breeds and four energy levels). Milk-production data were analyzed using a model that included the fixed effects of treatment and period, as well as their interaction (treatment×period), with doe included as a random effect. The general model was as follows:

$$Y_{ijkl} = \mu + T_i + d_{ij} + P_k + (TP)_{ijk} + \varepsilon_{ijkl}$$

where: Y_{ijkl} : Daily milk production of the doe receiving the i th treatment in the j -th period; μ : Overall mean; T_i : Effect of the i -th treatment ($i=1-4$); d_{ij} : Error term associated with the effect of the i -th treatment; P_k : Effect of the k -th period ($k=1-6$); $(TP)_{ijk}$: Effect of the interaction between the i -th treatment and the j -th period; ε_{ijkl} : Random error.

To characterize the dynamics of the milk-production curve and feed intake across periods, a nonlinear exponential regression was performed by fitting Wood's model (1967), which describes an incomplete gamma function, as follows:

$$Y_n = a n^b e^{-cn}$$

where: Y_n : Mean milk production of the doe across different time periods; a : Milk yield at the onset of lactation ($g \text{ day}(b+1)$); b : Rate of increase up to peak lactation; c : Rate of decline after peak lactation (days); n : Time period at which milk production is estimated; e : Base of the natural logarithms (2.71828).

Wood's equation (1967) describes the milk-yield curve, allowing estimation of the rate of increase in milk production from kindling until the doe reaches peak yield, followed by a gradual decline. This model enables the estimation of maximum yield, time to peak production, and lactation persistence.

To estimate the day at peak production, maximum milk yield, and persistence, the following equations were used: day at peak production: $n = b/c$; maximum yield $MY = a(b/c)^b e^{-b}$; persistence: $S = c - (b+1)$.

RESULTS AND DISCUSSION

Milk production

Milk production in rabbit does is a critical factor for achieving heavier kit weights at weaning (35 days). Milk-production (MP) results for New Zealand White (NZW) and Californian (CAL) does fed high-energy diets are presented in Table 2. No differences in MP were observed ($p>0.05$) among the different energy levels (2600, 2700, 2800, and 2900 kcal DE kg^{-1}). In NZW does, the highest MP was recorded in period 4 (day 21) for treatments (T) 2, 4, and 3, with values of 229.78, 209.11, and 197.78 g day^{-1} , respectively;

Table 2. Mean milk production and feed intake of New Zealand White and Californian rabbit does by period.

Period (days)	New Zealand White				California			
	MP/ Treatment (g day ⁻¹)				MP/ Treatment (g day ⁻¹)			
	1	2	3	4	1	2	3	4
1	88.44 ^a	81.11 ^a	70.67 ^a	88.00 ^a	62.44 ^a	72.00 ^a	67.11 ^a	71.33 ^a
7	146.00 ^b	172.22 ^a	118.67 ^c	143.56 ^b	134.89 ^a	136.00 ^a	118.89 ^b	112.44 ^b
14	195.78 ^b	215.78 ^a	176.44 ^c	191.33 ^b	189.33 ^a	194.00 ^a	173.56 ^b	177.56 ^a
21	184.44 ^c	229.78 ^a	197.78 ^b	209.11 ^b	198.44 ^a	199.43 ^a	156.89 ^b	151.67 ^b
28	136.83 ^a	148.44 ^a	140.67 ^a	151.11 ^a	148.22 ^b	192.29 ^a	157.41 ^b	140.22 ^b
35	77.78 ^c	126.89 ^a	91.11 ^b	104.44 ^b	97.33 ^b	132.00 ^a	120.22 ^a	74.44 ^c
SEM	10.53	10.50	10.50	10.50	10.50	11.90	10.57	10.50
** Feed intake (g day⁻¹)								
	318.80	335.50	295.00	294.00	338.69	335.45	299.69	291.47

Abbreviations: T, treatment; P, period; T×P, treatment×period; MP, milk production (g day⁻¹); feed intake, mean feed intake (g day⁻¹).
 Notes: ^{a, b, c} Means with different superscripts within periods differ (p>0.05).

in T1, the highest value occurred on day 14 (195.78 g day⁻¹). In CAL does, the greatest MP was observed in period 4 (day 21) for T1 and T2, with values of 198.44 and 199.43 g day⁻¹, respectively, whereas in T3 and T4 the highest MP occurred on day 14 (173.56 and 177.56 g day⁻¹, respectively). These findings are consistent with Pascual *et al.* (1999), who evaluated lactating NZW×CAL does fed three diets differing in energy density (2600, 2915, and 2965 kcal DE kg⁻¹) and reported that increasing dietary energy did not translate into significant increases (p>0.05) in MP.

Food consumption

In the New Zealand White (NZW) breed, the highest feed intake was observed in T2 (335.45 g day⁻¹), followed by T1, T3, and T4, with intakes of 318.80, 295.00, and 294.00 g day⁻¹, respectively. As shown in Figure 1, feed intake increased across the four treatments; however, no significant differences were detected (p>0.05).

In Californian (CAL) does, the highest feed intake was observed with diet 1 (338.69 g day⁻¹), followed by T2, T3, and T4, with values of 335.45, 299.69, and 291.61 g day⁻¹,

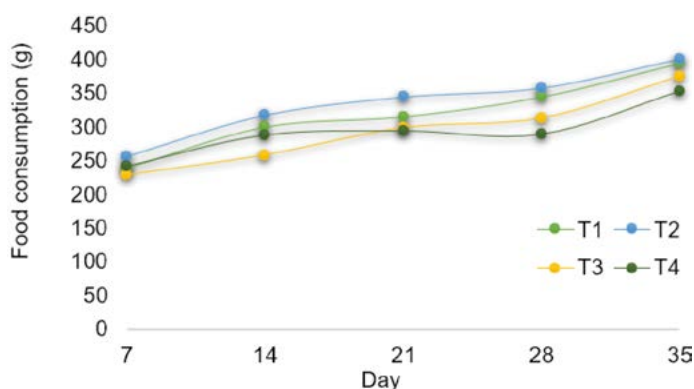


Figure 1. Feed intake of 36 New Zealand White (NZW) does across five observation periods.

respectively. As shown in Figure 2, feed intake increased across the four treatments, similarly to what was observed in NZW; however, no significant differences were detected among treatments ($p > 0.05$).

The present results are consistent with those reported by Xiccato *et al.* (1995), who found feed intakes of 307, 315, and 302 g day⁻¹ in NZW and CAL does fed diets containing 2600, 2800, and 2900 kcal DE kg⁻¹, respectively. In contrast, Pascual *et al.* (1999) reported lower feed intake during lactation than that observed in the present study, with a mean intake of 150 g day⁻¹ across three diets. Likewise, Prasad and Karim (1998) reported feed intakes of 113.07 g day⁻¹ when varying dietary energy and protein levels.

Feed intake was similar across breeds and treatments, suggesting that increasing dietary energy through soybean oil inclusion did not adversely affect diet palatability. Nevertheless, a tendency toward lower intake was observed as dietary energy concentration increased. This pattern may reflect intake regulation driven by dietary energy density. These findings align with Xiccato (1996), who indicated that, in rabbits, feed intake is primarily regulated by a chemostatic mechanism aimed at maintaining a stable daily energy intake as part of energy homeostasis. This regulation is more pronounced in lactating animals than in growing rabbits, reflecting a physiological adaptation to meet the high nutrient demands of milk production.

Wood's model

Lactation is a highly complex biological process influenced by both genetic and environmental factors (Quintero *et al.*, 2007). Accordingly, a model capable of predicting maximum milk yield, lactation persistence, and the day on which peak production occurs is required. For this purpose, the incomplete gamma function fitted by Wood's model has been applied in rabbit does, allowing analytical estimation of maximum yield and time to reach peak production (Gómez *et al.*, 2023).

Milk production under the different diets, as a function of days in lactation, follows an exponential equation described as an incomplete gamma function. Figure 3 presents the mean milk production across the six periods for each treatment in NZW does, along with the MP trend line.

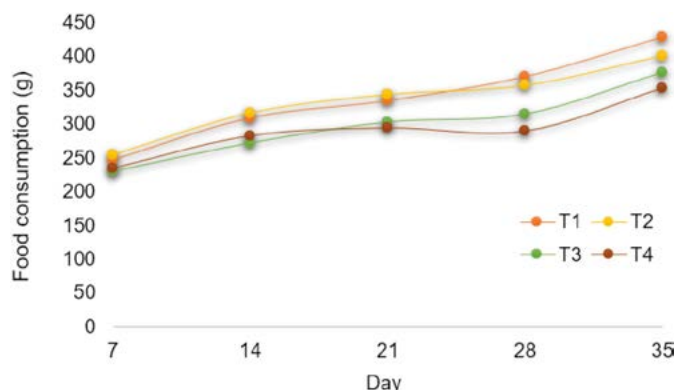


Figure 2. Feed intake of 36 Californian (CAL) does across five observation periods.

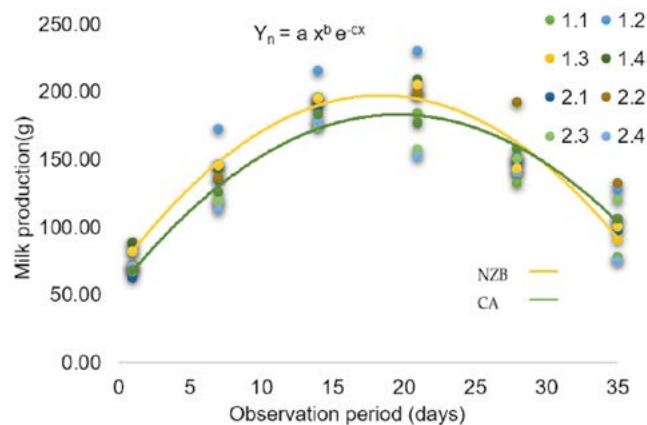


Figure 3. Milk-production curves for 36 New Zealand White (NZW; 1.1-1.4) and 36 Californian (CAL; 2.1-2.4) does, and their mean milk yield throughout a 35-day lactation.

The relationship between days in lactation and milk production (MP; Figure 3) indicates that, on average, does reached their highest MP between days 17 and 19, and MP began to decline from day 21 onward.

For CAL does, mean MP across the six periods for each treatment, together with the MP trend line, is also shown in Figure 3. The day-in-lactation-MP relationship similarly indicates that, on average, does achieved peak MP between days 18 and 19, after which MP began to decline from day 21 onward. In both breeds, peak production occurred at approximately day 19, closely matching the findings of Partridge and Allan (1982), who evaluated two diets with DE levels of 2800 and 2900 kcal and reported a production peak at 19 days. Xiccato *et al.* (1995) reported the highest production under high-energy diets (2600, 2800, and 2900 kcal DE kg⁻¹) between days 10 and 20 of lactation, with means of 233, 236, and 255 g day⁻¹, respectively. Other authors have reported peak production at 17 days (Gómez *et al.*, 2023) and as late as day 21 (Singh, 1996).

After fitting the incomplete gamma function using Wood's model solution procedure (Table 3), no significant differences were detected. In NZW does, the maximum yield (MY) was 215.33 g day⁻¹ for T2 on day 13 of lactation, followed by T4, T1, and T3, with values of 188.79, 187.95, and 173.75 g day⁻¹, respectively.

For CAL does, the maximum yield (MY) was observed in T1 (187.36 g day⁻¹), with peak production occurring on day 14 of lactation, followed by T2, T3, and T4, with values of 166.97, 162.91, and 159.15 g day⁻¹, respectively. Persistence (S) was similar in both breeds (NZW: 0.48-0.59; CAL: 0.45-0.67), suggesting a relatively pronounced post-peak decline from the third week onward, consistent with the increased energetic cost of lactation and the eventual mobilization of body reserves by the doe. This aligns with Gómez *et al.* (2023), who reported S values of 0.44.

An early lactation peak, occurring between days 18 and 21, represents the period of greatest nutrient demand, underscoring the need for adequate nutritional support during this phase to maximize MP and promote lactation-curve persistence (Maertens *et al.*, 2006). Mean MP values were slightly higher than those reported by McNitt and Lukefahr (1990), who observed a maximum MP of 185 g day⁻¹ at 20 days of lactation in NZW, CAL,

Table 3. Mean milk production and incomplete gamma-coefficient values for New Zealand White and California rabbits.

New Zealand White				
Estimators	Treatments			
	1	2	3	4
MP	137.40±19.72	162.37±22.76	132.55±19.98	147.92±19.26
A	75.39±30.72	49.95±30.05	44.05±21.77	58.96±18.76
b	0.61±0.26	0.75±0.36	0.87±0.29	0.55±0.19
c	0.05±0.02	0.05±0.02	0.06±0.02	0.03±0.01
S	0.50	0.56	0.59	0.48
b/c	12.06	13.19	14.30	13.13
MY	187.95	215.34	173.75	188.79
California				
MO	138.44±21.41	154.28±20.54	131.15±15.48	121.27±17.52
A	71.21±24.43	74.89±28.47	50.60±21.62	55.66±27.99
b	0.70±0.21	0.58±0.24	0.62±0.25	0.67±0.31
c	0.05±0.01	0.04±0.02	0.03±0.02	0.05±0.02
S	0.66	0.50	0.45	0.54
b/c	14.31	18.30	17.10	13.05
MY	187.36	166.98	162.91	159.15

MP: Mean milk production throughout lactation (g day^{-1}); a: Milk yield at the onset of lactation (g day^{-1}); b: Rate of increase in milk production up to the maximum; c: Rate of decline after the maximum; S: Persistence; b/c: Day at peak production; MY: Maximum yield (g day^{-1}).

CAL×NZW, and NZW×CAL does. Similarly, Xiccato *et al.* (1995) reported production values of 171, 180, and 191 g day^{-1} in NZW and CAL does. Pascual *et al.* (1999) reported a mean MP of 173.02 g day^{-1} , very close to that observed in the present study, and found that the highest MP occurred in the two high-energy diets (2915 and 2965 kcal). In another study, Pascual *et al.* (1999) reported mean milk production in NZW and CAL does of 164.0, 155.2, and 149.8 g day^{-1} for low (2350), medium (2650), and high (2950) DE diets, respectively. Gómez *et al.* (2008) reported peak production at 19 days (160 g day^{-1}) and a mean production of 122 g day^{-1} . In the study by Ludwiczak *et al.* (2020), which aimed to analyze milk quality, the highest values were reported (216.88 g day^{-1}) when the lactation period was shortened to 21 days, which may overestimate peak production and underestimate the decline phase when considering a 35-day lactation period.

CONCLUSIONS

Increasing digestible energy from 2600 to 2900 kcal kg^{-1} in diets for lactating rabbit does did not produce significant differences in milk production over the 35-day lactation period. Feed intake was similar across treatments and breeds, with a tendency to decrease as dietary energy increased, suggesting physiological regulation of intake as a function of energy supply. The incomplete gamma function adequately described the lactation curve in rabbit does. The lactation curve exhibited an average peak at day

17 postpartum, followed by a moderate decline from day 21 onward. Persistence was similar between breeds. Overall, the results suggest that, within the evaluated energy range, diets containing 17% crude protein and 2700 kcal DE kg⁻¹ are recommended to maintain MP in NZW and CAL does.

ACKNOWLEDGEMENTS

The authors thank the Secretariat of Science, Humanities, Technology and Innovation (SECIHTI) and the Colegio de Postgraduados, Montecillo Campus, for the support provided to conduct this study. This research forms part of the Knowledge Generation and Application Line (LGAC) “Efficient Livestock Production, Sustainable Welfare, and Climate Change” within the Genetic Resources and Livestock Productivity Program.

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