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Lactation curve, milk composition and metabolic status of goats from different genetic groups under tropical conditions

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Abstract The objectives of this study were 1) to compare models to describe the lactation curve of the Saanen, Moxotó, and Anglo-Nubian 2) to evaluate the effect of genetic groups on production and composition milk and efficiency of mobilization of body reserves during lactation. Twenty-three multiparous goats, newly calved, were divided into three treatments (genetic groups: 9 Saanen, 8 Moxotó, and 6 Anglo-Nubian). The goats were randomly distributed in collective pens, under the same feeding conditions. Five mathematical models were used to adjust the lactation curves: Wood (WD); Papajcsik and Bodero (PB); Adapted from Papajcsik and Bodero (APB); Nelder (ND) and Wilmink (WM). To indicate the best fit, the model evaluation system software was used, performing additional analyzes with the observed and predicted values for each fitted equation. There were differences (P<0.05) in the parameters a, b and c between the genetic groups in each mathematical model. The APB model is recommended for use in all genetic groups to evaluate milk yield (Y), following the parameters: $Y = 1.196+0.0545\times t\times e^{(-0.038\times t)}$ for Saanen, $Y = 0.297+0.031\times t\times e^{(-0.0462\times t)}$ for Moxotó and $Y = 0.757+0.0554\times t\times e^{(-0.0417\times t)}$ for Anglo-Nubian. The results for average milk production during 27 weeks of lactation were 1.37; 0.37 and 0.9 kg d^{-1} for Saanen, Moxotó and Anglo-Nubian, respectively. Except for lactose, there was a difference (P<0.05) between the genetic groups for milk composition and plasma beta-hydroxybutyrate (BHB) levels. Considering milk composition, the Saanen, Moxoto and Anglo Nubiana presented the averages (%) for fat of 3.66, 6.75, and 5.10, protein 3.32, 4.97, and 4.18 and lactose 4.28, 4.46, and 4.39%, respectively. There was no effect (P>0.05) on B-HBO in response to days of lactation, but Saanen and Anglo Nubian goats had higher plasma levels of this metabolite compared to Moxotó goats. Saanen had a greater weight loss of 12.83 kg, which was verified at 35 days of lactation. Saanen and Anglo-Nubian animals have a greater ability to mobilize body reserves compared to Moxotó. APB model is adequate to describe milk production of goats in tropical areas.

Keywords: Anglo-Nubian, beta-hydroxybutyrate, body weight change, Moxotó, Saanen

Introduction

The demand for goat milk has increased due to its beneficial properties for human health and higher concentrations of solids compared to cow milk (Nudda et al., 2019; Verruck et al., 2019). In this context, the introduction of specialized genotypes and the selection of adapted animals in production systems are the best strategies to increase productivity, milk composition and meet the consumer market demand (Amayi et al., 2016).

Studies have shown that the breed is an important factor that influences the milk composition (Bermejo et al., 2020; Brzáková et al., 2021). Among the genetic groups most used for the improvement of dairy herds in tropical regions are the Saanen, specialized in milk production and easy to handle (Tamime et al., 2011), and the Anglo Nubian, dual-purpose, improving the carcass weight and milk production (Chávari et al., 2020). The Moxotó breed, little studied, is quite rustic under tropical conditions and has low nutritional requirements (Araújo et al., 2017), being used in direct production or in crossbreeding with exotic breeds.

Several studies have analyzed the productive performance of these animals in different climatic conditions (Fonseca et al., 2016; Rocha et al., 2009), adaptability (Araujo et al., 2017), rearing systems (Felisberto Perdigão et al., 2016; Araújo et al., 2017) and feeding (Araújo et al., 2017; Ramos et al., 2017; Sousa et al., 2018; Fonseca et al., 2016). However, more studies with lactation curve, milk composition and metabolic responses of different genetic groups are crucial to improve the productivity of these animals under tropical conditions.

According to Bouallegue and M'Hamdi (2020), to describe the lactation curve, it is important to consider mathematical models that are easy to estimate the parameters, versatility (possibility of modeling the different constituents of milk and not just the amount of milk) and the quality of the adjustment (select models of lactation curves with a better adjustment to the observed data in models of milk production systems). Important to emphasize that under tropical conditions, these models have been more studied for dairy cattle (Veerkamp and Emmans, 1995; Yan et al., 2006; Oliveira et al., 2020) and there is still little information for goats. Therefore, it is necessary to test the different models to verify which best describes the lactation curve of the different genetic groups commonly exploited in these conditions.

In this context, the objectives of this research were 1) to compare models to describe the lactation curve of the Saanen, Moxotó, and Anglo-Nubian 2) to evaluate the effect of genetic groups on production and composition milk and efficiency of mobilization of body reserves during lactation.

Materials and methods

The experiment was carried out in the goat sector of the Experimental Farm of the Federal University of Bahia, located in the municipality of Entre Ríos (Latitude 11º56'31" south, Longitude 38º05'04" West, 162 m a.n.m), Bahia, Brazil. All the procedures with the animals were carried out with the authorization of the Ethics Committee in Animal Use (CEUA) of the Veterinary Medicine and Animal Science Department of the Federal University of Bahia, protocol N° 72/2014.

Animals, experimental design, and diets

Thirty adult and multiparous goats were subjected to a fixed-time artificial insemination protocol to constitute three experimental treatments according to the genetic group (10 Saanen, 10 Moxotó, and 10 Anglo-Nubian) adapted to the adverse conditions of the tropical region, which represent a dairy-purpose breed; a dual-purpose breed, and a breed considered without dairy ability, respectively. However, during the gestational, parturition, and postpartum periods, some animals presented problems such as spontaneous abortion and/or calving complications (1 Saanen, 2 Moxotó, and 4 Anglo-Nubian), therefore these animals were not considered in the statistical analyses. The goats were distributed in a completely randomized design being 9 of the Saanen breed, with initial body weight (BW) of 35.9 ± 1.3 kg, 8 of the Moxotó breed with initial BW of 25.9 ± 1.9 kg, and 6 of the Anglo-Nubian breed with initial BW of 42.6 ± 1.6 kg.

The animals were distributed in six collective pens (2.1 x 5 m; with a density of 2.1 m² per animal), covered, with a slatted floor, suspended, and provided with automatic drinkers (capacity of 7 L) and three feeders (totaling approximately 3.5 linear meters), with free access to water and feed. The animals were separated only by the genetic group, being two pens for the Saanen, two with Anglo-Nubian and two with Moxoto goats.

The experiment lasted 189 days, with nine experimental periods of 21 days each, beginning the first week of goat lactation, which were included in the experiment on different days according to the day of kidding. All animals were introduced into the experimental scheme during the first period, after which no other animals were introduced into the experiment.

The goats were kept feedlot under the same feeding management. The diets were formulated to meet the requirements of lactating goats with an expected daily milk production of 1.5 L, according to the NRC (2007). The forage and concentrate proportions were altered according to the lactation stage (Table 1). In the pre-partum period, the roughage: concentrate ratio was 65:35, and it changed to 60:40 post-partum. The 65:35 ratio was resumed at 120 days of lactation, being replaced by 70:30 at 180 days of lactation, and always adjusted daily to obtain 10-15% of refusals based on natural matter. The diet was supplied twice a day, 50% at 8 am and 50% at 3 pm.

Procedures for collecting samples and data

The goats were milked every day, by one experienced person using a mobile bucket milking machine under hygienic-sanitary practices, once a day (6:00 am). The control of milk production was taken using a digital scale

(AS-110 model, Elgin). Immediately, the goats were conducted to the pens. On the sixteenth day of each experimental period, a milk sample was taken from each animal, previously homogenized. The samples were placed in plastic bottles containing bromopol® and sent to the Clinical Milk Laboratory (ESALQ-USP/Piracicaba, SP).

Table 1. Ingredients and chemical composition of the experimental diets

Ingredients (g/kg DM)	Lactation period			
	Pre-partum	Beginning of lactation	Middle of lactation	End of lactation
Mixed silage	650.0	600.0	650.0	700.0
Soybean meal	151.0	135.0	151.0	66.0
Ground corn	43.0	40.0	43.0	130.0
Wheat meal	138.0	207.0	138.0	69.0
Urea	5.0	5.0	5.0	20.0
Mineral supplement[1]	13.0	13.0	13.0	15.0
Chemical composition				
g/kg as basis				
Dry matter	498.9	527.7	498.9	455.9
g/kg DM basis				
Ash	62.3	62.2	62.3	59.0
Crude protein	160.0	160.0	160.0	160.0
Ether extract	29.1	29.6	29.1	29.4
FDN_{cp}[2]	426.1	426.7	426.1	421.3
FDA_{cp}[3]	231.2	223.6	231.2	233.2
Hemicellulose	203.7	214.2	203.7	194.5
Cellulose	191.8	183.8	191.8	199.7
Lignin	38.2	38.3	38.2	37.7
Non-fibrous charbohydrates[3]	331.9	331	331.9	367.5

[1]Guarantee levels (per kg of active element): Calcium - 240.0 g, Phosphorus - 71.0 g, Potassium - 28.2 g, Sulfur - 20.0 g, Magnesium - 20.0 g, Copper - 400.0 mg, Cobalt - 30.0 mg, Chromium - 10.0 mg, Iron – 250.0 mg, Iodine - 40.0 mg, Manganese - 1,350.0 mg, Selenium - 15.0 mg, Zinc - 1,700.0 mg, Fluorine (max.) - 710.0 mg. [2]Fiber in neutral detergent run for ashes and protein; [3]Fiber in acid detergent corrected for ash and protein

To determine the BW variation, periodic weightings (every 10 days) were carried out before supplying the feed, until the end of the experiment. To measure the beta-hydroxybutyrate (BHB) levels, blood samples were collected from the animals by puncture of the jugular vein, before the first feeding. Blood samples were collected in vacutainer tubes without anticoagulant every seven days, totaling nine samples of serum per animal. The samples were centrifuged at 750×g for 15 minutes, divided into subsamples in Eppendorf microtubes, identified (considering the date and the collection period), and stored at -20° C for later analysis.

Analytic procedures

The samples of feeds were analyzed for DM and mineral matter (MM) or ash following official methods 934.01 and 942.05 (AOAC, 2005), respectively. Organic matter was quantified by the difference between DM and MM contents. Total N was quantified according to official method 968.06 (AOAC, 2005). Neutral (NDF) and acid (FDA) detergent fiber (corrected for ash and protein) concentrations were obtained according to Mertens (2002) and Licitra et al. (1996) methods. Lignin was measured according to official method 973.18 (AOAC, 2005) using 72% H_2SO_4, hemicellulose and cellulose through the difference between NDF and FDA, and FDA and lignin, respectively. The non-fibrous carbohydrates (CNF) of the diets were calculated according to Hall (2000), following the equation CNFcp = 100 - ((% PBdiet - %PBurea + %Ureadiet) + %EE + FDNcp + %Ash).

The infrared method (PO-ANA 001) was used to evaluate the levels of fat, protein, lactose, and defatted dry extract in milk. BHB concentrations were determined by the enzymatic endpoint and kinetic colorimetric method, using a commercial kit (RANDOX®, Crumlin, England); the reading was carried out in an automatic blood biochemistry analyzer (Automatic Biochemistry System SBA-200-CELM®).

Statistical analysis

Data on daily milk production were analyzed considering lactation curves. Five non-linear mathematical models were used to fit the curves, with their respective references, as follows:

Wood: Wood (1967) (WD model)	$Y = a \times t^{b} \times e^{-c \times t}$	(1)
Papajcsik e Bodero (1988) (PB model)	$Y = a \times t \times e^{-b \times t}$	(2)
Adapted Papajcsik e Bodero (1988) (APB model)	$Y = a + b \times t \times e^{-c \times t}$	(3)
Nelder (1966) (ND model)	$Y = a + b \times t^{-1} + c \times t$	(4)
Wilmink (1987) (WM model)	$Y = a + b \times e^{-c \times t} + d \times t$	(5)

Where, Y = milk production (kg/d); t = time in lactation days; "*a*", "*b*", "*c*" and "*d*" are numerical parameters adjusted for the equations. The parameter "*c*" in the WM equation is fixed, its value is 0.0173.

To obtain the parameters of the nonlinear regression equations, the interactive Marquardt algorithm and the t statistic were used to construct the asymptotic confidence intervals of the parameters ($1 - \alpha = 0.95$). The NLIN procedure of Statistical Analysis System (SAS Institute, 2009) version 9.2 was used. The maximum likelihood method was used to calculate the asymptotic standard deviation. To compare models between different genetic groups, the model identity test was used (Regazzi, 1999), in which the χ^2 test is performed using the sums of squares of the residues of two scenarios: a model that contains the three genetic groups identified by variable binary (the total number of parameters for each model is multiplied by 3), and another with all the data, without considering the effects of the genetic group (number of original parameters for each model). To indicate the best fit, the MES (model evaluation system) software (Tedeschi, 2006) was used, performing additional analyzes with the observed and predicted values for each fitted equation.

First, a simple linear regression test of observed values on predicted values was performed, under the following hypotheses: H_0: $\beta_0 = 0$ and $\beta_1 = 1$; H_a: no H_0. In the case of non-rejection of the null hypothesis, it was concluded by the similarity between the predicted and observed values. As a second criterion, the decomposition of the mean square of the prediction error in mean addiction, systematic addiction, and random error was adopted, according to the protocol described by Tedeschi (2004). And as a third criterion, the correlation and concordance coefficient (CCC) were analyzed.

To analyze the data on milk composition and plasma BHB, a similar procedure was performed. However, the main effects studied were the evaluation period (n = 9), breed (n = 3) and the interaction between these two factors, using the multiple linear regression model:

$Y = D_0\beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 t + \beta_4(t*D_1) + \beta_5(t*D_2) + \beta_6 t_2 + \beta_7(t_2*D_1) + \beta_8(t_2*D_2) + \epsilon$. For the analysis of the body weight variation curve the following model was used:

$$Y = D_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 t + \beta_4(t*D_1) + \beta_5(t*D_2) + \beta_6 t^{1/2} + \beta_7(t^{1/2}*D_1) + \beta_8(t^{1/2}*D_2) + \beta_9 t^{3/2} + \beta_{10}(t^{3/2}*D_1) + \beta_{11}(t^{3/2}*D_2) + \epsilon.$$

In which, D1 and D2 are binary variables corresponding to the breed effects, where D1 = 0 and D2 = 0 for Saanen, D1 = 1 and D2 = 0 for Anglo-Nubian, and D1 = 0 and D2 = 1 for Moxotó, β_0, β_1, β_2, $\beta_3 \ldots \beta_8$ = parameters adjusted by model and *t* is a variable that refers to the period effect (days in lactation) on the analyzed variables. The REG procedure of SAS (SAS Institute, 2009) was used for these evaluations. All procedures reported in this topic were completed using 0.05 as a critical probability level for type I error.

Results

Descriptive analysis of the milk composition and plasma metabolites

The results for average milk production during 27 weeks of lactation were 1.37; 0.37 and 0.9 kg d^{-1} for Saanen, Moxotó and Anglo-Nubian, respectively (Table 2). Note that Saanen average milk yields ranged between 0.31 and 2.91 kg d^{-1}. In terms of milk components, there were specific characteristics in each genetic group. The averages found for the percentage of fat (3.66, 6.75, and 5.10), protein (3.32, 4.97, and 4.18), defatted dry extract (12.04, 17.07, and 14.46), and lactose (4.28, 4.46, and 4.39) for Saanen, Moxotó, and Anglo- Nubian, respectively, were inversely proportional to milk production. As expected, the values of BHB differed statistically ($P<0.05$) between genetic groups. These values ranged from 0.21 to 1.04 for Saanen, 0.11 to 0.9 for Moxotó, and 0.11 to 0.87 for Anglo-Nubian goats, with averages of 0.42, 0.32, and 0.35, respectively.

The Saanen breed group presented a minimum BW of 34.8 kg, a maximum of 64.6 kg, and an average of 45.76 kg, which generated amplitude of 29.8 kg. The Moxotó breed, on the other hand, had a maximum BW of 45.8 kg, a minimum of 23 kg, an average of 34.52 kg, and amplitude of 22.8 kg. In Anglo-Nubian females, BW ranged from 39 to 71 kg, with an average of 54.14 and amplitude of 32 kg.

Estimation of the parameters of the equations fitted for the lactation curve

There were statistical differences ($P<0.05$) in the a, b, and c parameters between breeds in each mathematical model evaluated (Table 3). In addition, there was a difference ($P <0.05$) between genetic groups according to the identity test of the models, and a separated equations for each group was obtained (Figures 1, 2, and 3).

For the parameter *a*, which represents the intercept of the curves (beginning of lactation) there was a variation from 0.0667 (PB model) to 1.8337 (WD model) in the Saanen breed, 0.0245 (PB model) to 1.0059 (WD model) in Moxotó, and from 0.0465 (PB model) to 1.6408 (WD model) in Anglo-Nubian. The parameter *b* (magnitude of the lactation peak) ranged from 0.0111 (WD model) to 0.7118 (ND model) for Saanen, 0.0310 (APB model) to 1.99 (ND model) for Moxotó, and 0.0554 (APB model) to 1.56 (ND model) for Anglo-Nubian breeds. And the parameter c (persistence of lactation) ranged from 0.0023 (WD model) to 0.0378 (APB model); 0.00086 (WD model) to 0.0462 (APB model) and 0.0004 (WM model) to 0.0417 (APB model) for Saanen, Moxotó, and Anglo-Nubian, respectively.

Table 2. Descriptive statistics of the milk production and composition, and body weight in goats of different genetic groups in tropical conditions during lactation

Genetic Group	Milk, L	Body weight, kg	Fat, %	Protein, %	Defatted dry extract, %	Lactose, %	BHB[1], %
Saanen							
Average	1.37	45.76	3.66	3.32	12.04	4.28	0.42
Minimum	0.31	34.80	2.38	2.41	9.53	3.58	0.21
Maximum	2.91	64.60	5.57	4.01	14.38	4.96	1.04
SD[2]	0.56	6.41	0.70	0.39	1.15	0.29	0.19
Median	1.26	45.50	3.56	3.36	12.12	4.30	0.37
N	771	183	86	86	86	86	20
Anglo-Nubian							
Average	0.90	54.14	5.10	4.18	14.46	4.39	0.35
Minimum	0.19	39.00	3.66	3.39	12.75	3.78	0.11
Maximum	2.42	71.00	7.17	5.07	16.63	4.93	0.87
SD	0.47	8.08	0.81	0.32	0.93	0.26	0.18
Median	0.80	54.60	5.03	4.19	14.46	4.41	0.30
N[3]	522	125	59	59	59	59	20
Moxotó							
Average	0.37	34.52	6.75	4.97	17.07	4.46	0.32
Minimum	0.10	23.00	4.37	3.55	14.42	4.02	0.11
Maximum	0.91	45.80	9.28	6.16	20.22	4.88	0.90
SD	0.18	4.91	0.95	0.52	1.14	0.21	0.16
Median	0.35	33.90	6.69	4.99	17.14	4.48	0.30
N	582	146	69	68	69	68	20

[1]Beta-hydroxybutyrate; [2]SD, Standard deviation; [3]N, Number of observations

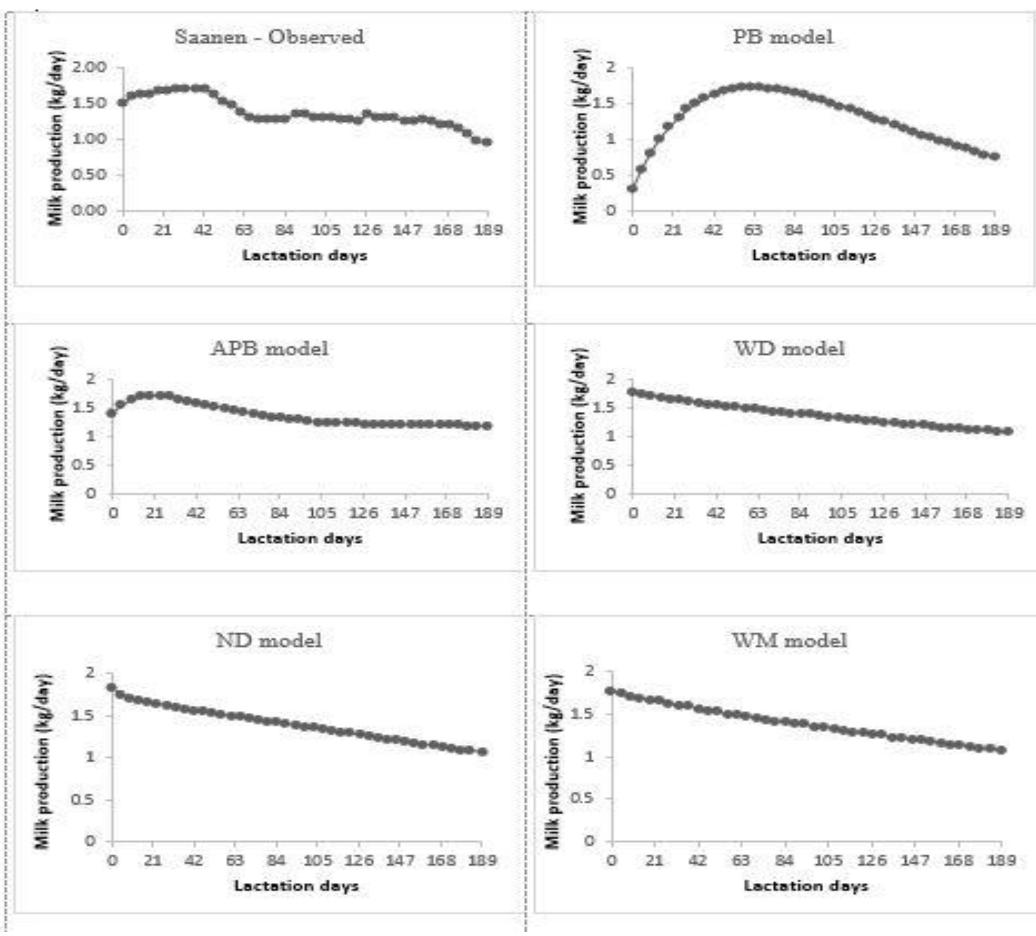

Figure 1. Parameter estimation of the equations fitted for the lactation curve of the Saanen genetic group using the Wood (WD), Papajcsik and Bodero (PB), Adapted from Papajcsik and Bodero (APB), Nelder (ND), and Wilmink (WM) models.

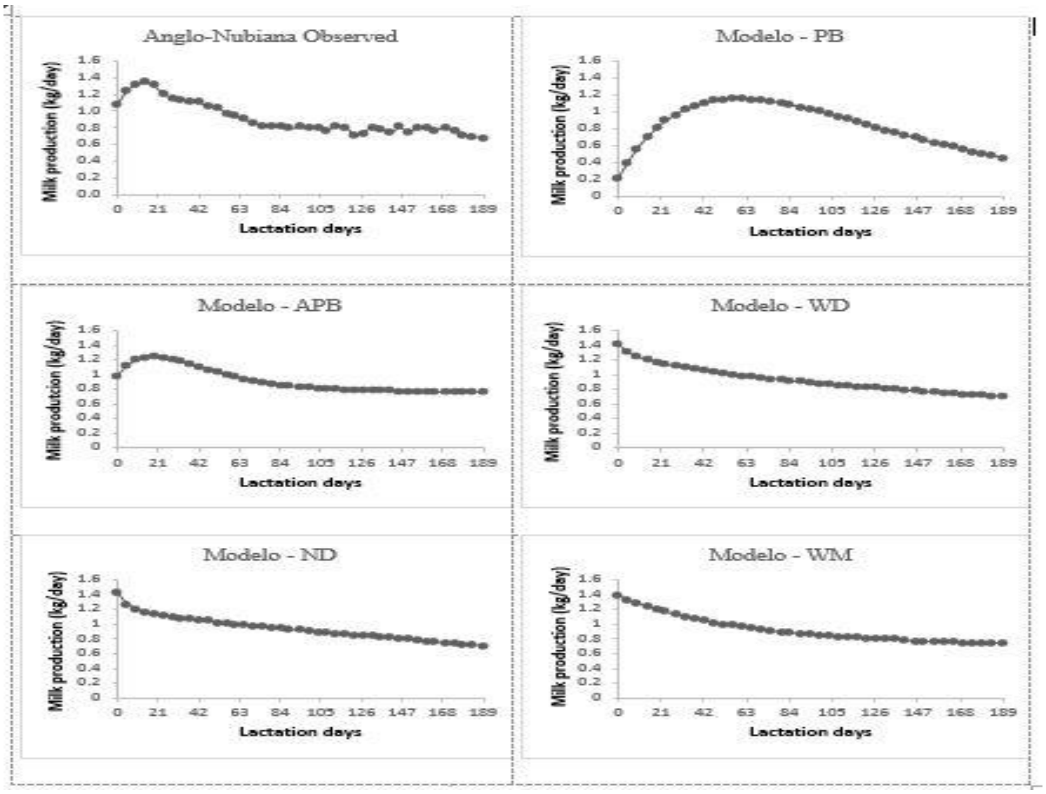

Figure 2. Parameter estimation of the equations fitted for the lactation curve of the Anglo-Nubian genetic group using the Wood (WD), Papajcsik and Bodero (PB), Adapted from Papajcsik and Bodero (APB), Nelder (ND), and Wilmink (WM) models.

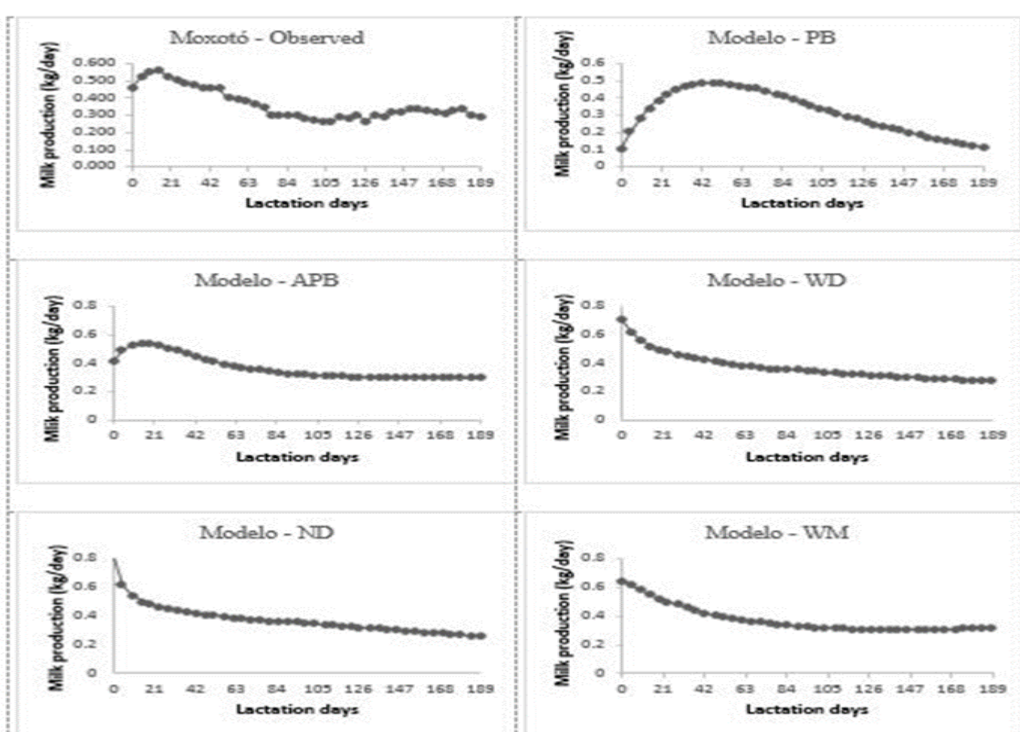

Figure 3. Parameter estimation of the equations fitted for the lactation curve of the Moxotó genetic group using the Wood (WD), Papajcsik and Bodero (PB), Adapted from Papajcsik and Bodero (APB), Nelder (ND), and Wilmink (WM) models.

Table 3. Estimation of the parameters of the fitted equations for lactation curve in goats of different genetic groups in tropical conditions during lactation

Genetic group	Papajcsik & Bodero (1988)	Adapted Papajcsik & Bodero (1988)	Wood (1967)	Nelder (1966)	Wilmink (1987)
Saanen					
a[1]	0.0667 ± 0.0025	1.1959 ± 0.0335	1.8337 ± 0.2575	1.7085 ± 0.0658	1.6409 ± 0.1387
b[1]	-	0.0545 ± .0085	-0.0111 ± 0.0452	0.7118 ± 1.2478	0.1560 ± 0.2129
c[1]	0.0141 ± 0.00036	0.0378 ± .0041	0.0023 ± 0.0006	-0.0032 ± 0.0004	-0.0028 ± 0.0008
ASD[2]	0.62	0.52	0.52	0.52	0.52
P - value	<0.01	<0.01	<0.01	<0.01	<0.01
Anglo-Nubian					
a[1]	0.0465 ± 0.0026	0.7570 ± 0.0312	1.6408 ± 0.4005	1.1272 ± 0.0765	0.7995 ± 0.1447
b[1]	-	0.0554 ± 0.0108	-0.0910 ± 0.0776	1.56 ± 1.7361	0.0643 ± 0.2305
c[1]	0.0148 ± 0.00054	0.0417 ± 0.0054	0.0018 ± 0.0011	-0.0022 ± 0.0005	-0.0004 ± 0.0008
ASD[2]	0.50	0.44	0.44	0.44	0.44
P - value	<0.01	<0.01	<0.01	<0.01	<0.01
Moxotó					
a[1]	0.0245 ± 0.0012	0.2967 ± 0.0109	1.0059 ± 0.1767	0.421 ± 0.0254	0.1805 ± 0.0505
b[1]	-	0.0310 ± 0.004	-0.2103 ± 0.0584	1.99 ± 0.5356	0.5098 ± 0.0773
c[1]	0.0183 ± 0.0006	0.0462 ± 0.004	0.00086 ± 0.0009	-0.0002 ± 0.0002	0.00059 ± 0.0003
ASD[2]	0.19	0.15	0.16	0.16	0.16
P - value	<0.01	<0.01	<0.01	<0.01	<0.01

[1]“a”, “b”, and “c”, Fitted parameters for the models; [2]ASD, Asymptotic standard deviation

Evaluation of fitted equations for lactation curves

The fitted equations for the lactation curves were evaluated according to four criteria (Table 4). The first, the Mayer joint intercept test, was significant (P <0.01) for the three genetic groups in the PB model, which means that the predicted and observed values by this model are different, then is not recommended for the representation of the lactation curve of the three groups of goats.

The CCC values varied between the models from 0.1103 (PB model) to 0.236 (WM model)) for Saanen, from 0.2380 (PB model) to 0.3569 (APB model) for Moxotó, and from 0.1071 (PB model) to 0.2187 (APB model) for Anglo-Nubian. The PB model showed the lowest values for all the evaluated breeds. The PB model also presented a higher sum of errors, with the highest value for the mean square prediction error (MSPE) among the studied models. In Saanen breed, when decomposing the MSPE, the random error (RE %) was equal to 100, except for the PB model (79.98). In Moxoto goat breed, RE (%) ranged from 88.46 (PB model) to 98.64 (WM model). In the Anglo-Nubian breed, the PB model also had the lowest percentage for this parameter (86.87), while the APB, WD, and WM models the maximum value (100). The mean bias error (MBE %) was 0.00 for APB, WD, ND, and WM, and 1.07 in the PB model for the Saanen animals. The variation of MBE was 0.43 (PB model) to 0.91 (ND model) for Moxotó and 0.00 (APB, WD, and WM models) to 1.10 (PB model) for Anglo-Nubian, which denotes a small magnitude of the adjustment bias of the models and providing high precision.

For the mean systematic bias (MSB %), a consequence of the constant bias in the estimated data and precision, minimum or similar values were found for the APB, WD, ND, and WM models, except for the PB model that presented high values. The mean deviation ranged between -0.0641 (PB model) and 0.0002 (WD model), -0.0130 (PB model) to 0.167 (ND model), -0.0528 (PB model) to 0.0126 (ND model) for Saanen, Moxotó, and Anglo-Nubian, respectively. The P-value of the mean deviation presented similar results those observed for the Mayer test.

Milk composition and plasma metabolites

Except for lactose (P>0.05), there was a difference between the genetic groups for milk composition and plasma BHB values (P<0.05) according to the model identity test (Table 5). For Saanen goats, there was an effect of lactation time on fat content (P=0.01) and defatted dry extract (P=0.02), which increased during lactation, showing a peak after 161 and 159 days, respectively. It is emphasized that there was effect on BHB content in response to days of lactation (P<0.05), then Saanen and Anglo Nubian goats had higher plasma levels of this metabolite compared to Moxotó goats.

In Moxoto goats, the protein (P<0.01) and defatted dry extract (P=0.03) showed significant variation in response to the days of lactation, therefore, there was an effect of lactation time on these variables analyzed in the milk of these animals which reached their highest values (maximum point) after 129 and 199 days of lactation, respectively. For Anglo-Nubian goats, there was an effect of lactation time for proteins (P=0.001). In addition, lactose content was influenced by lactation time showing a peak after 146 days of lactation.

Table 4. Evaluation of the fitted equations for the lactation curve in goats of different genetic groups in tropical conditions during lactation

Model	Teste de Mayer (P-valor)[1]	CCC[2]	MSPE[3]	RE[4], %	MBE[5], %	MSB[6], %	[7]MD
				Saanen			
Papajcsik & Bodero (1988)	<0.01	0.1103	0.3851	79.98	1.07	18.96	-0.0641 (P<0.01)
Adapted Papajcsik & Bodero (1988)	0.9996	0.1939	0.2793	100.00	0.00	0.00	-0.0005 (P=0.98)
Wood (1967)	0.9996	0.2117	0.2758	100.00	0.00	0.00	0.0002 (P=0.99)
Nelder (1966)	1.0000	0.2132	0.2756	100.00	0.00	0.00	-0.0001 (P=0.28)
Wilmink (1987)	0.9997	0.2136	0.2756	100.00	0.00	0.00	-0.0004 (P=0.98)
				Anglo-Nubian			
Papajcsik & Bodero (1988)	<0.01	0.1071	0.2541	86.87	1.10	12.04	-0.0528 (P=0.02)
Adapted Papajcsik & Bodero (1988)	0.9997	0.2187	0.1972	100.00	0.00	0.00	-0.0004 (P=0.98
Wood (1967)	0.9988	0.1920	0.2011	100.00	0.00	0.00	-0.0000 (P=0.52)
Nelder (1966)	0.7737	0.1738	0.2027	99.90	0.08	0.02	0.0126 (P=1.00)
Wilmink (1987)	0.9997	0.2000	0.1999	100.00	0.00	0.00	-0.0005 (P=0.98)
				Moxotó			
Papajcsik & Bodero (1988)	<0.01	0.2380	0.0395	88.46	0.43	11.11	-0.013 (P=0.11)
Adapted Papajcsik & Bodero (1988)	0.0143	0.3569	0.0289	98.62	0.88	0.50	0.0159 (P=0.02)
Wood (1967)	0.0145	0.3140	0.0301	98.63	0.88	0.50	0.0162 (P=0.02)
Nelder (1966)	0.0131	0.2909	0.0307	98.59	0.91	0.50	0.0167 (P=0.02)
Wilmink (1987)	0.0151	0.3395	0.0294	98.64	0.90	0.46	0.0163 (P=0.02)

[1]Mayer's test: H_0: B_0 = 0 and B_1 = 1; H_1: Non H0; [2]CCC: Concordance correlation coefficient; [3]MSPE: Mean square prediction error; [4]RE: Random error; [5]MSB: Mean bias error; [6]MSB: Mean systematic bias; MD[7], Mean deviation with their respective P-value

Table 5. Milk composition and plasma beta-hydroxybutyrate in goats from different genetic groups in tropical conditions during lactation

	Regression parameters						Critical time	
	Intercept	t	t²	R – SD[1]	R^2	P-value	Day	ER[2] %
Saanen								
Fat	4.292 ± 0.240	-0.010	0.00003	0.673	0.103	0.011	161.8	6.81
Protein	3.247 ± 0.137	0.003	-0.00002	0.387	0.033	0.253	90.1	3.64
Defatted dry extract	13.008 ± 0.394	-0.016	0.00005	1.115	0.088	0.022	159.8	11.73
BHB[3]	0.164 ± 0.013	0.0125	-0.00015	0.181	0.150	0.194	40.3	0.43
Anglo-Nubian								
Fat	5.061 ± 0.367	-0.003	0.00002	0.801	0.048	0.255	65.5	4.97
Protein	3.730 ± 0.132	0.010	-0.00004	0.289	0.218	0.001	119.8	4.32
Defatted dry extract	14.256 ± 0.428	0.000	0.00001	0.935	0.031	0.417	20.2	14.25
BHB[3]	0.614 ± 0.228	-0.016	0.00021	0.183	0.081	0.489	39.6	0.29
Moxotó								
Fat	6.369 ± 0.368	0.004	0.00000	0.943	0.048	0.199	154.1	8.69
Protein	4.159 ± 0.178	0.017	-0.00006	0.457	0.261	<0.01	129.7	5.23
Defatted dry extract	16.205 ± 0.430	0.013	-0.00003	1.102	0.098	0.033	199.9	17.50
BHB[3]	0.483 ± 0.115	-0.0132	0.00019	0.148	0.236	0.102	38.8	0.25
Saanen, Anglo-Nubian, and Moxotó								
Lactose	4.791 ± 0.053	-0.008	0.00003	0.233	0.267	<0.01	146.2	4.23

[1]R-SD:residual standard-deviation, [2]ER: Estimated response, [3]Beta-hydroxybutyrate

Body weight change curve

There was a difference (P<0.05) between the genetic groups for the BW change curve as a function of days in lactation (Figure 4). Then, by analyzing the BW variation data of the animals, the following adjusted equations of the BW variation curves were obtained for Saneen: BW (kg) = 61.79012 - (7.8148*($t^{0.5}$)) + (0.95524*t) - (0.03341*($t^{1.5}$)); for Moxotó: BW (kg) = 61.79012- (7.8148*($t^{0.5}$)) + (0.95524*t)-(0.03341*($t^{1.5}$)) and for the Anglo-Nubian: BW (kg) = 64.71198 -(5.85997*($t^{0.5}$)) + (0.70869*t) - (0.02334*($t^{1.5}$)). In the present study, Saanen had a greater weight loss of 12.83 kg, which was verified at 35 days of lactation (42.07 kg). For the Anglo-Nubian females, the weight oscillated with greater intensity, like that of the Saanen group. The minimum registered weight of 50.02 kg was presented at 35 days of lactation, where it showed a reduction of 8.89% of its initial live weight (54.9), a loss of 9.88 kg. The Moxotó breed, showed the lowest weight variation (33.69 to 32.27), with the lowest average observed at 40 days of lactation. The Moxotó breed, without milk capacity, showed the lowest weight variation (33.69 to 32.27), with the lowest average observed at 40 days of lactation.

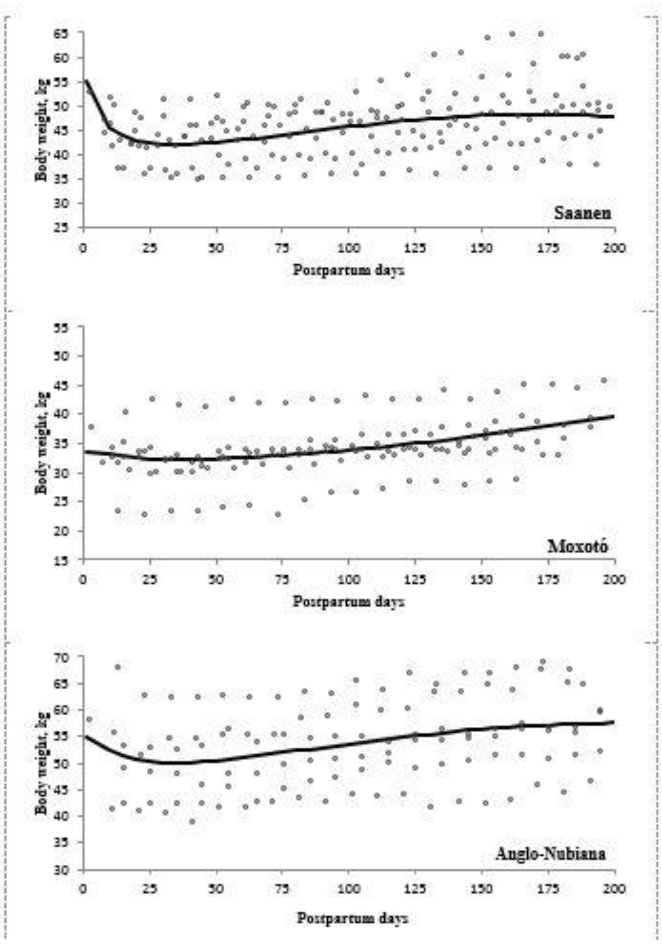

Figure 4. Weight recovery curves of goats of different dairy purposes during lactation. Saanen = $61.79012-(7.8148*t^{0.5}) + (0.95524*t) - (0.03341*t^{1.5})$, Moxotó = $35.6386 -(1.0293*t^{0.5}) +(0.06699*t) + (0.00181*t^{1.5})$; Anglo-Nubian = $64.71198 - (5.85997*t^{0.5}) + (0.70869*t) - (0.02334*t^{1.5})$.

Discussion

In the present study, the Saanen goats showed a greater weight loss of 12.83 kg, which was verified at 35 days of lactation (42.07 kg), corresponding to a reduction of 23.37% in relation to the initial BW (54.9 kg). Anglo-Nubian goats showed less reduction in BW (8.89% of initial BW) compared to Saanen goats. However, similar time (35 days) in negative energy balance was demonstrated for both genetic groups. On the other hand, Moxotó goats showed reduction of 1.42 kg corresponded to 4.22% of its initial BW. In addition, Moxotó goats presented the end of the negative energy balance at 40 days. Then, by analyzing the BW change curve, our results indicated that different genetic groups could influence the fat mobilization/deposition and energy efficiency.

The evaluation of the BW recovery curve is interesting, since the mobilized body mass provides metabolizable energy that can be directed to the production and compounds of milk (Santos et al., 2012). It should be considered that the energy liquid (EL) requirement for milk production depends on the content of its components: EL (MJ/kg) = 0.0386 * F 0.0245 * P + 0.0156*L, where F (fat), P (protein), and L (lactose) in g/kg of milk produced (NRC, 2001). Another interesting relationship is that the mobilized body mass provides metabolizable energy, which is used to produce milk with an efficiency greater than 50% (Tovar-Luna et al., 2010). Thus, much of this higher milk production of the Saanen and Anglo-Nubian animals is due to the greater capacity to mobilize body reserves, in which this mobilization also implied higher concentrations of plasma BHB.

The literature demonstrates that the breeds with the highest dairy potential and genetic selection for this trait, were the greatest milk producers, and more efficient by directing more energy to milk production rather than body reserves (Veerkamp & Emmans, 1995; Yan et al. 2006; Ledinek et al., 2019). It is noteworthy that in the present study the higher milk performance and efficiency were based on a higher degree of mobilization, milk composition and curve weight analysis. Considering that the net energy requirement for milk production is influenced by the milk components (Ledinek et al., 2019), we can confirm that the Moxotó group, still with lower milk production, had to mobilize body reserves to meet the higher EL requirement for the production of 1 kg of milk, which is due to the higher concentration of fats and proteins, as well as similar lactose content in the milk of this genetic group.

Anglo-Nubian goats, despite being dual-purpose, are animals that have been in the process of genetic selection for many years and, like the Saanen, are used worldwide to improve the productivity of herds directly or by crossing with indigenous animals (Aliloo et al., 2017; Miglior et al., 2017). It is interesting to note that due to the higher potential of this genetic group for milk production compared to Moxotó, these animals showed a sharp lactation curve, with parameters *a*, *b*, and *c* (onset, peak, and decline) more expressive and equidistant.

The Moxotó breed, despite being highly adapted to tropical conditions, is not considered suitable as a dairy breed, since its average production is low and the selection process for this characteristic is still recent (Lira et al., 2010). The lower values of production and the amplitude of the parameters, which indicate a less pronounced curve, without expressive peak, are similar to animals without a defined breed pattern or beef cattle breeds. These animals have a lactation curve with a linear trend (Macciotta et al., 2011; Santos et al., 2012).

According to Wood (1967), the lactation peak determines its shape beyond the maximum point of the curve. The studied groups obtained different curves, depending on the magnitude of the production peak and its amplitude about the initial and final lactation values. Macciotta *et al*. (2011) concluded that it is common in some genotypes to find lactation curves without the pronounced effect of parameter *b*, that is, without a large magnitude of the peak, as observed in the present experiment for Moxotó goats. This reinforces the productive superiority of animals with exclusively dairy aptitude about the others and allows us to affirm that there is a particularity in the shape of the goat lactation curve, which distinguishes them according to their purpose, assuming a specific pattern.

The present study demonstrated that the APB, WD, ND, and WM models, except for the PB model, presented high values. Considering the mean systematic bias (MSB %) is a consequence of the constant bias in the estimated data and precision, minimum or similar values, then our results showed high precision in the adjustment of these models to the observed data, being possible to affirm that 100% of the prediction error refers to the random error in these models.

In the present study, for Saanen goats, the WM model was the one that best fitted the data when analyzing all the proposed criteria but for Moxotó and Anglo-Nubiana goats, the APB model was the best fit. However, in general, the APB model presented a good data fit and a better biological interpretation of the lactation curves of the three genetic groups. Thus, we can suggest that the APB mathematical model is the most suitable for all genetic groups. We believe that these models are applicable to other breeds, but further studies are needed to establish the most appropriate model in a meta-analysis study.

In a study that evaluated milk production and composition in four goat genotypes under the same conditions, Prasad et al. (2005) concluded that genetic factors influenced milk production and chemical composition. It is important to note that, in addition to the higher percentage of milk solids, the Moxotó breed is the only one in which this parameter increased during lactation since milk production is reduced, reaching the maximum percentage point (8.69) in 154 lactation days. The same occurs with the levels of protein and total dry extract, which in addition to presenting averages higher than the others, also presents an increase in performance throughout lactation, which can make the breed interesting for specific purposes, such as the elaboration of artisan cheeses, since the yield of solids of the herd will be higher. It should be noted that Moxotó females are less productive and have less persistence of lactation, also considering the accumulation of milk solids throughout lactation.

According to Queiroga et al. (2007), lactose is the most stable nutrient in milk, as it is directly related to the regulation of osmotic pressure. In this research, the lactose levels were similar for the three genetic groups, reinforcing the characteristics of greater homogeneity of this component. Thus, even under the same management and feeding conditions, differences in the productive capacity and milk composition are evident, depending on the suitability of each genetic group and the selection process to which they were subjected.

Conclusions

Our results indicated that the APB mathematical model was adequate to describe the lactation curve for goats in tropical areas. From these models, the following equations are recommended to estimate milk production: $Y = 1.196+0.0545\times t\times e^{(-0.038\times t)}$ for Saanen, $Y = 0.297 + 0.031 \times t\times e^{(-0.0462\times t)}$ for Moxotó and $Y = 0.757 + 0.0554 \times t\times e^{(-0.0417\times t)}$ for Anglo-Nubian.

Saanen and Anglo-Nubian animals have a greater ability to mobilize body reserves, resulting in higher plasma concentrations of BHB compared to Moxotó. Moxotó goats showing low efficiency in energy use; however, with the end of the NEB at 40 days, the Moxotó breed had the highest content of solids in milk due to the longer period in NEB and lower milk production.

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Conflict of interest

There is no conflict of interest.

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