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Original Research

Models to Describe Growth Curve of Egyptian Damascus Goat Kids

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Abstract

This study was conducted to describe the growth curves of Damascus kids reared in Egypt, using some linear and nonlinear models to provide a specific shape of the growth curve for that breed. A total of 855 records belonging to 47 kids' progeny of 30 Damascus does between parities 1 and 5 kept in the Experimental Station of Alexandria University, Egypt, were used in this study. Kids were weighed immediately after birth and weekly thereafter till weaning at four months of age. All weights, except birth`s, were recorded early in the morning after 12 h fasting period. The effects of parity and type of birth on birth and weaning weights and on averages daily weight gains were evaluated. Also, the associations between age and weight within parities and types of birth were described using linear, quadratic and four modified nonlinear growth functions. Parity had no significant effects on birth and weaning weights. However, kids born in fourth parity had the greatest daily gain, while the second and fifth parities born kids had the lowest. Type of birth affected all studied traits. Single born kid had the highest birth and weaning weight and the highest daily weight gain compared to twice or triple born kids. Single kids born from does in third parity had the highest weights at birth and weaning and had the highest daily weight gain. Quadratic model exhibited the best goodness of fit for all kids.

KEYWORDS
Non-linear models, Growth curve, Damascus, Goat.

INTRODUCTION

Goats are an important component of animal production in developing countries because they have potential for feed storage compared to other farm animals. Thus, growing goats on low quality range land presents a great success in the field of animal production (Gül *et al*., 2016). Growth which is a trait of interest in livestock farming is primarily defined as increase in size, number, or mass over time (Cak *et al*., 2017). Several equations are used to describe animal growth, but none of them are based on a universally accepted theory that able to explain the entire process (de Sousa *et al*., 2021). These equations enable a bigger or littler adjustment to an exact dataset and the most generally used to describe animals' growth curve are non-linear Brody, Von Bertalanffy, Logistic, and Gompertz models. These non-linear models are more effective than linear because the growth illustrates a sigmoid form and describes relationship between lifetime weight and age (Omotosho *et al*., 2020).

Having a sigmoid shape, the livestock growth curve can be fitted and analyzed by the nonlinear mathematical models. The use of mathematical growth models provides a good way of summarizing the growth potential information into a small set of parameters (Abdelsattar *et al*., 2021). These estimated parameters are biologically meaningful and can be used to envisage growth patterns over time and to predict the growth of one variable by knowing the other variable (Norris *et al*., 2007).

Although studies involving the goat growth curve in tropical region are in their primary steps, they are necessary because they permit the format of the curve to be altered to improve growth and meat production efficiency (de Sousa *et al*., 2021).

The objective of this study was to describe the growth curves of Damascus kids in Egypt, through some linear and nonlinear models to provide specific shape of the growth curve of that breed.

MATERIALS AND METHODS

All animals and experimental procedures in this study were supervised and approved by the Institutional Animal Care and Use Committee of Alexandria University, Egypt.

Animal and Management

A total of 855 records belonging to 47 kids' progeny of 30 Da-

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mascus does between parities 1 and 5, maintained continually in the Experimental Station (31º 20′ N, 30º E), Faculty of Agriculture, Alexandria University, Egypt, were used in this study. Does and their kids were kept outdoors with shelter during the day and housed in a semi-open barn at night. Kids were allowed to suckle their mothers all day round and were fed on roughage and concentrate supplements according to their body weight requirements (NRC, 2007). Each Doe also received 1 kg/d of a concentrate mixture that contained 68% total digestible nutrient (TDN) and 16% crude protein (CP). Water was excessively available to all animals. Animals were free of diseases and had healthy appearance.

Weights and daily gain

Kids were weighed immediately at birth and then weekly thereafter till weaning at four months of age. Weekly weights of individuals were recorded in the morning after a 12 h fasting period.

Statistical Analysis

All data were tested for normality with the Shapiro-Wilk test from the UNIVARIATE procedure of SAS (SAS 9.0, 2004), and results indicated that all data were distributed normally (W ≥ 0.90). To avoid the heterogeneity of error, if existed, all percentage data records less than 10 % were transformed to their corresponding square root according to Steel and Torrie (1980). Least squares procedure using a mixed model, considering the day effect as repeated measurements (SAS Inst. Inc., Cary, NC), was used. The effects of parity and type of birth on birth, weaning weights (kg) and on averages daily weight gain (kg/d) were studied using the following models:

$$Y_{ijk} = \mu + P_i + T_j + e_{ijk,}$$

in which Yijkl is the kid birth and weaning weights and daily gain, μ is the overall mean, P_i is the fixed effect of the i^{th} parity (i = 1- 5), T_j is the fixed effect of the j^h type of birth (j = 1-3), and e_{ijkl} is the residual error.

Least significant difference (LSD 0.05) test was used for testing the differences among means.

Linear, quadratic and four modified nonlinear growth functions were applied to describe the associations between age and weight within parities and types of birth and were all fitted to the individual kid data using the NLIN procedure of SAS (SAS Institute Inc., Cary, NC): Brody model (Brody, 1945), Gompertz model (Laird, 1965), Von-Bertalanffy model (Von-Bertalanffy, 1957) and the logistic model (Nelder, 1961) as shown in Table 1.

Accuracy of fit was compared within each factor for different models by root of residual mean square error (RMSE), coefficient of determination (R2) and Akaike's information criteria (AIC) as shown in Table 1.

RESULTS

Results of factors affecting birth (BW, kg) and weaning (WW, kg) weights and daily gain (DG, kg/day) of Damascus kids are presented in Table 2. Parity had no significant effects on birth and weaning weights. However, kids born in fourth parity had the greatest daily gain (0.112 kg/d, P=0.001) and the second and fifth parities born kids had the lowest (0.097 and 0.096 kg/d, respectively). Type of birth had significant effects on all studied traits. Single born kid had the highest birth and weaning weight and the highest daily weight gain compared to twice or triple born kids, and the latter had the lowest weights and daily gain. The interaction between the parity and type of birth was also significant. Single kids born from does in the third parity had the highest weights at birth and weaning and had the highest daily weight gain (3.88 and 22.30 kg and 0.146 kg/d, respectively). In contrast, triple born kids from does in the fifth parity had the lowest weaning weight and daily gain (8.91 kg and 0.049 kg/d, respectively).

The average estimates of parameters a, b and c from growth curve models and goodness-of-fit indicators for each model of all, single, twin and triple born Damascus kids are presented in Table 3. The parameters estimate of different models were variable. Parameter a, which estimates mature weight, was the greatest (ranged from 959.7 to 1590.4) for Brody model, while it was the smallest for linear model (ranged from 2.15 to 2.71). Parameter b was the greatest for Logistic (ranged from 6.945 to17.835) followed by Gompertz (ranged from 2.66 to 6.33) models, while was the smallest for Quadratic then linear models. The growth rate parameter "c" ranged from 0.00007 to 0.020 and exhibited the earliest maturity for Logistic as compared to other models.

Table 1. Linear and nonlinear functions to describe the growth curves and goodness of fit equations

Model#	Equation
Brody	$y = a (1 – be^{-ct})$
Gompertz	$y = a \exp (– be^{-ct})$
Von-Bertalanffy	$y = a (1 – be^{-ct})^3$
logistic	$y = a / (1 + be^{-ct})$
quadratic	$y = a + bt + ct^2$
Linear	$y = a + bt$
Parameters$:	**Equation**
Determination coefficient (R^2)	(1-(SSE / SST))* 100
Akaike's information criteria (AIC)	-2 log L + 2 K
Root mean squares errors (RMSE)	$\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$

#y represents body weight at age t; a represents asymptotic weight, b is an integration constant related to initial animal weight, c is the maturation rate and t is the age in day.
$SSE is sum square of error and SST is total sum of square, K is the number of estimated parameters in the model but L is the maximized value of the likelihood function for the estimated model, y_i are the actual values and y_i are values predicted by the regression model and e_tis residual at time e, e_{t-1} is residual at time t-1.

The model exhibiting the best fit by R2 and RMSE for all kids was Quadratic but, for predicting growth of single, twins or triple kids, the variation in goodness of fit for all studied models did not reflect a superiorly of any model compared to others (Table 3).

The estimated parameters of linear and non-linear growth curve models and their goodness-of-fit indicators for different parities are presented in Table 4. Brody had the biggest parameter “a” values but Linear and Quadratic models had the smallest for all parities. Also, Logistic model had the greatest parameter “b” estimates followed by Gompertz model. Other models had

smaller “b” values. The parameter “c” estimates were positive close to zero for all models. Gompertz and Logistic models possessed the highest R2 (0.78) and lowest RMSE and AIC for the first parity born kids followed by Brody model. Although, very little differences were observed between models regarding goodness of fit parameters for parities 2-5 born kids. Quadratic function tended to be the best fitted for kids born for does in parities 2, 3 or 4. Similarly, Gompertz model tended to be the best one for parity 5 born kids.

DISCUSSION

There is a growing interest to describe the growth patterns of various goat breeds worldwide. The application of Richard growth curve model in the present study was problematic and difficulties in obtaining convergence have been similar to those reported by Malhado *et al*. (2009). The present estimates of all nonlinear functions were observed to be lower than those of Kor *et al*. (2006) who reported that Weibull (99.32 %R2) was the best nonlinear function model for Akkeci (White goat) female kids. Similarly, Kucuk *et al*. (2009) determined Gompertz nonlinear model to be the ideal growth model for colored Mohair kids (99.94 and 99.98 %R2) and Angora x colored Mohair crossbred F1 kids. However, in this study, the Quadratic model exhibited the best fit for all Damascus kids’ data. Özdemir and Dellal (2019) recorded that

Table 2. Factors affecting birth (BW) and weaning (WW) weights, kg and daily gain (DG), kg/day of Damascus kids in Egypt

Item	no.	Least squares means		
		BW	WW	DG
Parity		(0.385)[2]	(0.213)	(0.001)
1	8	2.88	15.74	0.104[abc]
2	7	2.94	14.95	0.097[bc]
3	9	2.99	16.72	0.110[ab]
4	9	2.95	16.74	0.112[a]
5	12	3.34	15.03	0.096[c]
SEM[1]	-	0.21	2.11	0.005
Type of birth		(0.001)	(0.001)	(0.001)
Single	18	3.37[a]	18.51[a]	0.123[a]
Twins	18	3.02[a]	14.83[b]	0.097[b]
Triple	9	2.46[b]	11.91[c]	0.076[c]
SEM	-	0.18	1.85	0.003
Parity*Type of birth		(0.018)	(0.003)	(0.001)
1*Single	4	3.23[cd]	20.11[ab]	0.136[a]
1*Twins	4	2.53[fgh]	11.36[ef]	0.073[e]
2*Single	4	3.02[de]	15.81[cd]	0.104[bc]
2*Twins	3	2.75[ef]	12.80[de]	0.081[de]
3*Single	4	3.88[a]	22.30[a]	0.146[a]
3*Twins	2	2.20[h]	11.21[ef]	0.072[e]
3*Triple	3	2.33[gh]	12.97[de]	0.089[de]
4*Single	4	3.44[bc]	17.37[bc]	0.117[b]
4*Twins	3	2.47[gh]	17.40[bc]	0.121[ab]
4*Triple	3	2.63[fg]	14.83[cde]	0.096[cd]
5*Single	3	3.34[bcd]	15.03[cd]	0.095[cd]
5*Twins	5	3.69[ab]	17.33[bc]	0.114[bc]
5*Triple	3	2.42[gh]	8.91[f]	0.049[f]
SEM	-	0.24	2.13	0.006

[a-h] Means with different letters in the same column within each item differ ($P < 0.05$).
[1]SEM: Standard errors mean [2]( ): (P-value).

the best nonlinear function for describing young Angora goat growth were Logistic and Gompertz. Celik *et al*. (2018) reported that the Janoscheck non-linear model gave more reliable results for the body weight–age relationship with a high coefficient of determination and the lowest mean square error.

Moreover, Waheed *et al*. (2011) revealed that Brody and Gompertz nonlinear functions described the growth of the Beetal kids at the highest predictive accuracy. Also, Nouman and Abrar (2013) found that Gompertz model obtained the highest predictive accuracy for Beetal goats too. Cak *et al*. (2017) reported that Gompertz and Richards's models gave 99.70% R2 for single but Richards's model achieved 99.57% R2 for twin kids and both were the most suitable in describing the growth of Colored Mohair kids. Ghiasi *et al*. (2018) reported that, Gompertz model showed a suitable fit to the body weight-age records of Raeini Cashmere goat. Kheirabadi and Rashidi (2019) found that, the Brody model provided the best goodness of fit for the individual growth curve of Markhoz kid and Waiz *et al*. (2019) found that the same model was favorable for determining body weight in both sexes of Sirohi goat. Wiradarya *et al*. (2020) concluded that Gompertz growth curve was the best predictor for body weight in Kacang goats. Also, Abdelsattar *et al*. (2021) recorded that Gompertz model was the best model for describing the body weight of Laiwu black goat kids.

Table 3. Estimated parameters (a, b, c) and goodness-of-fit indicators for growth models (R2; coefficients of determination, AIC; Akaike's information criteria and RMSE; root mean square error) of all, single, twin and triple born Damascus kids

Equations	a	b	c	R^2	AIC	RMSE
All						
Brody	1155.8	0.998	0.000	0.678	4230.57	3.025
Gompertz	117.8	3.501	0.005	0.685	4213.11	2.994
Von-Bertalanffy	1017.8	0.849	0.001	0.685	4211.93	2.992
Logistic	41.3	10.047	0.017	0.683	4216.32	2.999
Quadratic	3.28	0.071	0.000	0.731	4084.93	2.767
Liner	2.42	0.115	-	0.678	4229.96	3.024
Single						
Brody	989	0.997	0.000	0.813	1595.49	2.486
Gompertz	53.46	2.664	0.008	0.815	1591.1	2.47
Von-Bertalanffy	94.03	0.662	0.004	0.816	1589.96	2.466
Logistic	31.65	6.945	0.02	0.813	1594.63	2.483
Quadratic	3.37	0.102	0.000	0.817	1588.36	2.46
Liner	2.71	0.135	-	0.813	1595.02	2.484
Twins						
Brody	1590.4	0.998	0.000	0.681	1687.31	2.843
Gompertz	1986.7	6.327	0.002	0.696	1670.72	2.775
Von-Bertalanffy	1834.4	0.879	0.001	0.695	1671.93	2.78
Logistic	515.7	13.54	0.012	0.696	1670.94	2.776
Quadratic	3.4	0.051	0.001	0.695	1672.23	2.781
Liner	2.26	0.108	-	0.681	1687.07	2.842
Triple						
Brody	959.7	0.997	0.000	0.733	636.19	1.922
Gompertz	470.9	5.045	0.003	0.743	630.07	1.884
Von-Bertalanffy	1043.1	0.860	0.001	0.743	630.15	1.884
Logistic	59.2	17.835	0.013	0.743	630.51	1.887
Quadratic	2.84	0.047	0.000	0.743	630.31	1.885
Liner	2.15	0.082	-	0.733	636.04	1.921

Table 4. Estimated parameters (a, b, c) and goodness-of-fit indicators for growth models (R2; coefficients of determination, AIC; Akaike's information criteria and RMSE; root mean square error) of Damascus kids by parity of does.

Equations	a	b	c	R^2	AIC	RMSE
Parity 1						
Brody	1552.5	0.998	0.000	0.779	733.09	2.667
Gompertz	340	4.62	0.004	0.78	732.51	2.662
Von-Bertalanffy	1620.3	0.875	0.001	0.65	800.29	3.343
Logistic	59.67	15.94	0.016	0.78	732.63	2.663
Quadratic	3.109	0.06	0.001	0.65	800.41	3.344
Liner	1.974	0.117	-	0.639	805.01	3.395
Parity 2						
Brody	601.9	0.995	0.000	0.825	544.66	1.861
Gompertz	29.823	2.26	0.010	0.825	544.85	1.862
Von-Bertalanffy	39.782	0.576	0.006	0.825	544.53	1.86
Logistic	21.28	5.409	0.022	0.824	545.95	1.87
Quadratic	2.843	0.094	0.000	0.826	544.04	1.856
Liner	2.622	0.105	-	0.825	544.55	1.86
Parity 3						
Brody	1508.1	0.999	0.000	0.615	937.14	3.726
Gompertz	158.8	3.844	0.005	0.624	933.16	3.683
Von-Bertalanffy	1309.9	0.864	0.001	0.624	933.03	3.681
Logistic	45.387	11.672	0.017	0.623	933.59	3.687
Quadratic	3.168	0.068	0.000	0.624	933.07	3.682
Liner	2.072	0.122	-	0.615	937.05	3.725
Parity 4						
Brody	1121.6	0.997	0.000	0.785	709.43	2.442
Gompertz	101.9	3.305	0.005	0.791	705.61	2.412
Von-Bertalanffy	459.8	0.801	0.002	0.792	705.11	2.408
Logistic	41.71	9.538	0.016	0.789	706.88	2.422
Quadratic	3.382	0.081	0.000	0.792	704.71	2.404
Liner	2.598	0.12	-	0.786	709.24	2.44
Parity 5						
Brody	1252.6	0.997	0.000	0.654	1153.71	3.024
Gompertz	841.9	5.36	0.003	0.663	1147.44	2.983
Von-Bertalanffy	1413.9	0.862	0.001	0.663	1147.54	2.983
Logistic	100.8	23.437	0.013	0.662	1147.88	2.986
Quadratic	3.686	0.061	0.000	0.663	1147.71	2.985
Liner	2.753	0.108	-	0.654	1153.56	3.023

CONCLUSION

The lack of parity effect on birth and weaning weights of kids reflected the capability of does at different ages to withstand the burden of pregnancy without adverse impact on kids. However, to overcome the adverse effect of multi-birth, special care should be given to does pregnant in twins and triplets. The variability between models to describe a, b and c parameters necessitates more data manipulation to detect the best equation to describe growth in kids. Quadratic model, however, exhibited the best goodness of fit.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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