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# COMPARISON AMONG MODELS TO DESCRIBE GROWTH CURVES OF RAHMANI LAMBS IN RELATION TO EWE MILK YIELD AND COMPOSITION

**A. M. A. Rashad[1], T. A. Ramadan[2*] and A. E. Mahdy [1]**

***1- Animal and Fish Production Department, Faculty of Agriculture (El-Shatby), Alexandria University, Alexandria 22545, Egypt, 2- Animal Production Research Institute, Agricultural Research Center, 4 Nadi El-Said, 12311 Dokki, Giza, Egypt.***

## SUMMARY

*A total of 702 records for 39 lamb's progeny of 36 Rahmani ewes maintained continually between parities 1 and 6 were used. Milk production of dams was estimated at d 7 after lambing and milk samples were analyzed. Energy corrected milk, fat corrected milk and fat and protein corrected milk (FPCM) were calculated. Lamb weights were obtained at birth then weekly. Factors affecting milk production and composition were studied. Linear and non-linear models were applied to describe lamb growth curves. All milk parameters tended to increase significantly with parity except milk fat percentage. The correlations of daily gain with milk yield and composition were mild positive in harmony with the positive regression coefficients of lambs' daily gain on the same traits. The stepwise regression analysis indicated that milk yield was the best to predict daily gain of lambs followed by FPCM then total solids yield. Estimated parameters with lambs' growth curves from different models were variable. Parameter a was the greatest for Brody model but parameter b was the greatest for Logistic followed by Gompertz models. Parameter c exhibited the earliest maturity from Logistic model. The results suggested that Gompertz model was the most suitable for predicting weights as it has recorded the best goodness of fit parameters.*

***Keywords: Rahmani sheep, growth curve, milk composition***

## INTRODUCTION

Postnatal growth, as a fundamental biological characteristic, is a phenomenon that commences immediately after birth and can be interpreted mathematically as a momentous trait for livestock economics. It is an age dependent change manifested overtime on live weight of animal (Eisen, 1976). Mathematical models of growth curves in sheep assess the features of growth patterns in respect of body weight changes during different stages of maturity and used in livestock populations for breeding and management purposes (Lewis *et al*., 2002; Tekel *et al*., 2005). Additionally, they provide predictions about future growth of pre-selected animals in different stages of age and help to determine the optimum slaughter age (Tekel *et al*., 2005). Furthermore, information on growth patterns helps in fitting proper feeding and management plans early in the animal life, setting breeding strategies to improve the efficacy of whole growth process (Lambe *et al*., 2006), starting at point zero and depicting the factors which influence the shape of growth curve along with growth parameters (Morrow *et al*., 1978) after taking into account the amount and composition of milk suckled by the lambs during the nursing stage.

Chemical composition of sheep milk is variable due to genetic and environmental factors and is largely influenced by breed (Sakul and Boylan, 1992; Abd Allah *et al*., 2011; Abdelrahman and Aljumaah, 2012) and parity (Casoli *et al*., 1989).

The objective of this study was to describe the growth curves of Rahmani lambs, the most popular sheep breed in Egypt, through some linear and nonlinear models considering the effects of milk feeding during the suckling stage.

## MATERIALS AND METHODS

All procedures and experimental protocols were conducted in accordance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching, Federation of Animal Science Societies (FASS, 2010).

### *Animal and Management:*

A total of 702 records belonging to 39 Lambs progeny of 36 Rahmani ewes maintained continually at the Experimental Station (31º 20′ N, 30º E), Faculty of Agriculture, Alexandria University, Egypt between parities 1 and 6 , were used in this study. Ewes and their lambs were kept outdoors with shelter during the day and housed in a semi-open barn at night. Lambs were allowed to suckle their mothers all the day round. Ewes were fed on roughage and concentrate supplement according to their body weight requirements (NRC, 2007). Egyptian clover (*Trifolium alexandrinum*) was offered in winter and spring and chopped green maize in summer and autumn in addition to hay. Each ewe also received 1 kg/d of a concentrate mixture that contained 68% total digestible nutrient (TDN) and 16% crude protein (CP). Water was available to all animals at all times. Animals were clinically normal, diseases-free and had healthy appearance.

### *Milk Yield and Composition:*

Milk yield was estimated using the weigh-suckle-weigh technique as described by Ouedraogo *et al.* (2000). The sum of body weight (BW) gained by a lamb after 2 suckling sessions per day and the residual milk of both morning and afternoon milkings were considered as the daily milk production of the dam. An individual milk sample was taken daily for composition analysis from each dam. As lambs were allowed to suckle all the day round, the lambs were separated from dams on the night preceding milk sample collection. The next morning the lambs were allowed suckling for as long as the mothers allowed them (usually for 10-15 min). An individual representative milk sample was obtained daily at the middle of suckling process to avoid diluted and concentrated milk constituents at the beginning and end of suckling process, respectively. Milk samples were analyzed for crude protein and fat using the methods of Kjeldahl and Gerber, respectively (AOAC, 1984). Energy corrected milk (ECM) was calculated using the formula of Bernard (1997):

ECM (kg)=0.3246×milk yield+(12.86×fat yield)+ (7.04 × protein yield). Milk energy value (MEV) was calculated according to Baldi *et al.* (1992):

MEV (kcal/kg)=203.8+(8.36×fat%)+(6.29 × CP%).

Test day milk production was adjusted to 6.5 % fat corrected milk (FCM) and 6.5 % fat and 5.8 % protein for fat-protein corrected milk (FPCM) based on the following equations developed by Pulina *et al.* (2005):

FCM (kg/day)= M [0.37+(0.097×F)],

FPCM (kg/day)= M [0.25+ (0.085×F)+(0.035×P)],

Where: M = milk yield (kg) and F and P = fat and protein (%), respectively.

***Weights and daily gain:***

Lambs were weighed immediately at birth and then at weekly intervals till weaning at four months of age. The six months weight was also recorded. All weights, except birth weight, were recorded early in the morning after a 12 hr fasting period.

***Statistical Analysis:***

All data records (702 records) 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 ($W \geq 0.90$). 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 procedures using a mixed model, considering the day effect as repeated measurements (SAS Inst. Inc., Cary, NC), was used. The effects of parity, sex of lamb and type of birth on birth, weaning and six months weights (kg) and on averages of daily gain (kg/d) were studied using the following models:

$$Y_{ijkl} = \mu + P_i + S_j + T_k + e_{ijkl},$$

in which $Y_{ijkl}$ is the lamb birth, weaning and six months weights and daily gain, μ is the overall mean, $P_i$ is the fixed effect of the $i^{th}$ parity ($i$ = 1- 6), $S_j$ is the fixed effect of the $j^{th}$ sex of lamb ($j$ = 1-2), $T_k$ is the fixed effect of the $k^{th}$ type of birth ($k$ = 1-2), and $e_{ijkl}$ is the residual error. The effect of parity on milk production and composition was studied using the following models:

$$Y_{ij} = \mu + P_i + e_{ij},$$

in which $Y_{ij}$ is ewe milk production and compositions, μ is the overall mean, $P_i$ is the fixed effect of the $i^{th}$ parity ($i$ = 1- 6), and $e_{ij}$ is the residual error. Differences among means were tested using least significant difference ($LSD_{0.05}$). Correlation and regression coefficients for lambs' daily gain and milk compositions along with a stepwise multi regression analyses were performed.

The association between age and weight within parities, sex of lamb and types of birth were described using linear, quadratic and four modified nonlinear growth functions and were all fitted to the individual lamb 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 follows:

Linear: $y = a + bt$, Quadratic: $y = a + bt + ct^2$, Brody: $y = a(1 - be^{-ct})$

Gompertz: $y = a\exp(-be^{-ct})$, Von-Bertalanffy: $y = a(1 - be^{-ct})^3$

Logistic: $y = a / (1 + be^{-ct})$

Growth rate ($v_c$, kg) was calculated for each model, if available, as described by Lupi *et al.*, 2015 as follows:

| | | | |
|---|---|---|---|
| Brody: | $v_c = ac\left(1 - \frac{y}{a}\right)$ | Von-Bertalanffy: | $v_c = 3cy\left[\left(\frac{a}{y}\right)^{1/3} - 1\right]$ |
| Gompertz: | $v_c = cy\ln\left(\frac{a}{y}\right)$ | Logistic: | $v_c = abc\left(\frac{e^{-ct}}{1+e^{-ct}}\right)$ |

Where; "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.

Accuracy of fit was compared within each factor for different models by root of residual mean square error (RMSE), coefficient of determination ($R^2$) and mean absolute deviation (MAD). Correlation between the observed and the predicted body weights (r), which quantifies the degree of association between real and estimated growth curves, and Durbin-Watson coefficient (DW) values were calculated for each model as follows:

| | |
|---|---|
| Root mean squares errors (RMSE) | $\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$ |
| Determination coefficient ($R^2$) | (1-(SSE / SST))* 100 |
| Mean absolute deviations (MAD) | $\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n}$ |
| Durbin-Watson coefficient (DW) | $\frac{\sum_{t}^{n}(e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2}$ |

Where; "SSE" is sum square of error and "SST" is total sum of square, $y_i$ represents the actual values and $\hat{y}_i$ represents values predicted by the regression model, $e_t$ is residual at time $e$ and $e_{t-1}$ is residual at time $t-1$.

## RESULTS

Data on the effects of parity, sex of lamb and type of birth on birth, weaning and 6 months weights and daily gain of Rahmani lambs are presented in Table 1. Parity had no significant effects on birth, weaning and six months weights. However, lambs born in fourth parity had the greatest daily gain (0.146 kg/d, $P$<0.01) and the second and third parities born lambs had the lowest (0.117 and 0.121 kg/d, respectively). Also, male lambs had greater ($P$<0.05) weight at 6 month and greater ($P$<0.01) daily gain than female lambs, but birth and weaning weights were not influenced by the sex of lambs. Type of birth had no significant effects on any of the traits under investigation. As presented in Fig.1, body weight increased ($P$<0.01) gradually with advancement of age, but daily gain showed boost ($P$<0.01) within two weeks of birth to reach a peak at week 2 of age then decreased thereafter till week 5 and maintained fairly high fluctuations up to week 17 then declined until 6 months of age.

Parity affected ($P$<0.001) milk yield and composition; the fifth parity revealed the greatest values for all components of milk except fat percentage (Table 2). However, milk, fat, protein and total solid yields, ECM, FCM, FPCM and percentage of milk protein increased ($P$<0.01) gradually between first and fifth parities. The relationship between milk composition and the daily gain of lambs are presented in (Table 3). Milk yield and its composition were positively ($P$<0.01) correlated with lamb daily gain except for percentages of fat and protein, and MEV. This is supported by the positive ($P$ < 0.05) regression coefficients of daily gain of lambs on the mentioned milk parameters. Moreover, stepwise regression analysis indicated that milk yield was the best to predict daily gain of lambs followed by FPCM then total solids yield, but no other variables met the significance level ($P$ < 0.05).

The average estimates of parameters *a*, *b*, *c* and growth rate from growth curve models and goodness-of-fit indicators for each model are presented in Table (4); growth curves for all, male, female, single and twin Rahmani lambs are displayed in Fig. 2. The Richards model was problematic during convergence and, therefore, did not fit the data sets under study. The parameters estimates of different models were variable. Parameter *a*, which estimates mature weight, was the greatest (24.47 – 50.17) for Brody model for all lamb, male, female, single or twin lamb groups, while it was the smallest for Quadratic model (2.86 – 3.22). Parameter *b* was the greatest from Logistic followed by Gompertz models, while was the smallest from linear then Quadratic models. The growth rate parameter "*c*" ranged from 0.003 to 0.026 and exhibited the earliest maturity from Logistic as compared with other models. Quadratic model had unexplainable negative approaching zero (c parameter). The growth rate estimates for studied models ranged from 0.088 to 0.206 kg with large difference between models. The logistic models calculated the greatest growth rate (0.189-0.206 kg) but Brody model estimated the lowest ones (0.088-0.140 kg). Twins born lambs recorded the lowest growth rate estimates for Brody, Gompertz and Von-Bertalanffy models

**Table 1. Factors affecting birth (BW), weaning (WW) and 6 months (M6) weights, kg and daily gain (DG), kg/day of Rahmani lambs in Egypt**

| Traits | no. | Least squares means | | | |
|---|---|---|---|---|---|
| | | BW | WW | M6 | DG |
| Parity: | | ns | ns | ns | ** |
| 1 | 6 | 3.36 | 19.63 | 25.00 | 0.138 [ab] |
| 2 | 6 | 3.71 | 17.03 | 21.16 | 0.117 [c] |
| 3 | 6 | 3.24 | 17.10 | 20.66 | 0.121 [c] |
| 4 | 6 | 4.02 | 20.96 | 26.60 | 0.146 [a] |
| 5 | 8 | 3.95 | 20.41 | 23.92 | 0.133 [ab] |
| 6 | 7 | 3.69 | 18.79 | 22.43 | 0.126 [bc] |
| SEM[1] | - | 0.32 | 1.84 | 2.41 | 0.006 |
| Sex of lamb: | | ns | ns | * | ** |
| Male | 21 | 3.65 | 19.43 | 24.44[a] | 0.131[a] |
| Female | 18 | 3.64 | 17.66 | 20.60[b] | 0.114[b] |
| SEM[1] | - | 0.21 | 1.15 | 1.52 | 0.005 |
| Type of birth: | | ns | ns | ns | ns |
| Single | 33 | 3.80 | 20.20 | 24.30 | 0.132 |
| Twins | 6 | 3.52 | 17.78 | 22.29 | 0.123 |
| SEM[1] | - | 0.20 | 1.26 | 1.54 | 0.005 |

[a-c] Means with different letters in the same column within each trait differ ($P$ < 0.05).
[1] SEM: Standard error mean ns: non significant. *: $P$ < 0.05. **: $P$ < 0.01.

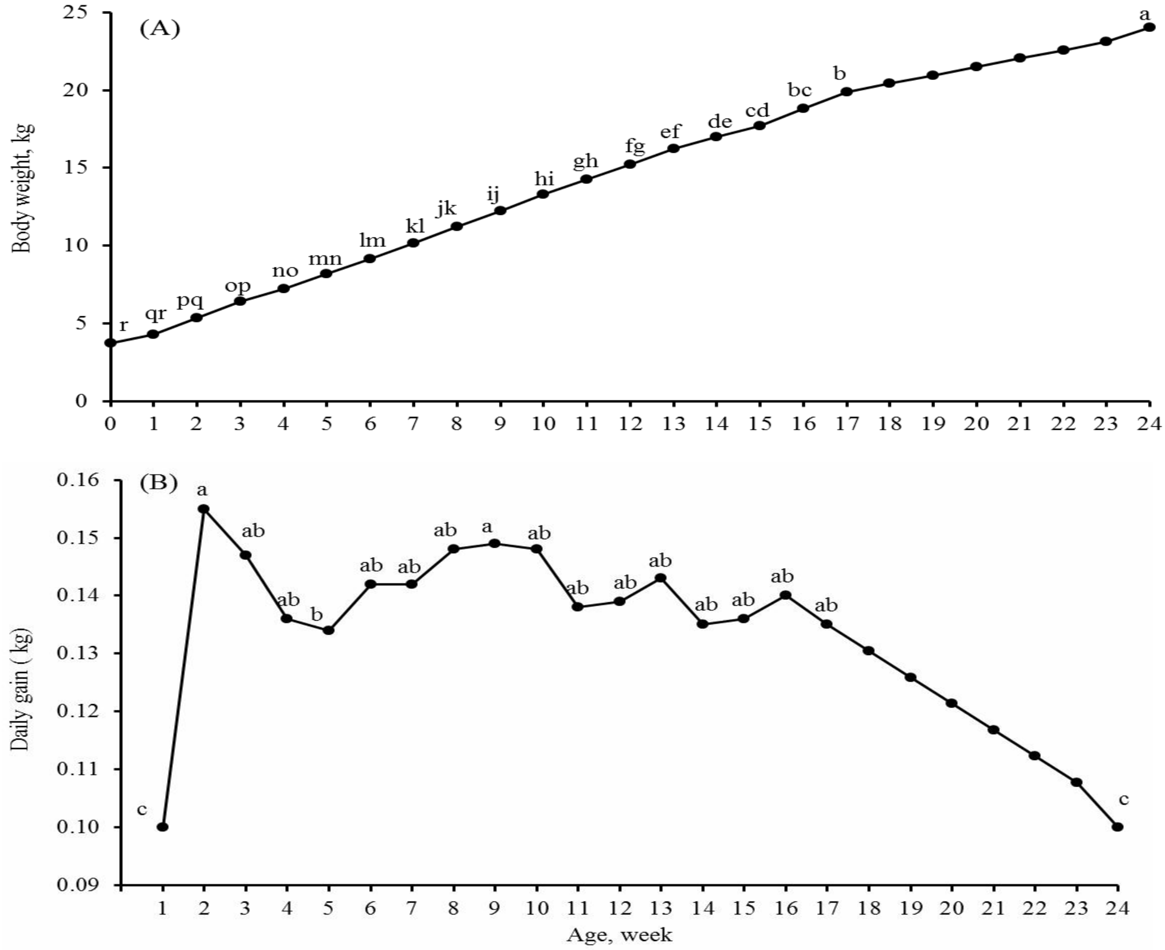


**Figure 1. Trends of body weight (A) and daily gain (B) over age from birth to 6 months for Rahmani lambs. $^{a\text{-}r}$ means with different superscript differ ($P$<0.05)**

**Table 2**. **Least squares means of milk yield and components of Rahmani ewes by parity**

| Traits | Parity | | | | | | SEM[6] | $P$-value |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | | |
| Milk fat (%) | $6.266^{a}$ | $4.508^{d}$ | $5.834^{b}$ | $4.992^{c}$ | $5.960^{b}$ | $5.758^{b}$ | 0.070 | 0.001 |
| Milk protein (%) | $4.977^{c}$ | $4.582^{d}$ | $4.946^{c}$ | $5.008^{c}$ | $6.056^{a}$ | $5.472^{b}$ | 0.067 | 0.001 |
| Total solids (%) | $15.968^{b}$ | $14.902^{cd}$ | $15.306^{c}$ | $14.800^{d}$ | $16.876^{a}$ | $15.921^{b}$ | 0.160 | 0.001 |
| MEV (kcal/kg)[1] | $287.4^{b}$ | $270.3^{e}$ | $283.6^{c}$ | $277.0^{d}$ | $291.7^{a}$ | $286.3^{b}$ | 0.733 | 0.001 |
| Milk yield (kg/day)[2] | $0.413^{c}$ | $0.477^{c}$ | $0.462^{c}$ | $0.685^{b}$ | $0.843^{a}$ | $0.664^{b}$ | 0.025 | 0.001 |
| Fat yield (kg/day)[2] | $0.027^{c}$ | $0.021^{d}$ | $0.027^{c}$ | $0.035^{b}$ | $0.051^{a}$ | $0.038^{b}$ | 0.001 | 0.001 |
| Protein yield (kg/day)[2] | $0.021^{c}$ | $0.021^{c}$ | $0.023^{c}$ | $0.035^{b}$ | $0.051^{a}$ | $0.038^{b}$ | 0.002 | 0.001 |
| Total solids yield (kg/day)[2] | $0.070^{c}$ | $0.071^{c}$ | $0.073^{c}$ | $0.105^{b}$ | $0.141^{a}$ | $0.107^{b}$ | 0.004 | 0.001 |
| ECM (kg/day)[3] | $0.617^{c}$ | $0.586^{c}$ | $0.658^{c}$ | $0.922^{b}$ | $1.294^{a}$ | $0.970^{b}$ | 0.035 | 0.001 |
| FCM (kg/day)[4] | $0.408^{c}$ | $0.386^{c}$ | $0.431^{c}$ | $0.595^{b}$ | $0.810^{a}$ | $0.617^{b}$ | 0.022 | 0.001 |
| FPCM (kg/day)[5] | $0.400^{c}$ | $0.380^{c}$ | $0.427^{c}$ | $0.594^{b}$ | $0.832^{a}$ | $0.622^{b}$ | 0.022 | 0.001 |

[1] Milk energy value (MEV) = 203.8 + (8.36 × fat %) + (6.29 × CP %). [2] Determined at day 7 of lambing.
[3] Energy corrected milk (ECM) = 0.3246 × milk yield + (12.86 × fat yield) + (7.04 × protein yield), determined at day 7 of lambing.
[4] 6.5% fat corrected milk. [5] 6.5% fat – and 5.8% protein – corrected milk. [6] SEM: Standard error mean
$^{a\text{-}g}$ Within a row, means without a common superscript differ ($P$ < 0.05).

**Table 3. The relationships between ewes milk yield and composition and lambs daily gain**

| Traits | Correlation coefficient | Regression[1] | | Stepwise regression step | | |
|---|---|---|---|---|---|---|
| | | b | Intercept | 1 | 2 | 3 |
| Milk fat (%) | -0.020 | - | - | - | - | - |
| Milk protein (%) | 0.033 | - | - | - | - | - |
| Total solids (%) | 0.123** | 0.004 | 0.084 | - | - | - |
| MEV (kcal/kg)[2] | 0.003 | - | - | - | - | - |
| Milk yield (kg/day)[3] | 0.317** | 0.011 | 0.102 | 0.011 | 0.027 | 0.031 |
| Fat yield (kg/day)[3] | 0.273** | 0.149 | 0.113 | - | - | - |
| Protein yield (kg/day)[3] | 0.268** | 0.138 | 0.117 | - | - | - |
| Total solids yield (kg/day)[3] | 0.296** | 0.059 | 0.108 | - | - | 0.004 |
| ECM (kg/day)[4] | 0.286** | 0.006 | 0.110 | - | - | - |
| FCM (kg/day)[5] | 0.293** | 0.010 | 0.108 | - | - | - |
| FPCM (kg/day)[6] | 0.287** | 0.010 | 0.110 | - | -0.017 | -0.021 |
| Determination coefficient ($R^2$) | - | - | - | 10.03 | 11.12 | 12.33 |

[1]Regression were performed for traits which had a significant correlation only. * $P < 0.05$
[2] Milk energy value (MEV) = 203.8 + (8.36 × fat %) + (6.29 × CP %).
[3] Determined at day 7 of lambing.
[4] Energy corrected milk (ECM) = 0.3246 × milk yield + (12.86 × fat yield) + (7.04 × protein yield), determined at day 7 of lambing. [5] 6.5% fat corrected milk. [6] 6.5% fat – and 5.8% protein – corrected milk. ** $P$<0.01

**Table 4**. **Parameter estimates (a, b, c and growth rate (GR)) and goodness-of-fit indicators [root mean square error (RMSE), coefficients of determination ($R^2$), mean absolute deviation (MAD), correlation coefficient between actual and predicted weights (r) and Durbin-Watson coefficient (DW)] for growth curve of linear and five non-linear models in all, male, female, single and twin born Rahmani lambs**

| Equation | a | b | c | GR (kg) | RMSE | $R^2$ | MAD | r | DW |
|---|---|---|---|---|---|---|---|---|---|
| All lambs: | | | | | | | | | |
| Brody | 43.24 | 0.929 | 0.004 | 0.131 | 2.55 | 0.966 | 1.83 | 0.910 | 1.99 |
| Gompertz | 27.91 | 2.018 | 0.014 | 0.145 | 2.53 | 0.966 | 1.53 | 0.911 | 2.00 |
| Von-Bertalanffy | 30.05 | 0.512 | 0.011 | 0.141 | 2.53 | 0.966 | 1.83 | 0.911 | 1.99 |
| Logistic | 25.04 | 4.924 | 0.024 | 0.195 | 2.54 | 0.966 | 1.88 | 0.910 | 1.98 |
| Quadratic | 3.08 | 0.166 | -0.0003 | - | 2.55 | 0.828 | 1.49 | 0.910 | 1.97 |
| Linear | 4.20 | 0.123 | - | - | 2.64 | 0.815 | 1.92 | 0.903 | 1.83 |
| Sex of lamb: | | | | | | | | | |
| Male lambs: | | | | | | | | | |
| Brody | 50.17 | 0.936 | 0.003 | 0.140 | 2.65 | 0.832 | 2.01 | 0.912 | 2.67 |
| Gompertz | 30.27 | 2.047 | 0.013 | 0.152 | 2.64 | 0.967 | 2.01 | 0.913 | 2.69 |
| Von-Bertalanffy | 32.84 | 0.517 | 0.010 | 0.149 | 2.64 | 0.967 | 2.01 | 0.913 | 2.69 |
| Logistic | 26.91 | 5.038 | 0.023 | 0.195 | 2.66 | 0.966 | 2.04 | 0.911 | 2.66 |
| Quadratic | 3.22 | 0.169 | -0.0002 | - | 2.65 | 0.833 | 2.01 | 0.913 | 2.67 |
| Linear | 4.23 | 0.131 | - | - | 2.72 | 0.823 | 2.06 | 0.907 | 2.53 |
| Female lambs: | | | | | | | | | |
| Brody | 36.82 | 0.922 | 0.005 | 0.119 | 2.34 | 0.831 | 1.71 | 0.911 | 2.36 |
| Gompertz | 25.17 | 1.995 | 0.015 | 0.134 | 2.31 | 0.969 | 1.65 | 0.915 | 2.04 |
| Von-Bertalanffy | 26.90 | 0.506 | 0.012 | 0.129 | 2.31 | 0.968 | 1.66 | 0.914 | 2.41 |
| Logistic | 22.78 | 4.855 | 0.025 | 0.189 | 2.30 | 0.969 | 1.63 | 0.915 | 2.42 |
| Quadratic | 2.86 | 0.161 | -0.0002 | - | 2.33 | 0.832 | 1.71 | 0.912 | 2.03 |
| Linear | 4.08 | 0.114 | - | - | 2.45 | 0.814 | 1.77 | 0.902 | 2.14 |
| Type of birth: | | | | | | | | | |
| Single born lambs: | | | | | | | | | |
| Brody | 45.29 | 0.932 | 0.004 | 0.134 | 2.38 | 0.851 | 1.70 | 0.923 | 1.71 |
| Gompertz | 28.60 | 2.037 | 0.014 | 0.147 | 2.36 | 0.972 | 1.67 | 0.924 | 1.71 |
| Von-Bertalanffy | 30.86 | 0.515 | 0.011 | 0.144 | 2.36 | 0.971 | 1.67 | 0.924 | 1.71 |
| Logistic | 25.58 | 5.014 | 0.024 | 0.193 | 2.37 | 0.971 | 1.68 | 0.923 | 0.78 |
| Quadratic | 3.08 | 0.168 | -0.00002 | - | 2.38 | 0.852 | 1.69 | 0.923 | 1.71 |
| Linear | 4.19 | 0.126 | - | - | 2.47 | 0.840 | 1.79 | 0.916 | 1.67 |
| Twins born lambs: | | | | | | | | | |
| Brody | 24.47 | 0.884 | 0.007 | 0.088 | 3.27 | 0.636 | 2.52 | 0.797 | 2.86 |
| Gompertz | 19.80 | 1.760 | 0.017 | 0.097 | 3.27 | 0.926 | 2.49 | 0.797 | 2.88 |
| Von-Bertalanffy | 20.66 | 0.461 | 0.014 | 0.094 | 3.27 | 0.926 | 2.50 | 0.798 | 2.87 |
| Logistic | 18.46 | 3.808 | 0.026 | 0.206 | 3.29 | 0.925 | 2.52 | 0.795 | 2.87 |
| Quadratic | 3.00 | 0.143 | -0.00003 | - | 3.27 | 0.636 | 2.51 | 0.798 | 2.87 |
| Linear | 4.33 | 0.092 | - | - | 3.35 | 0.612 | 2.55 | 0.782 | 2.58 |

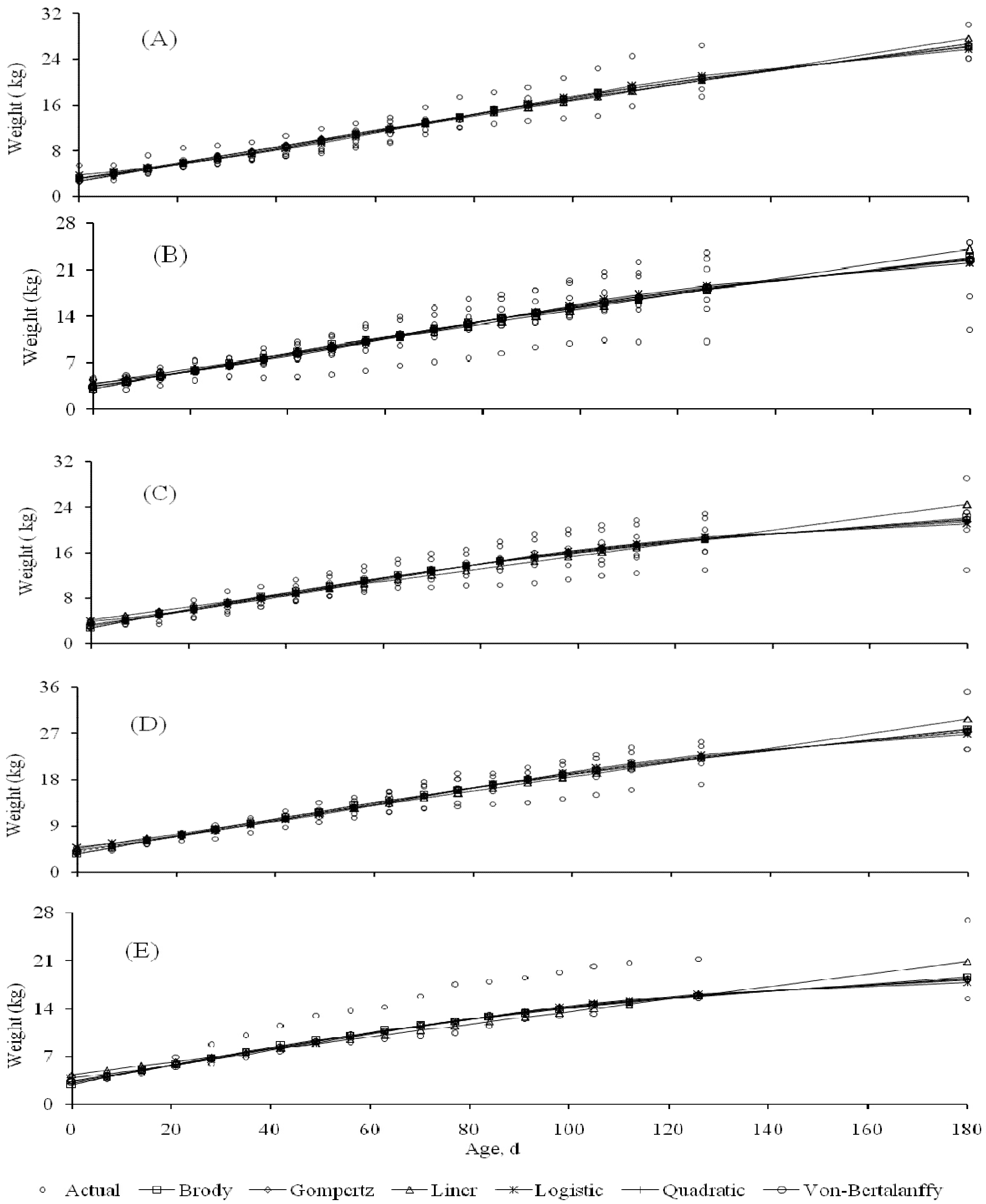


**Figure 2. Actual weights and estimated growth curves as a function of age obtained from the linear, quadratic, Brody Gompertz, Von Bertalanffy, and Logistic models in Rahmani lambs for all (A), male (B), female (C), single (D) and twin (E) Rahmani lambs.**

The models exhibiting the best fit by RMSE were Gompertz's and Von Bertalanffy's (Table 4). The coefficients of determination ($R^2$) for all lamb groups under all models were above 80% with little differences observed except for single and twin lamb born group under Quadratic and Linear models which were 0.63 and 0.61, respectively. However, the best $R^2$ estimates were obtained from Gompertz and Von-Bertalanffy models, whereas, the worst fit was for the linear model. With respect to MAD values, Gompertz and Quadratic models possessed the lowest magnitude and, therefore, recorded the best fit, though the latter having low $R^2$. Correlation coefficients between actual and predicted weights for different functions were nearly similar and over 0.90 for all groups except those for twins born lambs which were almost 0.80 for all models. Durbin-Watson coefficients were near two indicating the absence of autocorrelations which suggests that these functions could be appropriate for the data sets.

The parameters estimates of linear and non-linear growth curve models and their goodness-of-fit indicators for different parities are presented in Table (5) and growth curves for each parity are in Fig. (3).

Brody had the greatest parameter "*a*" estimates but Quadratic and Linear models had the smallest for all parities. Also, Logistic model had the greatest parameter "*b*" estimates with a range from 4.43 to 6.34, followed by Gompertz model with a range from 1.91 to 2.29. Other models had smaller "*b*" values. The parameter "*c*" estimates were positive near zero for all models except Quadratic which had negative "c" parameter near zero. The estimated growth rates for studied models were different and ranged from 0.115 to 0.228 kg. The logistic models calculated the greatest growth rate but Brody model estimated the lowest ones.

**Table 5. Parameter estimates (a, b, c and growth rate (GR)) and goodness-of-fit indicators [root mean square error (RMSE), coefficients of determination ($R^2$), mean absolute deviation (MAD), correlation coefficient between actual and predicted weights (r) and Durbin-Watson coefficient (DW)] for growth curve of linear and five non-linear models in Rahmani lambs by parity of ewes**

| Equations | a | b | c | GR (kg) | RMSE | $R^2$ | MAD | r | DW |
|---|---|---|---|---|---|---|---|---|---|
| Parity 1: | | | | | | | | | |
| Brody | 88.64 | 0.970 | 0.002 | 0.139 | 1.81 | 0.921 | 1.30 | 0.960 | 2.05 |
| Gompertz | 33.01 | 2.296 | 0.013 | 0.154 | 1.75 | 0.984 | 1.23 | 0.962 | 2.17 |
| Von-Bertalanffy | 37.23 | 0.563 | 0.009 | 0.150 | 1.76 | 0.984 | 1.24 | 0.962 | 2.14 |
| Logistic | 28.16 | 6.342 | 0.024 | 0.131 | 1.76 | 0.984 | 1.27 | 0.962 | 2.16 |
| Quadratic | 2.64 | 0.157 | -0.0001 | - | 1.81 | 0.921 | 1.29 | 0.960 | 2.05 |
| Linear | 3.20 | 0.136 | - | - | 1.83 | 0.918 | 1.34 | 0.958 | 2.00 |
| Parity 2: | | | | | | | | | |
| Brody | 50.17 | 0.939 | 0.003 | 0.115 | 2.98 | 0.749 | 2.15 | 0.865 | 2.40 |
| Gompertz | 27.19 | 2.036 | 0.013 | 0.127 | 2.95 | 0.947 | 2.12 | 0.867 | 2.45 |
| Von-Bertalanffy | 29.87 | 0.516 | 0.010 | 0.123 | 2.96 | 0.947 | 2.13 | 0.867 | 2.44 |
| Logistic | 23.79 | 5.025 | 0.023 | 0.170 | 2.95 | 0.948 | 2.12 | 0.868 | 2.46 |
| Quadratic | 3.06 | 0.142 | -0.0002 | - | 2.97 | 0.750 | 2.15 | 0.865 | 2.41 |
| Linear | 3.82 | 0.113 | - | - | 3.00 | 0.743 | 2.13 | 0.862 | 2.33 |
| Parity 3: | | | | | | | | | |
| Brody | 31.87 | 0.917 | 0.006 | 0.119 | 2.42 | 0.821 | 1.85 | 0.906 | 1.50 |
| Gompertz | 23.76 | 1.965 | 0.017 | 0.133 | 2.41 | 0.966 | 1.83 | 0.908 | 1.52 |
| Von-Bertalanffy | 25.08 | 0.501 | 0.013 | 0.129 | 2.41 | 0.966 | 1.84 | 0.908 | 1.52 |
| Logistic | 21.83 | 4.668 | 0.027 | 0.201 | 2.43 | 0.966 | 1.84 | 0.906 | 1.50 |
| Quadratic | 2.74 | 0.167 | -0.00003 | - | 2.42 | 0.822 | 1.85 | 0.907 | 1.51 |
| Linear | 4.17 | 0.113 | - | - | 2.57 | 0.798 | 1.96 | 0.893 | 1.33 |
| Parity 4: | | | | | | | | | |
| Brody | 53.92 | 0.935 | 0.004 | 0.153 | 1.94 | 0.915 | 1.36 | 0.957 | 2.89 |
| Gompertz | 32.58 | 2.034 | 0.014 | 0.163 | 1.93 | 0.984 | 1.33 | 0.957 | 2.91 |
| Von-Bertalanffy | 35.34 | 0.516 | 0.010 | 0.160 | 1.93 | 0.985 | 1.32 | 0.957 | 2.92 |
| Logistic | 28.97 | 4.970 | 0.023 | 0.212 | 1.97 | 0.984 | 1.39 | 0.955 | 2.80 |
| Quadratic | 3.53 | 0.181 | -0.00002 | - | 1.94 | 0.916 | 1.35 | 0.957 | 2.90 |
| Linear | 4.61 | 0.140 | - | - | 2.04 | 0.905 | 1.51 | 0.951 | 2.63 |
| Parity 5: | | | | | | | | | |
| Brody | 36.19 | 0.910 | 0.006 | 0.136 | 1.66 | 0.919 | 1.18 | 0.959 | 2.64 |
| Gompertz | 26.78 | 1.910 | 0.016 | 0.148 | 1.65 | 0.987 | 1.17 | 0.959 | 2.71 |
| Von-Bertalanffy | 28.32 | 0.491 | 0.012 | 0.145 | 1.65 | 0.987 | 1.15 | 0.960 | 2.71 |
| Logistic | 24.57 | 4.432 | 0.025 | 0.228 | 1.68 | 0.986 | 1.24 | 0.958 | 2.64 |
| Quadratic | 3.33 | 0.178 | -0.00003 | - | 1.65 | 0.920 | 1.16 | 0.959 | 2.68 |
| Linear | 4.78 | 0.123 | - | - | 1.88 | 0.896 | 1.47 | 0.947 | 2.01 |
| Parity 6: | | | | | | | | | |
| Brody | 36.73 | 0.917 | 0.005 | 0.126 | 3.15 | 0.747 | 2.55 | 0.865 | 0.75 |
| Gompertz | 26.78 | 1.910 | 0.016 | 0.148 | 1.65 | 0.987 | 2.59 | 0.866 | 0.77 |
| Von-Bertalanffy | 28.32 | 0.491 | 0.012 | 0.145 | 1.65 | 0.987 | 2.60 | 0.866 | 0.76 |
| Logistic | 24.57 | 4.432 | 0.025 | 0.228 | 1.68 | 0.986 | 2.57 | 0.866 | 0.78 |
| Quadratic | 3.33 | 0.178 | -0.00003 | - | 1.65 | 0.920 | 2.61 | 0.865 | 0.75 |
| Linear | 4.78 | 0.123 | - | - | 1.88 | 0.896 | 2.64 | 0.855 | 0.69 |

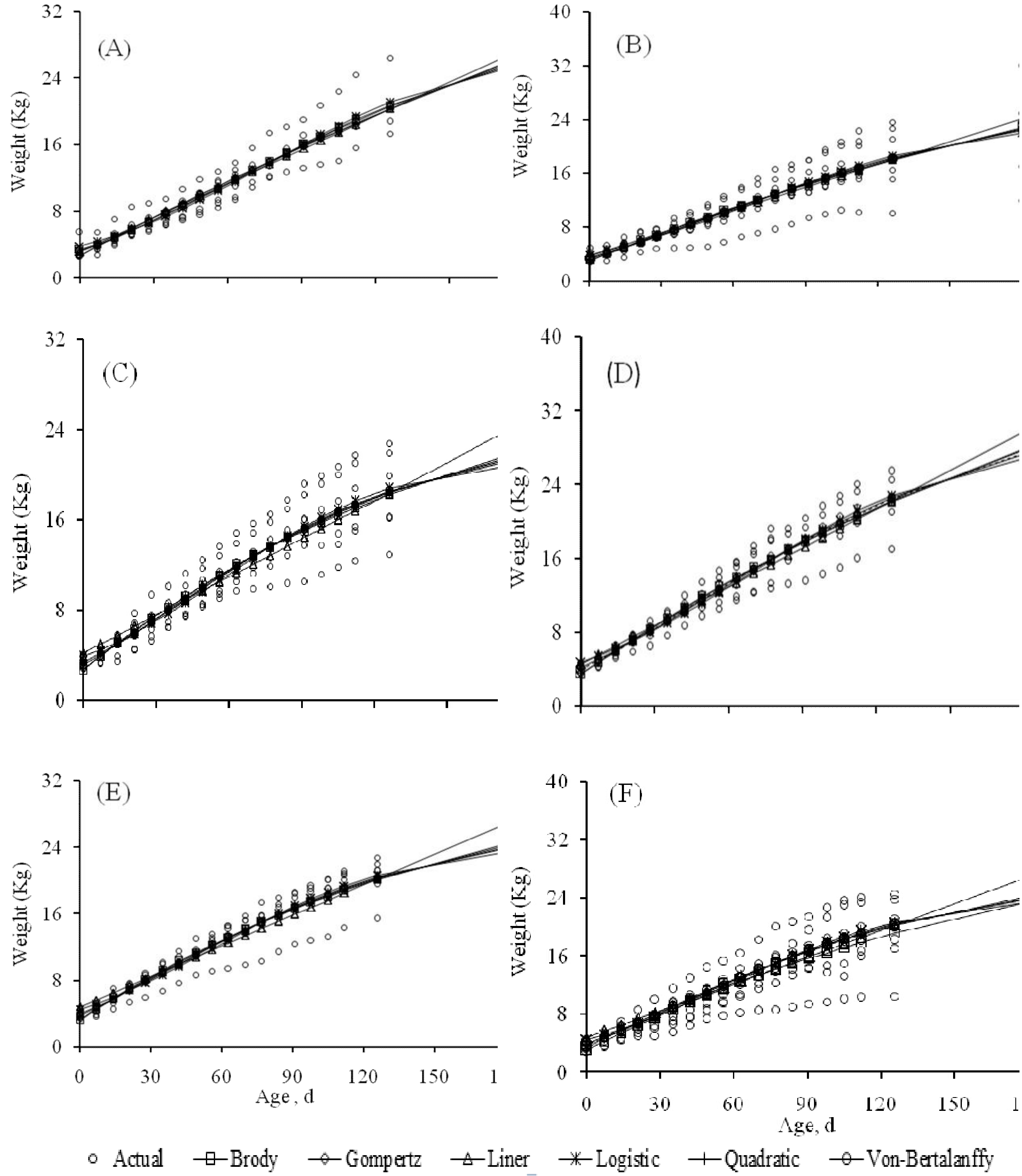


**Figure 3. Actual weights and estimated growth curves as a function of age obtained from the linear, quadratic, Brody Gompertz, Von Bertalanffy, and Logistic models for Rahmani lambs sorted by ewe parity (A = 1, B = 2, C = 3, D = 4, E = 5 and F = 6).**

High RMSE values were obtained for all parities from Brody, Logistic, Quadratic and Linear functions as compared with Gompertz and Von-Bertalanffy. Gompertz, Von-Bertalanffy and Logistic functions accounted for high $R^2$ values between 0.94 and 0.98 in different parities. MAD values diminished indicating that Gompertz function presented the best predictor followed by Von-Bertalanffy function. The correlation coefficients between actual and predicted weights (r) for Gompertz and Von-Bertalanffy functions were similar and possessed the greatest values compared to other models. Also, most of Durbin-Watson coefficients were near 2 indicating absence of autocorrelation.

## DISCUSSION

Daily gain of Rahmani lambs recorded the greatest ($P < 0.01$) value at parity four which was similar to results obtained by Movarogenis and Constantinou (1986) and Nawaz and Khalil (1998) who revealed that lambs born at parities 4 and 5 had the best growth performance, and were also in agreement with results on sheep in the tropics (Fall *et al* 1982; Adu *et al* 1985; Wilson and Murayi 1988). The high quality of ewes' milk has been reported to occur in later lactations (Casoli *et al*., 1989), where considerable development in the udder glandular tissues that take place as the number of lactations rises could result in an increase in synthesis of milk constituents (Hart, 1983). Hence, parity being one of the significant environmental sources of variation in milk yield and composition (Kala and Prakash, 1990). The maximum milk yield in sheep has been reported to occur at the third (Casoli *et al*., 1989) and fourth (Marìa and Gabiña, 1993) lactations. The effect of lactation number on milk production was suggested to be due to differences in metabolic performance of young and mature ewes. The low yield of milk in the first parity ewes insinuates poor production levels due to immaturity (Wiggans, 1984), while the decline in lactation yields after lactation 5 is likely to be due to ageing (Iloeje and Van Vleck, 1978).

Male lambs achieved greater ($P < 0.05$) 6 months weight and daily gain ($P < 0.01$) compared to female lambs which were in accordance with results reported in several sheep breeds (Hammel and Laforest, 2000; Dixit *et al*., 2001; Macit *et al*., 2001; Matika *et al*., 2003) . The larger weight of males in comparison to female lambs might be due to the differences in their endocrinological and physiological activities related to hormonal functions (Ebangi *et al*., 1996).

Concerning application of growth curve models in the present study, the Richard model was problematic and similar difficulties in obtaining convergence for Richards and Janoschek functions have been reported by Sarmento *et al*. (2006) and Malhado *et al*. (2009). However, Gompertz model was the most suitable for predicting Rahmani lambs weight in the present study (Table 4) as it recorded the highest goodness of fit parameters. Similar results were obtained by Lewis *et al*. (2002) who have chosen the Gompertz function to analyze the growth curve of Suffolk sheep affirming that this model would present desirable properties for the growth function. Also Sarmento *et al*. (2006) observed that Gompertz function presented the best adjustments compared to the other models used for studying of growth curves of Santa Inês sheep. In addition, a comparison performed among Brody, Gompertz, Logistic and Von-Bertalanffy functions to estimate growth of Morkaraman and Awassi lambs showed consistently that the Gompertz function had the best fit, whereas Topal *et al*. (2004) reported that the Von-Bertalanffy function was the best for Awassi breed.

In contrast, Bathaei and Leroy (1996) selected the Brody function to evaluate the growth curves of Mehraban Iranian fat-tailed sheep, because of simplicity of interpretation and ease of estimation. Moreover, McManus *et al.* (2003) compared the Richards, Brody and Logistic models and found that the latter was more appropriate to explain the growth performance of Bergamasca sheep. Freitas (2005) reported that Logistic, Von-Bertalanffy and Brody functions were more versatile to fit growth curves in sheep.

## CONCLUSION

The present study indicates that the best predictor for lamb daily gain was milk yield followed by FPCM then total solid yield. In addition, Gompertz model reflected high reliability and explained efficiently the relationship between weight and age of Rahmani sheep. This might be helpful to accurate determination of feeding plans, maturity and marketing ages, and for finding solutions for problems related to growth and development of this breed over time.

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## مقارنة بين بعض النماذج الإحصائية لوصف منحني النمو في حملان الرحماني وعلاقة نمو الحملان بإنتاج أمهاتها من اللبن ومكوناته

**عمرو محمد أحمد رشاد[١] ، تامر عوض رمضان*[٢] ، أحمد الطاهر مهدي[١]**

***١- قسم الانتاج الحيواني والسمكي- كلية الزراعة (الشاطبي)، جامعة الأسكندرية الأسكندرية ٢٢٥٤٥، مصر، ٢- معهد بحوث الإنتاج الحيواني، مركز البحوث الزراعية، ٤ نادي الصيد، الدقي١ ١٢٣١ - الجيزة ، مصر***

تم أستخدام عدد ٣٦ نعجة في مواسم الولادة من الأول للسادس. إنتاج اللبن من الامهات تم قياسة عند اليوم السابع بعد الولادة ومن ثم كل أسبوع كما تم أخذ عينات لبن للتحليل أسبوعيا. تم حساب إنتاج اللبن المعدل للطاقة ،للدهن وللدهن والبروتين معا. تم وزن الحملان عند الولادة ثم أسبوعيا. تم دراسة العوامل المؤثرة علي إنتاج اللبن ومكوناته. لتقدير ووصف منحني النمو في الحملان، تم أستخدام الموديل الخطي وبعض الموديلات غير الخطية. لوحظ أن جميع معايير اللبن مالت للزيادة معنويا مع تقدم موسم الولادة عدا نسبة الدهن في اللبن. الارتباط بين معدل نمو الحملان اليومي وإنتاج الأمهات من اللبن ومكوناته كان متوسط وموجب وهذا تماشي مع معاملات الإنحدار لمعدل نمو الحملان علي نفس الصفات. تحليل الإنحدار المتعدد أظهر أن إنتاج اللبن هو الصفة الأهم للتنبؤ بمعدل النمو للحملان يليه إنتاج اللبن المعدل لصفتي نسبة الدهن ونسبة البروتين يليه نسبة المكونات الصلبة الكليه في اللبن. كان تقدير معايير منحنيات النمو للمعادلات المختلفة متغير من معادلة لأخري. المعيار a كان أكبر ما يمكن في معادلة Brody ولكن المعيار b حقق أعلي قيمة في معادلة Logistic يليه Gompertz. قيم المعيار c للمعادلات المختلفة دلت علي سرعة النضج في منحني النمو المقدر بمعادلة Logistic. النتائج المتحصل عليها عموما أوضحت أن معادلة Gompertz هي الأفضل والأكثر ملائمة للتنبؤ بوزن الحملان في الأعمار المختلفة حيث أنها حققت أفضل تقدير لمعايير الدقة.