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PHENOTYPIC AND GENETIC VARIATION IN LAMBS' GROWTH USING LINEAR MODELS

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ABSTRACT

Data used in the present study was collected during 1992 to 2005 for two different sheep breeds, Farafra (2559 records) and Saidi (1539 records). The aim was to determine the efficiency of three Linear models [Linear with two parameters (L1), Linear with three parameters (L2) and second order polynomial (Quadratic) models] to the growth curves of Farafra and Saidi lambs by using monthly records of live weight from birth to 540 days of age. Farafra breed was raised in Mallawi research station and Saidi breed was raised in Seds research station belonging to Animal Production Research Institute (APRI).

The models were evaluated according to coefficient of determination (R^2), Akaike's information criterion (AIC) and Schwarz's Bayesian information criterion (BIC). In both breeds, all models fitted the data, with high R^2 ranged from 98.7 to 99.5 for males and 98.8 to 99.7 for females. The L1 model gave the best R^2 value which was 99.7 in Saidi females, while the Quadratic model gave the lowest R^2 value of 98.7 in Farafra males.

Absolute Growth Rate (AGR) obtained from L1, L2 and Quadratic models for Farafra were 0.14, 0.13 and 0.10, respectively, while for Saidi were 0.13, 0.12 and 0.10, respectively in the first month and decreased gradually to reach 0.03, 0.04 and 0.04 for Farafra and 0.03, 0.04 and 0.03 for Saidi at 540 days of age, respectively.

All growth curve parameters were significantly influenced by sex, type of birth, age of dam, year and season of birth ($P<0.01$), except the effect of age of dam on parameters B and C in Quadratic model for Saidi sheep that was not significant ($P>0.05$).

Parameters A, B and C were moderate to highly heritable in Farafra lambs ($h^2=0.24$ to 0.74). Genetic correlations between parameters were all positive and ranged from 0.35 to 1.00. In Saidi lambs, parameters had low to moderate heritabilites (0.01 to 0.48). Genetic correlations between parameters ranged from −0.87 to 1.00.

The results of this study suggest that L1 ($Y=A+Bt^{0.5}$) for growth monitoring can be useful with both breeds under condition of both stations.

***Keys words*: growth models, Farafra and Saidi lambs, heritability, correlation, fixed effects.**

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INTRODUCTION

Growth is one of the important traits in farm animals. Growth is a result of genetic potential of the individual, environmental and climatic factors and the interaction between themes. Growth curve explains the changes in yield occurring with the time.

Growth curve models are the most efficient means for describing growth of live body weight with reasonable indicative to its component because they summarize valuable information into few parameters, which have biological meaning.

The linear model is a linear equation in parameters and in independent variable (time). Akbaş *et al.* (1999) studied live weight changes of Kivircik and Daglic male lambs from birth to 420 days using growth models, and concluded that the simple Linear model gave the best fit for Daglic and the Quadratic model for Kivircik lamb, while Lambe *et al.* (2006) pointed out that the polynomial models of order greater than 1 do not provide biological meaning. In general, Linear models, with a polynomial structure from second (Quadratic) up to fourth (Quartic) order of fit, were applied. Higher orders of fit did not achieve significant influence on the fit of the growth curve (Kohn *et al.,* 2007).

The quadratic model, however, is a linear equation in parameters but second order in independent variable (time). Quadratic model with three additional parameters has been used to describe the growth data in Merino male lambs (Keskin and Dag, 2006), Daglic and Kivircik lambs (Akbas *et al.,* 1999) and Rahmani and Ossimi lambs (Mousa, 1989).

After selection of the best function for growth curve, the parameters that describe it would be studied, in order to identify the environmental factors that are likely to affect them, such as sex (Goliomytis *et al.,* 2006), type of birth (Tsukahara *et al.*, 2008), age of dam (Lambe *et al.*, 2006), year (Gbangboche *et al*., 2008) and season (Malhado *et al.,* 2009), thus assuring good adjustment of the growth rate (Sarmento *et al.*, 2006).

Heritability is one of the important genetic parameters as it indicates the proportion of the total variation due to additive genetic effect (Falconer and Mackay, 1996).

The aim of this work was to study the phenotypic and genetic parameters of some linear models describing the growth curve of Farafra and Saidi lambs from birth to 540 days.

MATERIALS AND METHODS

Data

Data was collected from the experimental station of the Animal Production Research Institute (APRI), Ministry of Agriculture and Land Reclamation, during 1992 to 2005 on two different sheep breeds and locations, Farafra (F) lambs raise in Mallawi experimental station and Saidi (S) lambs raise in Seds experimental station. Farafra data started from year 1992 while Saidi data started from year 1994. A total number of 2559 Farafra and 1539 Saidi lamb records progeny of 66 and 34 sires, 681 and 318 dams, respectively were available for this study.

Management

An accelerated lambing system of a crop every eight months was practiced. Mating seasons were January, May and September and therefore lambs were dropped in June, October and February. Only weight not less than 35 kg was permitted for ewe to join the first time to enter the mating. Ewes were randomly divided into mating groups of 20 to 25 ewes. Each group was exposed to a fertile ram about 540 days of age in a separate mating pen for a period of 35 to 45 days. Ram should be replaced by another, in case of failing to mate the ewes after one week. Lambs were kept with their dams in nursery facility all the time up to weaning at eight weeks of age. Lambs were weighed monthly until 18 mo of age.

In the morning, lambs were fed ad libitum on wheat straw or rice stubbles, in addition to a concentrate mixture consisting of (24% yellow corn, 38% cotton-seed meal, 34% wheat bran, 3% Molasses and 1% salt). During November to May the lambs were allowed to graze Egyptian clover pasture (*Trifolium Alexandrinum)*. In the rest of the year they grazes crop stubbles and green fodder, if available, while clover hay or silage may be offered. Mineral mixture blocks were freely available all the day. Extra supplement of concentrate feed of 250 g per head a day was offered one week before and another after the beginning of the mating season for flushing the ewes and also during the last two to four weeks of pregnancy and through the first four weeks of lactation. Sheep were allowed to drink fresh tap water twice or thrice daily. Animals were sheared twice a year in March and August.

Statistical analysis

Growth curve: Many mathematical models have been used extensively to describe growth data in various species such as linear and Quadratic (Mousa, 1989), Richards (Brown *et al.,* 1976), Brody (Bathaei and Leroy, 1998; Staniar *et al.,* 2004), Gompertz (Lambe *et al.,* 2006) and Von Bertalanffy (Forni *et al.,* 2007). In this study three different linear models were applied to describe Saidi and Farafra data. Preliminary investigation on the growth data of this study that used Table curve 2D version 5.01 software showed that these equations are preferable than the others. This conclusion was based on the simple coefficient of determination (R^2), the computational ease and the relatively simple biology interpretation of the estimated parameters. All models were fitted to the data from each lamb using the NLIN procedure of SAS (Release 6.12, SAS Inst. Inc., Cary, NC, 1989).

Biological Interpretation of Growth Curve Parameters: Models describing growth-age relationship in Farafra and Saidi lambs were given according to the following equation:

L1 model:

$$\mathbf{Y_t = A + Bt^{0.5} + e_t} \quad \textbf{[1]}$$

Where:

Y_t is the weight of lamb at time t, kg,

A is the initial body weight at t = 0, reflects the birth weight,

B is the summation of monthly absolute growth rate from birth to 540 days of age,

t is the age expressed in days and

e_t is the error term associated with each weigh.

L2 model:

$$\mathbf{Y_t = A + B\,t^C + e_t} \quad \textbf{[2]}$$

Where:

Y_t, A, t, e_t as defined before,

B is the partial linear regression coefficient of body weight on age t; reflects the average growth rate and

C is the outcome of subtraction the average growth rate from the summation of monthly absolute growth rate from birth to 540 days of age.

Quadratic model:

$$\mathbf{Y_t = A + Bt + Ct^2 + e_t} \quad \textbf{[3]}$$

Where:

Y_t, A, t, e_t as defined before,

B is the partial linear regression coefficient of body weight on age t; reflects the average growth rate and

C is the partial quadratic regression coefficient of body weight on t^2; which means that the decrease in daily gain over time (Mousa, 1989).

Growth rate: The first derivative with respect to time (dy/dt) is a measure of absolute growth rate (Brown *et al.,* 1976). Because time in this study was measured in days, dy/dt represents an instantaneous measure of gain per day. Gain calculated as the difference between the starting and ending weights for a given time interval $(Y_{t2} - Y_{t1}) / (t_2 - t_1)$ are approximated by dy/dt at the midpoint of the time interval (average growth rate). Absolute growth rate was calculated for the three models by the following equations:

L1 model:

$$\mathbf{dy/dt = 1/2\,B\,t^{-1/2}} \quad \textbf{[4]}$$

L2 model:

$$\mathbf{dy/dt = B\,C\,t^{C-1}} \quad \textbf{[5]}$$

Quadratic model:

$$\mathbf{dy/dt = B + 2\,C\,t} \quad \textbf{[6]}$$

Where

dy/dt is the absolute growth rate,

B and C is the parameters of each models and

t is the age expressed in days.

Model selection: The goodness of fit was assessed by using the higher R^2 (Staniar *et al.,* 2004; Lambe *et al.,* 2006), the lower Akaike's information criterion (AIC) (Akaike, 1973, Meyer, 2001; Huisman *et al.,* 2002) and Bayesian-Schwarz information criterion (BIC) values (Schwarz, 1978) through the following equations:

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$$\mathbf{AIC = -2\,Lm + 2\,m} \quad \textbf{[7]}$$

$$\mathbf{BIC = -2\,Lm - \log(n) \times m} \quad \textbf{[8]}$$

Where

Lm is the maximized log-likelihood,

m is the number of model parameters and

n is equal to the number of records used in the analysis.

Data analysis

Least squares analysis of variance option, available in SAS software (Release 6.12, SAS Inst. Inc., Cary, NC, 1989), was used to determine the effect of sex (male or female), type of birth (single, twin or triplet), age of dam at lambing which classified into four classes 11 – 29, 30 – 44, 45 – 64 and 65 – 150 month for Farafra breed and 14 – 29, 30 – 43, 44 – 60 and 61 – 124 month for Saidi breed (this classification based on the number of ewes in every class is equal to the other, approximately to avoided genetic variation), year of birth (every year included three successive lambing seasons) and season of birth (February, October or June) on the selected growth curve.

Estimation of genetic parameters

Estimates of heritability and genetic correlation were calculated using the Multiple Trait Derivative Free Restricted Maximum Likelihood program (MTDFREML; Boldman *et al.*, 1993), a set of programs employing the simplex procedure to locate the maximum of the log likelihood (logL) for each parameter.

RESULTS AND DISCUSSION

Estimate of parameters

The least-squares estimates parameters A, B and C of the three competing models were reported in Table 1. The parameter A for overall mean was maximum in the Quadratic model (3.41 & 2.59 kg) and considerably less in L1 model (1.99 & 1.29 kg) for Farafra and Saidi breeds, respectively. The estimate of B was smaller in the Quadratic model (0.1 & 0.1 kg), while L1 model showed greater values (1.52 & 1.40 kg), for Farafra and Saidi breeds, respectively. The parameter C estimates ranged from -0.0001 to 0.6178.

Mousa (1989), when applying linear model with two parameters ($Y_t = A + Bt + e_t$) from birth to 4 months of age in local breeds of Rahmani and Ossimi, reported higher estimates for A and lower estimates for B parameters than the two breeds in this study. When applying Quadratic model from birth to 540 days on the same breeds the same author reported higher estimates for A and B and lower estimates for C parameters compared with estimates in this study. This difference may be due to genotypic and environmental variation. Figure 1 shows the pattern of each model from birth to 540 days of age; L1 (Figure 1, 2); L2 (Figure 3, 4) and Quadratic (Figure 5, 6) models classically sigmoid in the Farafra and Saidi breeds, respectively.

Comparison of different growth models

The coefficient of determination is a measure of how well the model fitted the body weight data. Table 2 shows that R^2 ranged from 98.8 to 99.7 for L1 model, 99.1 to 99.7 for L2 model and 98.3 to 99.3 for Quadratic model. All competing models in this study had high R^2 from 98.3 in Quadratic equation for Farafra overall mean to 99.7 in L1 for Saidi females.

L1 model had the greatest average R^2 in each breed, suggesting the preferable fit overall. Ranking the models according to their average R^2 value gives the following order: L2 – L1 - Quadratic, for Farafra breed, L1 – L2 - Quadratic, for Saidi breed. However, when AIC and BIC values were used to compare models, taking account of the number of variables estimated in each model, L1 for Saidi and Quadratic for Farafra had the least values, suggesting that these models are suitable for predicting growth with minimum number of parameters. Ranking the models according to their average AIC and BIC values gives the following order: L1 – Quadratic – L2 for Saidi breed and Quadratic – L1 – L2 for Farafra breed.

Various R^2 and AIC values have been found in the literature, depending on the applied model, the structure of data set and the species of animal. Higher R^2 values (98 to 99) were reported for Morkaraman and Awassi lambs (Topal *et al.*, 2004). In the Scottish Blackface and Texel lambs, the values of R^2 ranged from 93.8 to 99.4 and AIC from 46 to 84 (Lambe *et al.*, 2006). In the West African Dwarf sheep the values of R^2 ranged from 82.1 to 84.6 and AIC from 32395 to 33409 (Gbangboche *et al.*, 2008).

Growth rate

The absolute growth rate (AGR) based on the first derivative of models in relation to time is shown in table 3. AGR was similar in all models and higher in Farafra than Saidi. Body gain calculated from the difference of ending and starting weights for a given time interval is equivalent to (dy / dt) at the midpoint of the two time interval. It is generally expected that individuals with lower initial growth rate would reach the age of maximum growth sooner and, consequently, show a higher exponential decay, than individuals with higher initial growth rate. Figure 2 shows the AGR for Farafra (1) and Saidi (2) based on the three computing models.

Non genetic factors affecting growth curves

The analysis of variance showed that sex, type of birth, age of dam, lambing year and season were sources of variation (P < 0.01) in the A, B and C values except the effect of age of dam that was not significant on Quadratic B and C parameters in Saidi breed.

Male was heavier than female lambs. The higher weight of male than female has been described in West African Dwarf sheep (Ebangi *et al.,* 1996) and could be attributed to the hormonal and physiological differences between sexes. Lambs from single birth present a better performance in the early development than lambs from double birth, what can be partly explained by the lack of competition for maternal milk in lambs from single lambing and the limited capacity of dams to provide more feed for the development of multiple fetuses. The superiority of single lambs over the twins was similarly reported by Yapi-Gnaore *et al.* (1997). Age of dam declined as the animal weaned. Pre weaning weight was greatly influenced by the level of milk production of the ewes while age had a considerable influence on milk production (Bathaei and Leroy, 1994). Lambs born in winter season were heavier and grew faster than their counterparts from the summer season. Similar seasonal influences were found in tropical area (Ebangi *et al.,* 1996) which may be due to variation in physical environment that affects the availability and quality of forage during dry season. The incidence of year was reported in previous studies (Ebangi *et al.,* 1996; Gbangboche *et al.,* 2006a and 2006b) and the reasons could be due to the changes during the year, in management, herdsman's skills and other environmental factors.

Genetic factors affecting growth curves

Heritabilities and genetic correlations for the variables estimated within each model are presented in Table 4. It is important to point out that genetic correlations are subject to varying degrees of error than heritabilies for the same amount of data (Bowman, 1968). Heritabilities for growth curve parameters differed markedly at each parameter of model and between the two breeds (Farafra: 0.24 to 0.74 and Saidi: 0.01 to 0.48). Genetic correlations ranged from 0.35 to 1.00 for Farafra and from 0.87 to 1.00 for Saidi. Heritability estimates the L1 were moderate for parameters A and B in the two studied breeds. However, it was higher in Farafra than in Saidi breeds. Results of this study are differing from those obtained by Mousa (1989) in Rahmani and Ossimi breeds who higher heritability than those had obtained in this study for Farafra and Saidi. Correlations between variables were similar in both studied breeds.

Heritability estimates for L2 ranged from 0.01 to 0.74. Heritability for variables A and B were moderate in Farafra breed. While in Saidi it was higher in variable A than B. Heritability estimates for C was high for Farafra, while it was very low for Saidi. In Farafra lambs, correlation between variables were high and positive, whereas in Saidi it was positive and low between A and B and for variable C it was negative with A and moderate and positive with B.

Using the Quadratic model heritability estimates for parameters were moderate to high in Farafra breed which is in agreement with Mousa (1989) for parameter C, but different for parameters A and B. In Saidi breed, heritability estimates for parameters B and C were moderate, but less heritable than those in Farafra breed. Parameter A shows less heritable than all parameters in this model. Genetic correlation was moderate among all parameters in this model, but it was high between A and B for Farafra and B and C for Saidi.

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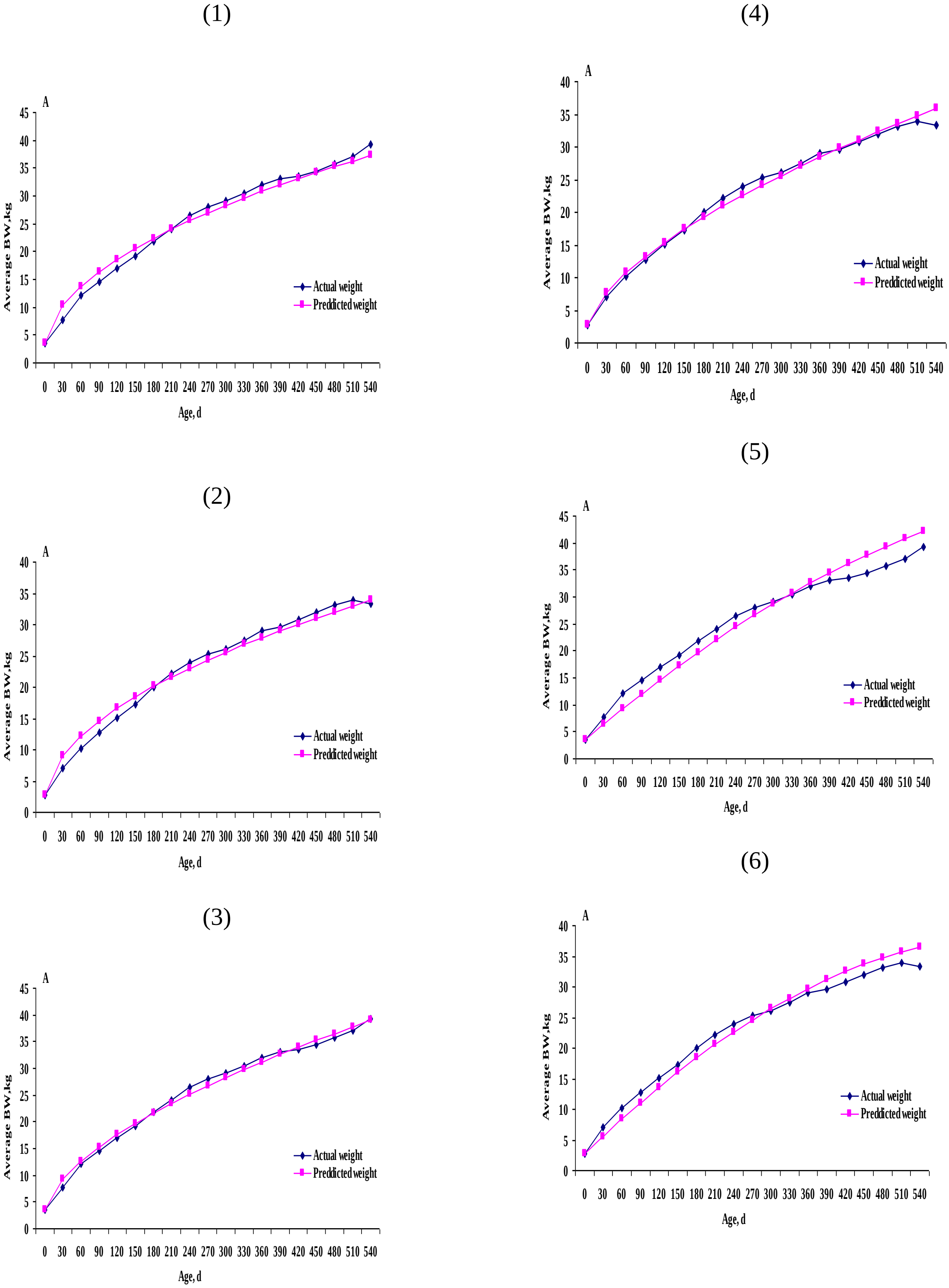
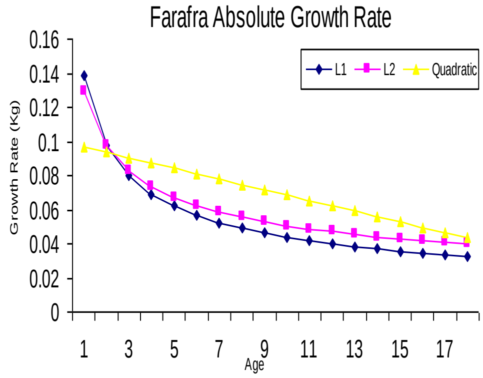


Figure 1. The estimated L1 (1, 2), L2 (3, 4) and Quadratic (5, 6) growth curves for average monthly weight from the birth to 540 days of age in Farafra and Saidi lambs overall means, respectively.

(1)



(2)

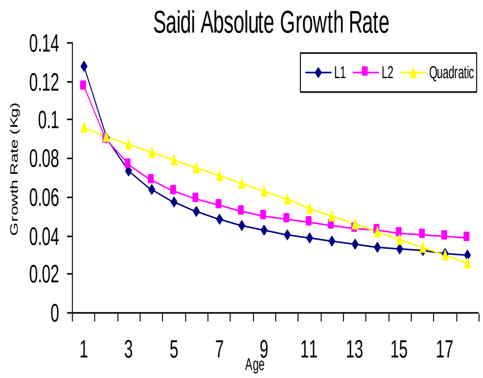


Figure 2. Absolute growth rate for Farafra (1) and Saidi (2) overall mean from birth to 540 days of age based on L1, L2 and Quadratic models.

The high positive correlations obtained in this study suggest that a high correlated response is expected when selection is practiced to improve variable in any age within the above-mentioned range. The moderate to high heritabilities and correlations among the growth curve parameters makes it clear that genetic changes in growth patterns can be accomplished.

CONCLUSIONS

Divergent growth response was obtained among the three models applied [Linear with two parameters (L1), Linear with three parameters (L2) and second order polynomial (Quadratic) models]; L1 model would serve as valuable tools for overall weights because of simplicity of interpretation, ease of computation and the high accuracy . On the other hand, this study show the importance of adjustment the model parameters A, B and C, when environmental factors affected significantly the observed weight, in order to provide a specific slope of growth curve.

In this study the shape of growth curve due to the effect of sex of lamb, type of birth, age of dam, year and season of birth have been built. However, it can’t be assumed that the L1 model could produce the goodness of fit in the Farafra and Saidi sheep when the environmental conditions change. For this purpose, the model parameters need to be routinely re-adjusted, allowing even the possibility of testing all other linear growth models.

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Table 1. Parameter estimates for Linear with two parameters (L1), three parameters (L2) and second order polynomial (Quadratic) models in the Farafra and Saidi breeds.

Model		Farafra			Saidi		
		A	B	C	A	B	C
L1	Overall mean	1.99	1.52		1.29	1.40	
	Male	1.94	1.69		1.19	1.62	
	Female	1.99	1.41		1.33	1.25	
L2	Overall mean	2.64	0.88	0.59	2.00	0.70	0.62
	Male	2.66	0.97	0.59	1.87	0.94	0.59
	Female	2.59	0.82	0.59	1.86	0.72	0.59
Quadratic	Overall mean	3.41	0.10	0.00	2.59	0.10	0.00
	Male	3.52	0.11	0.00	2.70	0.10	0.00
	Female	3.30	0.10	0.00	2.48	0.10	0.00

Table 2. Determination coefficients (R^2 values), Akaike's information criterion (AIC) and Bayesian-Schwarz information criterion (BIC) in Farafra and Saidi breeds.

Model		Farafra			Saidi		
		R^2	AIC	BIC	R^2	AIC	BIC
L1	Overall mean	99.35	16094.48	16083.06	99.22	14698.98	14688.01
	Male	98.92			98.83		
	Female	99.50			99.72		
L2	Overall mean	99.49	41589.58	41571.93	99.10	31494.54	31477.55
	Male	99.53			99.52		
	Female	99.68			99.66		
Quadratic	Overall mean	98.32	775.17	757.51	99.07	30326.57	30309.57
	Male	98.65			99.32		
	Female	99.07			98.79		

Table 3. Estimates of absolute growth rate from L1, L2 and Quadratic models for Farafra (F) and Saidi (S) breeds.

Trait	L1 model		L2 model		Quadratic model	
	F	S	F	S	F	S
G_{w1}	0.14	0.13	0.13	0.12	0.10	0.10
G_{w2}	0.10	0.09	0.10	0.09	0.09	0.09
G_{w3}	0.08	0.07	0.08	0.08	0.09	0.09
G_{w4}	0.07	0.06	0.07	0.07	0.09	0.08
G_{w5}	0.06	0.06	0.07	0.06	0.08	0.08
G_{w6}	0.06	0.05	0.06	0.06	0.08	0.08
G_{w7}	0.05	0.05	0.06	0.06	0.08	0.07
G_{w8}	0.05	0.05	0.06	0.05	0.08	0.07
G_{w9}	0.05	0.04	0.05	0.05	0.07	0.06
G_{w10}	0.04	0.04	0.05	0.05	0.07	0.06
G_{w11}	0.04	0.04	0.05	0.05	0.07	0.06
G_{w12}	0.04	0.04	0.05	0.05	0.06	0.05
G_{w13}	0.04	0.04	0.05	0.04	0.06	0.05
G_{w14}	0.04	0.03	0.04	0.04	0.06	0.04
G_{w15}	0.04	0.03	0.04	0.04	0.05	0.04
G_{w16}	0.04	0.03	0.04	0.04	0.05	0.03
G_{w17}	0.03	0.03	0.04	0.04	0.05	0.03
G_{w18}	0.03	0.03	0.04	0.04	0.04	0.03

Table 4. Heritabilities (on the diagonal) and genetic correlation (below the diagonal) between growth curve variables within each model in Farafra and Saidi lambs.

Model	Variable	Farafra			Saidi		
		A	B	C	A	B	C
L1	A	0.31			0.23		
	B	1.00	0.28		1.00	0.22	
L2	A	0.31			0.48		
	B	0.95	0.24		0.10	0.01	
	C	0.82	0.96	0.74	-0.87	0.40	0.05
Quadratic	A	0.50			0.11		
	B	0.98	0.56		0.38	0.24	
	C	0.51	0.35	0.64	0.36	1.00	0.25