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Comparison of the Growth Curve Models on Live Weights in Terms of Different Environmental Factors in Awassi Lambs

Research Article

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ABSTRACT

In this study, it was aimed to model the growth curves of Awassi lambs in terms of live weight-age relationships and macro environmental factors such as sex, birth type, year, month, and dam age, as well as to determine a nonlinear model that explains the growth curves better. For this purpose, Gompertz and Logistics were used. The data set of the study comprised of the 3523 Awassi lambs' live weights obtained at 10, 20, 30, 50, 60, 90, and 120th days of age. In order to compare both models, the coefficient of adjusted determination (R^2_{adj}) and the mean squared error (MSE) were used as the goodness of fit criteria. For the Gompertz and Logistics models, Gompertz model has the lowest MSE in all of macro environmental factors. While the estimated mean and standard errors of the asymptotic weight (A), the constant of integration (B), and growth rate (k) parameters were found respectively as 54.13 ± 0.59, 2.56 ± 0.008, and 0.01 ± 0.0001 for the Gompertz model, they were found respectively as 37.47 ± 0.18, 7.30 ± 0.03 and 0.03 ± 0.0001 for the Logistic model. For the Gompertz and Logistic models, age at inflection point (AIP), weight at inflection point (WIP) and maximal increment (MI) were found to be 5.55, 19.92, 51.00 and 66.26, 18.74, 68.40, respectively. In addition, correlations between model parameters (r_{AB}, r_{Ak}, r_{Bk}) were found as 0.86, -0.98, -0.75 and 0.45, -0.91, -0.08 respectively for the Gompertz and Logistics models.The model that better described the growth of Awassi lambs in terms of MSE, AIP, WIP, MI and r_{AB}, r_{Ak}, r_{Bk} values were found as the Gompertz growth model.

KEY WORDS Awassi, body weight, Gompertz model Logistic model, growth curve, Nonlinear model.

INTRODUCTION

Growth is one of the most important biological features of living things. While the proportional increase of body weight and organs biologically is defined as growth, the expression of the change observed in growth depending on age by a mathematical function is defined as growth curve or model (Trenkle and Marple, 1983; Efe, 1990; Owens *et al*. 1993; Kshirsagar and Smith, 1995). In general, the growth in living beings continues increasingly from birth to adult ages, then continues decreasingly and finally it stops. Although the growth curve varies from species to species, it is generally in the shape of the letter 'S' (sigmoidal curve) and consists of three parts as preparation phase, growth phase, and stagnation phase (Brown *et al*. 1976; Ratkowsky, 1983; Hyankova *et al*. 2001; Yakupoğlu and Atıl, 2001; Oda *et al*. 2016). While the curve orientation are being found by growth curve parameters, phases are estimated and meaningful interpretations can be made at different growth points (Akbaş, 1995; Fekedulegn *et al*. 1999; Bilgin and Esenbuğa, 2003; Guatam *et al*. 2018; Balafrej, 2019). On the other hand, these phases and hence the growth curve are affected by environmental factors such as genotype, dam age, sex, year, and season (Bilgin *et al*.

2004b; Saghi *et al*. 2007; Aytekin *et al*. 2011; Çelikoğlu and Tekerli, 2014; Kutluca and Emsen, 2016; Zimmermann *et al*. 2019). Furthermore, estimation of the weight-age relationship in farm animals by an appropriate model can be used for selection purposes in breeding studies (Akbaş, 1996; Mignon-Grasteau *et al*. 2000; Gamasaee *et al*. 2010; Lalit Malik *et al*. 2016; Mohammadi *et al*. 2019).

As a result of this, many growth curve studies have been carried out in different species and breeds (Wilson *et al*. 1982; Perotto *et al*. 1992; Fekedulegn *et al*. 1999; Mignon-Grasteau, 2000; Soysal *et al*. 2001; Şengül and Kiraz, 2005; Bayram and Akbulut, 2009; Şahin *et al*. 2014; Sariyel *et al*. 2017). By various researchers, the growth characteristics of sheep have been explained by growth curves (Bhadula and Bhat, 1980; Akbaş *et al*. 1999; Thieme *et al*. 1999; Keskin and Dağ, 2006; Yıldız *et al*. 2009; Aytekin and Zulkadir, 2013; Aktaş and Doğan, 2014; Koncagül *et al*. 2013; Lalit Malik *et al*. 2016; Yılmaz *et al*. 2017; Ghaderi-Zefrehei *et al*. 2018; Hojjati and Hossein, 2018; Paz *et al*. 2018; Van der Merwe *et al*. 2019).

Awassi sheep is one of the domestic sheep breeds of Turkey, which is well adapted to hot and arid climate conditions, has high adaptability to different environments, is raised with a migratory system in the Southeast Anatolia region, has priority in milk yield, and is dual-purpose breed. Many researchers have conducted studies related to the Awassi sheep and growth curve models. In their research carried out with Awassi, Morkaraman, and Tuj lambs, Esenbuğa *et al*. (2000) examined the relationship between live weight and age comparatively with the linear and nonlinear Brody model and they estimated the parameters of the nonlinear Brody growth curve. Bilgin *et al*. (2004b) estimated model parameters by using the Brody, Logistic, Gompertz, Bertalanffy, and Richards growth models in Awassi and Morkaraman sheep, and they reported that the parameters of the Brody model were more reliable and easier to interpret than the Richards model. In their another study focusing on testis circumference in Awassi lambs, Bilgin *et al*. (2004a) compared three-and four-parameter growth models with R^2 values and reported that the Logistic model was the best models among the four-parameter Tanaka model and three-parameter models. In another study, Bilgin *et al*. (2004c) investigated the effect of dam age on growth in Awassi sheep by using the Brody model. Topal *et al*. (2004) estimated model parameters in Morkaraman and Awassi sheep breeds by using Brody, Bertalanffy, Gompertz, and Logistic growth models and compared the models with R^2 and MSE criteria. Tekel *et al*. (2005) reported that the Logistic, Gompertz, and Bertalanffy models identified the growth of Awassi lambs better than the Brody and Negative exponential models. Some researchers compared Brody, Gompertz, Bertalanffy, and Logistic growth curve models in Awassi and Morkaraman female lambs and they reported that the best fit was ensured by the Brody model in Awassi lambs and by the Gompertz model in Morkaraman lambs.

This study was carried out at the "Awassi-Sub-Project" of the "National Project on Animal Breeding in Public Hand" conducted under the coordination of the General Directorate of Agricultural Research and Policies under the Ministry of Agriculture and Forestry. The study was conducted on the elite herd consisted of 3523 Awassi lambs which were the offspring of 2006 dam and 85 rams. In this study, it was aimed to estimate Awassi lambs' 10, 20, 30, 50, 90, and 120th days age-live weight relationships in terms of macro environment factors such as sex, birth type, birth year, dam age, and month of birth by using the Gompertz and Logistic growth curve models. In addition, it was aimed to use the goodness of fit criteria the R^2_{adj}, MSE, and the correlation coefficients between the model parameters, and age at inflection point (AIP), weight at inflection point (WIP) and Maximal Increment (MI) in the comparison of the models.

MATERIALS AND METHODS

Animal materials

This study was carried out in Osmaniye province within the scope of the "Awassi-Sub-Project" of the "National Project on Animal Breeding in Public Hand" conducted under the coordination of the General Directorate of Agricultural Research and Policies under the Ministry of Agriculture and Forestry. The study was conducted on the elite herd consisted of 3523 Awassi lambs which were the offspring of 2006 dams and 85 rams. The lambs were housed together with their dams after birth and weaned on about 90th day. Farmers of the region are generally engaged in animal breeding in close conditions to each other. While the feeding based on pasture and stubble grazing is performed through the nomadic system outside the winter period, the feeding based on hay and supported by grain is applied during the winter months. In this study, 3523 lambs' live weights measured at the 10, 20, 30, 50, 60, 90, and 120th days of age starting from birth and total of 28184 data records were used.

Statistical analysis

In the study, variance analysis was performed using the GLM procedure and univariate option of the IBM SPSS v20.0 in order to examine the effects of macro environmental factors, such as sex, birth type, birth year, birth months, and dam age, on live weight (IBM Corp., 2011). The model used for this purpose is given below (Kuzu and Eliçin 2002; Yılmaz *et al*. 2017).

$Y_{ijklmn} = \mu + a_i + b_j + c_k + d_l + f_m + e_{ijklmn}$

Where:
μ: mean of the population in terms of live weight.
Y_{ijklmn}: live weight of n^{th} lamb which has i sex, j birth type, and which was born in l^{th} month in k^{th} year from a dam with m age.
a_i: effect of i sex (i=1, 2).
b_j: effect of j birth type (j=1, 2).
c_k: effect of k^{th} year (k=1, 2).
d_l: effect of l^{th} month (l=1,…, 6).
f_m: effect of m dam age (l=1,…, 8).
e_{ijklmn}: effect of thee random environmental factor affecting n^{th} Awassi lamb which has i sex, j birth type, and which was born in l^{th} month in k^{th} year from a dam with m age.

In comparison of weight means related to the macro environmental factors for each age, the t-test statistic was used for sex, type of birth, and year of birth, and the Duncan multiple comparison test statistic was used for birth months and means of dam ages (Genç and Soysal, 2018).

The Gompertz and Logistic growth curve models were used to estimate the live weights of the Awassi lambs. The model equations and parameters examined are presented in Table 1 (Richards, 1959; Fatten, 2015).

In the equations, BWt is the body weight at age t; BWA is the asymptotic or mature weight; B is the initial weight; k is the growth rate; t is the age in days. In addition, while AIP and WIP refer to the inflection points of age and weight dividing the curve into two at the point having the highest growth rate in sigmoid models, MI refers to the highest growth rate at these points (Richards, 1959; Fatten, 2015). In order for the comparison of the growth curve models, the coefficient of adjusted determination (R^2_{adj}) and mean squared error (MSE) values, which are goodness of fit criteria, were used (Pham, 2019). The goodness of fit criteria to compare the functions that will explain the growth of lambs are as follows:

Adjusted determination of coefficient (R^2_{adj})=

$$1-\frac{\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2/(n-k)}{\sum_{i=1}^{n}(Y_i-\bar{Y}_i)^2/(n-1)}$$

Mean square error (MSE)= $\frac{1}{n}\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2$

Y_i: i. observation value.
$\hat{Y}_i$: i. estimated value.
$\bar{Y}_i$: average of observation values.
k: number of parameters.
n: number of samples.

Parameter estimates in the models were made with the Levenberg-Marquardt iteration method by using the NLR procedure in the IBM SPSS v20.0 (IBM Corp, 2011).

RESULTS AND DISCUSSION

The means and standard errors of macro environmental factors such as sex, birth type, birth year, birth months and dam age, which are thought to have an effect on growth of the Awassi lambs, from birth to their 120^{th} day age (10, 20, 30, 50, 60, 90, and 120^{th} days of age) are presented in Table 2. Also in this table, means are compared in each row.

The macro environment factors of sex, birth type, month of birth, and dam age, which are thought to affect the growth of Awassi lambs, were found to be significant in the variance analysis (P<0.05). It was observed that male lambs were born heavier than females and single-born lambs were born heavier than twinborn lambs and their superiority continued until the 60^{th} day. However, this difference was not found significant in later ages. On the other hand, the effect of only the year of birth on live weight was not statistically significant (P>0.05).

In terms of their birth months, the live weight of the Awassi lambs was found to be significant in every age group studied (P<0.001). It was seen that the lambs born in February are the heaviest and this superiority continues at any age. In terms of birth weight, whereas the lambs born in November, December, and January rank second, the lambs born in March and April rank third. In terms of dam age, live weights of the Awassi lambs were found to be significant in all age groups (P<0.001).

The oldest dam's (eight-year-old) lambs were also the heaviest, and this situation affected the growth of the lambs at any age. The lambs of dams aged 7, 6, 5, and 4 years were also born as the heaviest respectively, and the smallest lamb was identified as the offspring of a one-year old sheep. Means and standard errors of the parameters estimated according to the Gompertz and Logistics growth curves models used to compare the models are given respectively in Table 3.

In Table 3, When the Logistic and Gompertz models A parameters are compared in terms of macro environmental factors, were found between 32.14-38.52 in Lojistic model, and 50.41-61.45 in Gompertz model. The A parameter calculated with the Gompertz model was higher than Lojistic model those estimated with all of macro environmental factors. The highest mean A parameter values were estimated by the Gompertz model 61.45 ± 6.535 for lambs of born in January. The B parameter was representing the ratio of live weight gain after birth to adult live weight and is also called live weight increase rate.

Table 1 Growth curve equations and coordinates of inflection point

Growth curve models	Equations	AIP	WIP	MI
Gompertz	$BW_t = BW_A \exp(-B \exp(-kt))$	ln(B) / k	A × 0.368	BWIP
Lojistik	$BW_t = BW_A / (1+B \exp(-kt))$	ln(B) / k	A / 2	BWIP / 2

A, B and k: model parameters.
AIP: age at inflection point; WIP: weigth at inflection point and MI: maximal increment.

Table 2 Live-weight means and standard errors (Means±SE) of the Awassi lambs at ages from birth to 120th day according to the macro environment factors

Age (days)	Sex Means ± SE			Type of birth Means ± SE			Year Means ± SE			Month Means ± SE							Dam age Means ± SE								
	F	M		S	T		2014	2015		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.		1	2	3	4	5	6	7	8	
N	1831	1692	P	3347	176		1138	2385		397	741	1381	805	146	53		14	623	417	996	436	105	588	344	
Birth day	3.91± 0.70^{b}	4.22± 0.69^{a}	***	4.09± 0.71a	3.40± 0.44^{b}	*	4.01± 0.73	4.08± 0.70	-	4.04± 0.82^{ab}	4.04± 0.69^{ab}	4.10± 0.46^{ab}	4.16± 0.74^{a}	4.00± 0.69^{b}	3.99± 0.68^{b}	**	3.53± 0.28^{ab}	3.89± 0.68^{ab}	3.97± 0.72^{ab}	4.04± 0.69^{a}	4.07± 0.74^{a}	4.14± 0.76^{a}	4.16± 0.64^{a}	4.25± 0.69^{a}	**
10. day	5.41± 0.70^{b}	5.72± 0.69^{a}	***	5.59± 0.71^{a}	4.90± 0.44^{b}	*	5.51± 0.73	5.58± 0.70	-	5.54± 0.82^{ab}	5.54± 0.69^{ab}	5.60± 0.46ab	5.66± 0.74a	5.50± 0.69^{b}	5.49± 0.68^{b}	**	5.03± 0.28ab	5.39± 0.68^{ab}	5.47± 0.72^{ab}	5.54± 0.69^{a}	5.57± 0.74^{a}	5.64± 0.76^{a}	5.66± 0.64a	5.75± 0.69^{a}	**
20. day	7.31± 0.71^{b}	7.62± 0.69^{a}	***	7.49± 0.71^{a}	6.80± 0.44^{b}	*	7.41± 0.73	7.48± 0.70	-	7.44± 0.83^{ab}	7.44± 0.69^{ab}	7.50± 0.46^{ab}	7.56± 0.74^{a}	7.40± 0.69^{b}	7.39± 0.68^{b}	**	6.93± 0.28^{ab}	7.29± 0.68^{ab}	7.37± 0.72^{ab}	7.44± 0.69^{a}	7.47± 0.74^{a}	7.54± 0.76a	7.56± 0.64^{a}	7.65± 0.69^{a}	**
30. day	9.41± 0.71^{b}	9.72± 0.69^{a}	***	9.59± 0.71^{a}	8.90± 0.44^{b}	*	9.51± 0.74	9.58± 0.70	-	9.54± 0.84^{ab}	9.54± 0.69^{ab}	9.60± 0.46^{ab}	9.66± 0.74^{a}	9.50 ± 0.69b	9.49± 0.68^{b}	**	9.03± 0.28^{ab}	9.39± 0.68^{ab}	9.47± 0.72^{ab}	9.54± 0.69a	9.57± 0.74^{a}	9.64± 0.76^{a}	9.66± 0.64^{a}	9.75± 0.70^{a}	**
50. day	11.61± 0.71^{b}	11.92± 0.69^{a}	***	11.79± 0.71^{a}	11.10± 0.44^{b}	*	11.71± 0.73	11.78± 0.70	-	11.74± 0.84^{ab}	11.74± 0.69^{ab}	11.80± 0.46^{ab}	11.86± 0.74^{a}	11.70± 0.69^{b}	11.69± 0.68^{b}	**	11.23± 0.28^{ab}	11.59± 0.68^{ab}	11.67± 0.72^{ab}	11.74± 0.69^{a}	11.77± 0.74^{a}	11.84± 0.76^{a}	11.86± 0.64^{a}	11.95± 0.70^{a}	**
60. day	16.29± 2.75	16.99± 2.79	-	16.63 ±2.81	16.59± 2.35	-	16.50± 2.54	16.69± 2.91	-	16.83± 2.38^{ab}	16.79± 2.57^{ab}	16.92± 1.66^{ab}	17.03± 2.78^{a}	15.97± 2.38b	16.47± 3.04^{b}	**	14.78± 0.79^{c}	15.72± 2.80^{bc}	15.95± 2.48^{bc}	16.26± 2.79^{b}	16.37± 2.88^{b}	16.85± 2.88^{ab}	16.93± 0.68^{ab}	17.38± 2.77^{a}	**
90. day	22.03± 3.91	22.93± 4.00	-	22.46 ±4.00	22.54± 3.50	-	22.31± 3.49	22.54± 4.19	-	22.73± 3.51^{ab}	22.66± 1.96^{ab}	23.20± 3.92^{a}	23.34± 4.12^{a}	21.52± 3.32^{c}	22.00± 4.24^{bc}	**	20.09± 0.77^{c}	21.03± 4.00^{bc}	21.75± 3.32^{b}	21.70± 4.12^{bc}	22.21± 4.15^{ab}	22.74± 4.07^{ab}	23.01± 0.68^{a}	23.46± 3.98^{a}	**
120. day	29.03± 3.91	29.93± 4.00	-	29.46 ±4.00	29.54± 3.50	-	29.31± 3.49	29.54± 4.13	-	29.73± 3.51^{ab}	29.66± 1.96^{ab}	30.20± 3.92^{a}	30.34± 4.12^{a}	28.52± 3.32^{c}	29.00± 4.24^{bc}	**	27.09± 0.77^{c}	28.03± 4.00^{bc}	28.75± 3.32^{b}	28.70± 4.13^{bc}	29.21± 4.15^{ac}	29.74± 4.07^{ab}	30.01± 0.68^{a}	30.46± 3.98^{a}	**

F: female; M: male; S: single and T: twin.
*** (P<0.0001); ** (P<0.001); * (P<0.05) and -: non significant.
SE: standard error.

The B parameter was estimated higher then Logistic model than Gompertz model on all of macro environmental factors. The highest mean B parameter values 8.32 ± 0.15 were estimated by the Lojistic model for lambs of single born. Furthermore, the k parameter that was commonly estimated by growth curve models shows at what rate the live weight at age t approaches the adult live weight. On all of macro environmental factors k value giving information about the growth rate was estimated with Logistic (0.03±0.0001), followed by the Gompertz (0.01±0.0001) model. The phenotypic correlations (r_{AB}, r_{Ak}, r_{Bk}) of the estimated A, B and k parameters for the Gompertz and Logistics growth curves, the inflection of point on age and live weights AIP, WIP, and MI points, and the goodness of fit criteria R^2_{adj}, and MSE values were given in Table 4.

Table 4 shows in terms of the phenotypic correlations, r_{AB}, r_{Ak}, r_{Bk}, inflection points, AIP, WIP, MI, and, goodness of fit criteria, R^2_{adj}, MSE, values for the Gompertz and Logistic models.

In the Gompertz model, in terms of r_{AB} value, the highest value was seen with 98% in lambs born in January, and the lowest value was seen with 40% in lambs of four-year old dams. In terms of r_{Ak} value, the highest value was found as -99% in lambs born in January, February and April, and the lowest value was found as -90% in lambs of four-year-old dams. In terms of r_{BK} value, the highest value was found as -99% in lambs born in January, while the lowest value was found as -4% in lambs of four-year-old dams.

In the Logistic model, in terms of r_{AB} value, the highest value was observed as 90% in lambs of five-year-old dams and the lowest value was observed as 19% in twinborn lambs.

In terms of r_{Ak} value, the highest value was seen with -98% in lambs of four, five and eight-year old dams and the lowest value was seen with -89% in twinborn lambs. In terms of r_{BK} value, the highest value was found as -85% in lambs of the five-year old dams and the lowest value was found as -0.3% in lambs born in December.

Table 3 Means and standard errors (Mean±SE) of the parameters estimated for the Gompertz and Logistic models

	Lojistic Model			Gompertz Model		
	Parametre (Mean ± SE)			Parametre (Mean ± SE)		
	A	B	k	A	B	k
	37.47±0.18	7.30±0.03	0.03±0.0001	54.13±0.59	2.56±0.008	0.01±0.0001
Sex						
F	36.96±0.25	7.37±0.05	0.03±0.0001	53.35±0.80	2.57±0.01	0.01±0.0001
M	38.03±0.26	7.24±0.05	0.03±0.0001	54.98±0.85	2.55±0.01	0.01±0.0001
Type of birth						
S	37.55±0.59	7.26±0.04	0.03±0.0001	54.34±0.61	2.56±0.008	0.01±0.0001
T	36.07±0.59	8.32±0.15	0.03±0.0001	50.41±1.80	2.67±0.03	0.01±0.0001
Year						
2014	37.31±0.29	7.32±0.05	0.03±0.0001	53.90±0.93	2.57±0.01	0.01±0.0001
2015	37.55±0.23	7.30±0.04	0.03±0.0001	54.24±0.74	2.56±0.01	0.01±0.0001
Dam age						
1	35.50±1.16	7.33±0.21	0.03±0.0001	52.07±3.388	2.58±0.05	0.01±0.0001
2	37.47±0.37	7.73±0.08	0.03±0.0001	53.51±1.200	2.61±0.02	0.01±0.0001
3	38.08±0.49	7.50±0.10	0.03±0.04	54.38±1.567	2.58±0.02	0.01±0.0001
4	37.52±0.34	7.40±0.06	0.03±0.0001	53.85±1.076	2.57±0.02	0.01±0.0001
5	37.27±0.49	7.26±0.09	0.03±0.0001	54.76±1.599	2.57±0.02	0.01±0.0001
6	37.06±1.26	6.76±0.21	0.03±0.0001	54.64±4.111	2.50±0.06	0.01±0.0001
7	37.52±0.35	6.81±0.09	0.03±0.0001	54.49±1.652	2.50±0.02	0.01±0.0001
8	37.55±0.63	7.24±0.11	0.03±0.0001	54.78±2.067	2.56±0.02	0.01±0.0001
Month						
Nov.	36.92±0.311	7.13±0.06	0.03±0.0001	53.00±0.986	2.534±0.014	0.01±0.0001
Dec.	38.52±0.381	7.51±0.07	0.03±0.0001	56.10±1.271	2.592±0.017	0.01±0.0001
Jan.	34.71±1.410	7.12±0.25	0.03±0.0001	61.45±6.535	2.705±0.090	0.01±0.0001
Feb.	32.14±1.258	6.41±0.22	0.03±0.0001	51.21±4.885	2.511±0.078	0.01±0.0001
Mar.	37.02±0.521	7.05±0.09	0.03±0.0001	54.10±1.684	2.537±0.023	0.01±0.0001
Apr.	32.67±0.515	6.69±0.09	0.03±0.0001	53.51±2.097	2.576±0.032	0.01±0.0001

F: female; M: male; S: single and T: twin.
SE: standard error.

In both models, a highly high and negative phenotypic correlation was estimated between the parameters of A and k in all macro environmental factors. This relationship shows that lambs with high maturation rate will have a shorter time to reach adult weight, but less adult weight. In the Gompertz model, the inflection point age and weight were estimated as 5.55 days and 19.92 kg respectively for the overall average, while in the Logistics model, these values were estimated as 66.26 days and 18.74 kg, respectively.

According to Table 4, the model with the lowest MSE value (0.56) was the Gompertz model for the youngest dam's (one-year-old) lambs. The model with the highest MSE value (6.48) was the Lojistic Model for the lambs born in November. In addition, Gompertz model has the lowest MSE and Lojistic model has the highest MSE values in all of macro environmental factors.

Also, Figure 1 and Figure 2 show the growth curves of Gompertz, Logistic and real body weight growth patterns according to sex and bith of type of lambs, respectively.

The study was carried out to determine the best model among Gompertz and Lojistic growth curve models by using the data on the increase in the live weights of Awassi lambs from birth to the age of 120 days. For this purpose, R^2_{adj} and MSE values were primarily used to determine the best model.

When the model fitness is sorted in accordance with the MSE values, the model with the lowest MSE value and, the model with the highest R^2_{adj} value are accepted as "the best" model. According to the results, Gompertz model has the lowest MSE, the highest R^2_{adj} and, Lojistic Model has the highest MSE and the lowest R^2_{adj} in all macro environment factors.

According to the results, in females, the lowest mean square error was 5.52, the highest R^2_{adj} value was 92% obtained with the Gompertz model, while, in males, the lowest MSE was 5.80, the highest R^2_{adj} value was % 92, again, obtained with Gompertz model. When the Logistic and Gompertz models A parameter's means are compared in terms of macro environmental factors, were found between 32.14-38.52 in Lojistic model, and 50.41-61.45 in Gompertz model. The B parameter was estimated higher then Logistic model than Gompertz model on all of macro environmental factors. The highest mean of B parameter were estimated as 8.32 by the Lojistic model for lambs of single born.

Table 4 In terms of the phenotypic correlations, r_{AB}, r_{Ak}, r_{Bk}, inflection points, AIP, WIP, MI, and, goodness of fit criteria, R^2_{adj}, MSE,values for the Gompertz and Logistic models

	Lojistic model								Gompertz model							
	Correlations			Goddness of fit					Correlations			Goddness of fit				
	r_{AB}	r_{Ak}	r_{Bk}	AIP	WIP	MI	R^2_{adj}	MSE	r_{AB}	r_{Ak}	r_{Bk}	AIP	WIP	MI	R^2_{adj}	MSE
	0.45	-0.91	-0.08	66.26	18.74	68.4	0.92	5.79	0.86	-0.98	-0.75	5.55	19.92	51.00	0.92	5.73
SEX																
F	0.45	-0.91	-0.08	66.58	18.48	68.10	0.92	5.59	0.85	-0.98	-0.75	5.55	19.63	50.45	0.92	5.52
M	0.45	-0.91	-0.08	65.99	19.02	68.85	0.92	5.84	0.86	-0.98	-0.75	5.54	20.23	51.59	0.92	5.80
Type of birth																
S	0.46	-0.91	-0.10	66.08	18.78	68.17	0.92	5.84	0.86	-0.98	-0.76	5.55	20.00	51.20	0.92	5.79
T	0.19	-0.89	0.23	70.62	18.04	75.05	0.94	4.55	0.68	-0.97	-0.52	5.59	18.55	49.53	0.94	4.55
Year																
2014	0.45	-0.91	-0.08	66.35	18.66	68.3	0.94	4.71	0.86	-0.98	-0.75	5.55	19.84	50.99	0.94	4.65
2015	0.45	-0.91	-0.08	66.26	18.78	68.55	0.92	6.29	0.86	-0.98	-0.75	5.55	19.96	51.10	0.92	6.24
Dam Age																
1	0.58	-0.92	-0.24	66.4	17.75	65.05	0.99	0.69	0.90	-0.98	0.58	5.55	19.16	49.43	0.99	0.56
2	0.33	-0.90	0.07	68.17	18.74	72.43	**0.93**	5.31	0.79	-0.98	-0.67	5.56	19.69	51.39	**0.99**	5.28
3	0.35	-0.90	0.04	67.16	19.04	71.4	0.92	5.95	0.81	-0.98	-0.69	5.55	20.01	51.63	0.93	5.93
4	0.89	-0.98	-0.80	66.72	18.76	69.41	0.92	6.06	0.40	-0.90	-0.02	5.55	19.82	50.94	0.92	6.02
5	0.92	-0.98	-0.85	66.08	18.64	67.66	0.94	4.27	0.53	-0.91	-0.18	5.55	20.15	51.79	0.94	4.20
6	0.65	-0.92	-0.34	63.7	18.53	62.63	0.91	5.60	0.92	-0.98	-0.85	5.52	20.11	50.28	0.91	5.51
7	0.59	-0.92	-0.26	63.95	18.76	63.88	0.91	5.98	0.90	-0.98	-0.82	5.52	20.05	50.13	0.91	5.90
8	0.88	-0.98	-0.78	65.99	18.78	67.98	0.91	6.16	0.50	-0.91	-0.14	5.55	20.16	51.61	0.92	6.09
Month																
Nov.	0.48	-0.91	-0.11	65.48	18.46	65.81	0.91	6.48	0.86	-0.98	-0.76	5.53	19.50	49.41	0.91	6.41
Dec.	0.41	-0.90	-0.03	67.21	19.26	72.32	0.92	6.11	0.85	-0.98	-0.74	5.56	20.64	53.50	0.92	6.10
Jan.	0.83	-0.93	-0.59	65.43	17.36	61.8	0.91	3.95	0.98	-0.99	-0.99	5.6	22.61	61.16	0.91	3.94
Feb.	0.77	-0.93	-0.50	61.93	16.07	51.5	0.96	1.71	0.96	-0.99	-0.91	5.53	18.85	47.33	0.96	1.71
Mar.	0.56	-0.91	-0.22	65.1	18.51	65.25	0.94	4.33	0.89	-0.98	-0.81	5.54	19.91	50.51	0.94	4.25
Apr.	0.78	-0.93	-0.51	63.35	16.34	54.66	0.91	3.65	0.97	-0.99	-0.92	5.55	19.69	50.72	0.91	3.64

F: female; M: male; S: single and T: twin.
AIP: age at inflection point; WIP: weigth at inflection point and MI: maximal increment.
MSE: mean squared error.

The mean of k parameter that gives information about the growth rate was estimated with Logistic as 0.03 and followed by the Gompertz model as 0.01.

In a study conducted by Topal *et al*. (2004), the means of A, B, k parameters in Awassi lambs were found as 40.6, 2.08, and 0.012 in the Gompertz model and as 38.9, 5.09, and 0.018 in the Logistic model, respectively. They found also R^2 and MSE values as 98%, 2.2 and 98%, 2.8 for Gompertz and Logistic models, respectively. The means obtained in the study are consistent with the Gompertz model in terms of B and k and with the logistics model in terms of the A parameter. In addition, R^2 and MSE values were similar and found to be greater than the values found in the study. In their research, Bilgin *et al*. (2004a) found A, B, k and R^2 values in Awassi sheep breeds as 44.94, 1.77, 0.19, and 97% for the Gompertz model and as 44.12, 3.93, 0.28, and 97% for the Logistic model, respectively. Some researchers compared the growth patterns of the Awassi female lambs and they obtained the best fit with the Brody model. Additionally, they found the A, B, k, and R^2 values as 34.09, 1.79, 0.0064, and 83.33% in the Gompertz model, and as 43.68, 0.89, 0.0005, and 97.21% in the Logistic model. In a study they conducted, Akbaş *et al*. (1999) used 15 models together with the Gompertz and Logistic models in Kivircik and Daglic male lambs. They found A, B, k, and R^2 values for the Gompertz model as 113.16, 2.87, 0.0047, and 99.63% in Daglic lambs and as 88.18, 2.35, 0.0054, and 99.28% in Kivircik lambs, respectively. In addition, for the Logistic model, they found the same values respectively as 79.93, 6.81, 0.0080 and 99.37% in Daglic lambs and as 76.3, 6.25, 0.0093 and 98.67% in Kivircik lambs.

Van der Merwe, (2019) reported that the asymptotic mature weights estimated by the logistic model are noticeably lower than those estimated by the Gompertz model in all of production groups. Tahtalı *et al*. (2020) reported that used live weights of both female and male Romanov lambs and the individual growth curves estimated with the Richard, Logistic, Gompertz and Cubic Spline models. They found the best model of the Cubic Spline model for both female and male lambs.

These results show that even if the breeds were different, the results found in the study were consistent in terms of magnitude in the compared models.

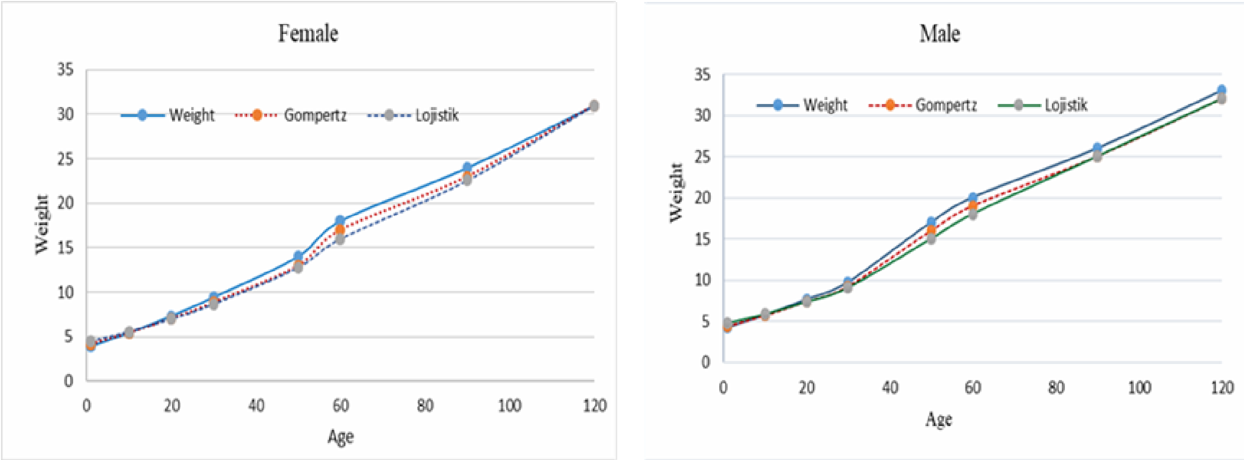

Figure 1 Sex growth curves according to Gompertz and Logistic growth functions

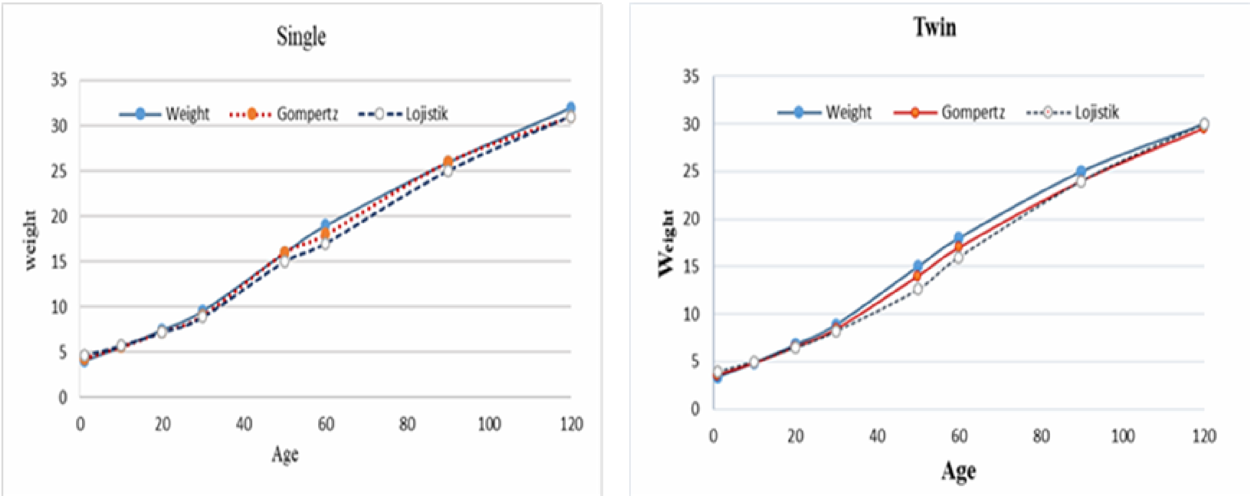

Figure 2 Type of birth growth curves according to Gompertz and Logistic growth functions

On the other side, it is thought that factors such as sheep breeds, measurement range, and measurement time were effective on finding the R^2 and MSE values different.

When the ages and weights at the inflection point were compared, it was determined that these points were reached at a later age and lower weight in the Gompertz model compared to the logistics model. In the logistics model, depending on the k parameter, the inflection point was reached at an early age in lambs. The same results were found by Van der Merwe, (2019).

In both models, whereas r_{AB} is found positive, r_{Ak} and r_{Bk} were found negative. Furthermore, in the Gompertz model, the relationship level was found higher in all studied macro environmental factors compared to the Logistic model. The same correlation coefficients consistent with the results by Bilgin *et al*. (2004c) were obtained using the Brody model on Awassi sheep.

Of the macro environmental factors studied, except the year, the effects of sex, birth type, month of birth, and maternal age were found significant at birth and various ages in the Awassi sheep. In their studies on different sheep breeds, many researchers reported that the effect of macro environmental factors such as sex, birth type, and maternal age on live weight at birth and at various ages was significant (Wilson *et al*. 1982; Aktas and Doğan, 2014; Lalit Malik *et al*. 2016; Yılmaz *et al*. 2017; Ghaderi-Zefrehei *et al*. 2018).

Throughout literature, it has been seen that models vary in accuracy according to the breed and situation that is being modelled. The studies that used body weight measurements during the study periods with fewer animals showed that the Brody, Gompertz, Logistic and Von Bertalanffy models are most suited to describe these datasets (Bilgin *et al*. 2004a; Topal *et al*. 2004). On the other hand, Mohammadi *et al*. (2019), found success in using the Brody model to describe growth of Mehraban sheep on a few static recordings per animal from a large population and, they were not estimated the parameters of growth curve under Logistic and Gompertz models for male and female Kordi lambs because of no convergence. In this study, when n number is large, convergence was achieved in Gompertz and Logistics models and Gompertz model was chosen as the better model.

Also, Figure 1and Figure 2 the distributions of models and real body weights are examined in terms of sex and the birth of type of lambs, it is seen that the Gompertz model curve is closer to the real body weights.

CONCLUSION

As a result, "National Project on Animal Breeding in Public Hand" The Gompertz model explained the live weight-age change of Awassi lambs raised in Osmaniye province within the scope of the "Awassi-Sub-Project". The growth characteristics of Awassi lambs can be estimated using this model. Especially adult weight maturation rate by making use of the relationship between adult live herd possible to change the weight in the desired direction it seems. In addition, when n number is large, convergence was achieved in Gompertz and Logistics models and Gompertz model was chosen as the better model.

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