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COMPARISON OF GROWTH CURVES USING NON-LINEAR MODELS IN MORKARAMAN MALE LAMBS SUBJECTED TO DIFFERENT FEEDING REGIMES

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ABSTRACT

The aim of this study was to determine the best mathematical model for growth curve in different feeding practices of slaughter Morkaraman male lambs after weaning to explain the change in live weights of lambs in the period prior to the slaughter. For this purpose, Morkaraman 45 male lambs, at 75 days of age (weaning) were selected and divided into 3 groups of 15 heading through random sampling and different feeding regimes were followed for each group. The first group was traditionally grazing in pasture alongside suckling dams in the morning and evening; the second group was fed with concentrate feeds, dried grass feeding and alfalfa as *ad libitum* in containment pens; the third group was fed traditionally by grazing in the pasture. Live body weight records that were collected every 15 days from birth to 135 days of age were analyzed with non-linear Brody, Bertalanffy, Logistic, Gompertz and Richards models. The model with high coefficient of determination (R^2) and low mean square error (MSE) was chosen as the best model defining growth. Richards and Logistic models were the best determinants of the overall growth of lambs in non-linear models. Among the groups, the lowest MSE and the highest R^2 were obtained in the second group and in the Logistic model. According to this model; A, B, k, R^2 and MSE were found as 43.78±1.873, 8.18±0.523, 0.027±0.0012, 0.999±0.0002 and 0.41±0.060 respectively. As a result, it was observed that the second group lambs developed faster and achieved the slaughter weight at an earlier age than the other groups. The study also revealed that the additional feeding (concentrate feed, clover, fodder, milk) was a significant factor affecting the growth of the lambs.

Keywords: Different feeding, Morkaraman lamb, growth curve, non-linear models.

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INTRODUCTION

Sheep farming is major component of livestock farming practices in Turkey where the number of heads of sheep reach 37.3 million. Statistically, it represents 56.3% of the farm animals and accounts for 9.10% of the total red meat production. The average carcass weight per slaughtered sheep is 22 kg (Anonymous, 2020). Even though lamb farming is preferred on the basis that lambs are multi-purpose animals and raised for the different sources of income they provide, such as, their meat, milk, wool and hides depending on the genotypic traits, a significant portion of the income of sheep farming is generated from slaughter lamb breeding in Turkey. The main source of slaughter lamb production in Turkey is mostly extensive form of sheep farming. The lambs, which graze in pastures with their dams or separately during spring and summer months, are considered to be ready for slaughter when they reach 25-30 kg live weight. After the lambs are weaned, they are fed with the sources of concentrate feed and coarse fodder and when they reach 35-40 kg live weight, they are sent for slaughter and prepared for the market. However, sheep farmers may also have to resort to early lamb slaughtering due to socio-economic reasons at times.

Shaped by the interaction between the genetic structure and environmental conditions of the living things, the increases in the number and size of the cells occurring in certain time intervals are defined as growth. Furthermore, development is the change in the proportions of body parts as a result of physiological and morphological differences formed by the new biological functions in living things (Akbas, 1995; Bayram and Akbulut, 2009). Growth and development occur in prenatal and postnatal periods. The change of a characteristic studied in a certain period is defined as the growth curve. This change varies in species, races and lines and especially in the characteristic studied. (Akbas *et al.,* 1999).

The change that living things show in their growth depending on the age is called growth curve (Goonewardene *et al.,* 1981; Kocabas *et al.,* 1997). The growth curve is a mathematical expression of the growth, shaped by the influence of genetic and environmental factors. In other words, the growth curve shows the mathematical relationship between the weight and age of an animal (Bethard, 1997). Growth models have biological parameters that explain the physiological mechanism of growth until adult live weight is reached, that is the time when living things stop growing (Menchaca *et al.,* 1996; Behr *et al.,* 2001). These parameters help to understand the growth process, which has a complex structure, and determine the factors affecting growth in this process (Brown *et al.,* 1976). The most important benefit of growth curve models is the biological interpretation of information obtained at different points of age that is difficult to explain (Akbas, 1995).

This research was conducted in order to identify the best nonlinear model for determining the slaughter weights of Morkaraman male lambs, which were subject to different feeding regimes after weaning. In addition, slaughter Morkaraman male lambs have been studied to identify the best growth curve model that can explain the age-related changes in live weight.

MATERIALS AND METHODS

The animal material of the research composed of 45 Morkaraman male lambs born on 13-15 March 2017 in a facility within the scope of the project "National Project for Small Ruminant Farming Run by Public", initiated in the province of Agri in 2013. The lambs were with their dams for three days after the birth and they suckled their dams *ad libitum*. Then, the lambs were separated from their mothers and suckled twice a day in the morning and evening until about 75 days of age (weaning), and in addition to breastfeeding from 10 days of age, they were fed with alfalfa and lamb beginning fodder *ad libitum*. The lambs, weaned at 75 days of age, were separated into 3 groups through random sampling. The first group (after weaning) were grazing on pasture *ad libitum* in the morning and evening, the second group (after weaning) was fed with lamb growth fodder + hay-alfalfa *ad libitum* in extensive feeding conditions and the third group (after weaning) was fed by grazing on the pasture *ad libitum*. Water was given to all three groups three times a day. The dams of the suckling lambs grazed on pasture *ad libitum* and were given water three times a day. The lambs in all three groups were sent to the slaughter at 135 days of age. The birth weights of the lambs were measured using a sensitive digital hand scale, with 10 grams precision, within an hour following the birth. The following weighing of the lambs were done after the lambs were left hungry-thirsty for 12 hours. Weight-age data of 45 lambs, whose live weight records were collected every 15 days from birth to 135 days of age, were analyzed individually. In order to identify the content of the fodders used in the feeding of lambs, they were analyzed in The Feed Analysis Laboratory of Ataturk University Faculty of Agriculture. The contents of the fodders used are given in Table 1.

Table 1. The contents of the feeds used for feeding lambs (%).

Feed	Dry Matter	Raw Protein	Raw Fat	Raw Ash	ADF	NDF
Lamb Augmentation Feed	91.29	13.29	2.10	9.32	21.43	40.38
Barley Meal	90.63	8.51	2.48	5.31	27.64	45.31
Alfalfa	92.83	19..20	1.74	11.12	18.53	30.99
Pasture	93.67	10.80	2.30	9.68	32.47	52.36

ADF: Acid Detergent Fiber; NDF: Neutral Detergent Fiber.

In order to identify the best growth model, non-linear models specified in Table 2 were used. The A, B, k and m parameters were generalized using SPSS statistical program and identified by The Least Squares Method (GLSM) and the Levenberg-Marquardt iteration process. In the iteration process, the convergence criterion 1.0 E-8 was used (Akbas *et al.,* 1999; Akbas *et al.,* 2001). Duncan multiple comparison test (SPSS) was carried out for the comparison of the mean values of the parameters (SPSS, 2016).

In the models, the characters stand for the following; W(t): t observed weight at daily age, t: the age of the lambs in the weighing periods, A: the average maximum weight to reach the slaughter age (asymptotic limit), B: rate of weight gain afterbirth to mature weight rate, k: growth rate (this parameter indicates the speed at which the live weight approaches the mature weight), exp: base of a natural logarithm, m: it indicates the change point that occurs when the change in the predicted growth rate, which gives information about the shape of the curve, shifts from increase to decrease. In Bertalanffy, Logistic and Gompertz models the point of change is constant (m=3, -1,∞), while in Richards model the m parameter is variable. In comparison of the models, the coefficient of determination, denoted R^2, representing the part explained by the model in the total variation and also the mean of error squares, denoted MSE, expressing the difference between the predicted growth curve of the model and the points of the actual growth curve were used. The model with a high coefficient of determination (R^2) and a low mean of error squares (MSE), was chosen as the best growth model.

Table 2. Non-linear growth curve models used in the research.

Models	Mathematical Equality	Number of Parameters
Brody	$Wt = A[1 - B^{*}exp(-k^{*}t)]$	3
Bertalanffy	$Wt = A[1 - B^{*}exp(-k^{*}t)]^{3}$	3
Gompertz	$Wt = A^{*}exp[- B^{*}exp(-k^{*}t)]$	3
Logistic	$Wt = A[1 + B^{*}exp(-k^{*}t)]^{-1}$	3
Richards[1]	$Wt = A[1 \pm B^{*}exp(-k^{*}t)]^{m}$	4

[1] A positive sign was used in the case of m<1 and a negative sign in other cases in the Richards model.

RESULTS

The parameters acquired by analyzing the individual weights of 45 Morkaraman male lambs with 5 non-linear growth curve models are given in Table 3.

The effectiveness of the models for explaining weight-age change was between 99.4 and 99.9% in individual analyses. Regarding the MSE value, significant differences were observed between the values acquired in the form of group analysis of the models. The differences between the A, B and k parameters estimated for groups with Brody, Bertalanffy and Gompertz models were found to be significant ($p<0.01$). However, the differences between parameter A in the Logistic model and the parameters A and k in the Richards model were significant ($P<0.01$). When all of the Morkaraman male lambs were evaluated together, without group distinction, Logistic and Richards models found to have the lowest MSE. When all the lambs were evaluated together, the differences between the A, B and k parameters estimated by the models were found to be significant ($P<0.01$). The lowest MSE and highest R^2 values were acquired in Group 2 with Bertalanffy, Logistic, Gompertz and Richards models and in Group 1 with Brody models.

Variance analysis was applied to R^2 and MSE statistics obtained from the models for choosing the best model and the results are given in Table 4. The effects of models on R^2 and MSE on nonlinear models were significant ($P<0.01$).

By applying Duncan multiple comparison test to the R^2 and MSE values, the best model was chosen analytically and the results are given in Table 5. According to the Duncan multiple comparison test, the Brody model had the lowest agreement level regarding the R^2 and MSE values among non-linear models. The other four models presented similar agreement levels. The Brody model showed approximately 0.5% lower agreement level regarding the R^2 value.

Table 3. Parameters acquired from individual weight analysis of Morkaraman male lambs by nonlinear models.

Models		A	B	k	m	MSE	R^2
		$\bar{X}\pm S_{\bar{X}}$	$\bar{X}\pm S_{\bar{X}}$	$\bar{X}\pm S_{\bar{X}}$	$\bar{X}\pm S_{\bar{X}}$	$\bar{X}\pm S_{\bar{X}}$	$\bar{X}\pm S_{\bar{X}}$
				OVERALL (N = 45)			
Brody		69.72 ± 4.630^{d}	0.95 ± 0.004^{a}	0.006 ± 0.0005^{a}		2.61 ± 0.329^{b}	0.994 ± 0.0007^{a}
Bertalanffy		55.84 ± 4.364^{c}	0.58 ± 0.010^{a}	0.013 ± 0.0008^{b}		1.00 ± 0.117^{a}	0.998 ± 0.0003^{b}
Logistic		46.62 ± 2.902^{b}	2.42 ± 0.058^{b}	0.018 ± 0.0009^{bc}		0.83 ± 0.090^{a}	0.998 ± 0.0002^{b}
Gompertz		36.63 ± 1.313^{a}	7.15 ± 0.330^{c}	0.037 ± 0.0050^{d}		0.73 ± 0.087^{a}	0.998 ± 0.0002^{b}
Richards		40.10 ± 1.690^{ab}	2.22 ± 0.419^{b}	0.024 ± 0.0011^{c}	-2.998 ± 0.1936	0.84 ± 0.089^{a}	0.998 ± 0.0002^{b}
		**	**	**		**	**
				INTERGROUPS (N = 15)			
	Group 1	70.43 ± 6.275^{b}	0.95 ± 0.007^{a}	0.006 ± 0.0009^{a}		2.11 ± 0.491	0.995 ± 0.0011
Brody	Group 2	94.70 ± 7.738^{c}	0.97 ± 0.005^{b}	0.004 ± 0.0005^{a}		3.44 ± 0.654	0.992 ± 0.0014
	Group 3	44.01 ± 3.323^{a}	0.94 ± 0.008^{a}	0.008 ± 0.0006^{b}		2.28 ± 0.524	0.994 ± 0.0010
		**	**	**		ns	ns
	Group 1	55.08 ± 4.698^{b}	0.56 ± 0.014^{a}	0.012 ± 0.0014^{b}		1.17 ± 0.157^{b}	0.997 ± 0.0004^{a}
Bertalanffy	Group 2	80.19 ± 8.589^{c}	0.62 ± 0.015^{b}	0.009 ± 0.0010^{a}		0.61 ± 0.144^{a}	0.999 ± 0.0004^{b}
	Group 3	32.25 ± 1.493^{a}	0.56 ± 0.017^{a}	0.018 ± 0.0010^{c}		1.21 ± 0.259^{b}	0.997 ± 0.0006^{a}
		**	**	**		*	**
	Group 1	38.29 ± 1.455^{b}	6.41 ± 0.503	0.045 ± 0.0147		1.31 ± 0.160^{b}	0.997 ± 0.0003^{a}
Logistic	Group 2	43.78 ± 1.873^{c}	8.18 ± 0.523	0.027 ± 0.0012		0.41 ± 0.060^{a}	0.999 ± 0.0002^{b}
	Group 3	27.81 ± 1.102^{a}	6.85 ± 0.614	0.039 ± 0.0014		0.49 ± 0.085^{a}	0.999 ± 0.0003^{b}
		**	Ns	ns		**	**
	Group 1	47.75 ± 3.650^{b}	2.30 ± 0.087^{a}	0.016 ± 0.0014^{a}		1.14 ± 0.125^{b}	0.997 ± 0.0003^{a}
Gompertz	Group 2	61.79 ± 5.373^{c}	2.64 ± 0.091^{b}	0.013 ± 0.0010^{a}		0.47 ± 0.111^{a}	0.999 ± 0.0003^{b}
	Group 3	30.31 ± 1.288^{a}	2.32 ± 0.103^{a}	0.023 ± 0.0009^{b}		0.89 ± 0.178^{b}	0.997 ± 0.0004^{a}

		**	**	**		**	**
Richards	Group 1	41.86±2.013[b]	2.29±1.690	0.022±0.0063[a]	-3.359±0.3704	1.33±0.152[b]	0.997±0.0003[a]
	Group 2	49.50±2.477[c]	2.40±0.555	0.020±0.0013[a]	-2.904±0.3745	0.46±0.104[a]	0.999±0.0003[b]
	Group 3	28.95±1.160[a]	1.98±0.608	0.030±0.0016[b]	-2.733±0.2468	0.74±0.140[a]	0.998±0.0004[a]
		**	ns	**	ns	**	**

**: ($p<0.01$), *: ($p<0.05$) significant; ns: not significant; a, b, c, d: the differences between the averages indicated by the same letter are statistically insignificant.

Table 4. The variance analysis results of R^2 and MSE values obtained from models.

Source of Variation	SD	Coefficient of Determination (R^2)		Mean Squared Error (MSE)	
		Squares Mean	F	Squares Mean	F
Non-linear Models					
Model	4	0.000163	25.962**	28.223	21.491**
Error	220	0.000006		1.313	

**: ($p<0.01$) significant.

Table 5. The Least squares averages, standard errors and multiple comparison test results for R^2 and MSE statistics for nonlinear models.

Variation Sources	R^2	MSE
	$\bar{X}\pm S_{\bar{X}}$	$\bar{X}\pm S_{\bar{X}}$
Non-linear Models	F = 25.962 **	F = 21.491 **
Brody	0.993±0.0007[a]	2.61±0.329[b]
Bertalanffy	0.998±0.0003[b]	1.00±0.117[a]
Logistic	0.998±0.0002[b]	0.83±0.090[a]
Gompertz	0.998 ± 0. 0002[b]	0.73±0.087[a]
Richards	0.998 ± 0. 0002[b]	0.84±0.089[a]

**: ($p<0.01$) significant; ns: not significant; a, b: the differences between the averages indicated by the same letter are statistically insignificant.

DISCUSSION

The early growth in animals usually presents a linear increase. However, studies have shown that this alone will not be always sufficient (Bilgin and Esenbuga, 2003; Topal *et al.,* 2004; Bayram and Akbulut, 2009; Daskiran *et al.,* 2010). Therefore, current study explains the change in growth over time for Morkaraman male lambs based on different feeding factors, using five non-linear growth.

It has been reported that the best model to explain the growth is the one that has the highest R^2 and smallest MSE values when the models are compared. (Topal *et al*., 2004; Bayram and Akbulut, 2009; Karakus *et al*., 2010; Kopuzlu *et al*., 2014). In this study, Logistic and Richards models defined the best growth according to R^2 and MSE values (Table 3). Some studies conducted in small ruminants reported that the models given below represent high levels of agreement with regard to the growth curves of the animals we mentioned. Accordingly, the authors and the models they employed are as follows: Bilgin *et al*. (2003), Akbas *et al.* (1999), Balan *et al.* (2017) and Ali *et al.* (2020) used the Brody Model, Daskiran *et al.* (2010), Sireli and Ertugrul (2004) used the Logistic model, Kopuzlu *et al.* (2014) used the Richards model, Akkol *et al*. (2011) used the Bertalanffy model, Topal *et al.* (2004) used the Bertalanffy and Gompertz models and Lambe *et al*. (2006) used the Richards and Gompertz models.

Without group distinction, Brody model indicated the highest estimate and Gompertz model indicated the lowest estimate in the Morkaraman male lambs mature live weight (A). The difference between these two models is 33 kg. The estimated mature weight in the intergroup models was obtained in Group 2, using the Brody model. The lowest adult weight was estimated in Group 3, using the Logistic model. The rate of growth (k) indicates how rapidly the weight observed at t age approaches the mature living weight (A). Some studies on growth curves (Brown *et al*., 1976; DeNise and Brinks, 1985; Krieter *et al*., 1987) have reported a very high and negative relationship between mature live weight and (A) growth rate (k). Therefore, it is understood that lower mature live weight in animals leads to higher growth rate and higher mature live weight in animals leads to lower growth rate. In this study, the Brody model, which estimated the highest mature body weight, estimated the lowest rate of growth and the Gompertz model, which estimated the lowest mature body weight, estimated the highest rate of growth. This study reveals that the model that estimated high k in animals of the same race, estimated low A.

In growth curve models, the parameter B shows the ratio of live weight gained after birth to the mature live weight. Other than Brody model, in the other four nonlinear models, this parameter does not exactly have the biological meaning we pointed out earlier. It is reported that adding the variable m parameter as the fourth parameter to the Richards model limits the biological significance of the B parameter in this model. However, the value of B varies since m takes different values due to the negative relationship between B and m. (Brown *et al*., 1976).

"m" is a parameter giving information about the shape of the curve. It indicates the point of inflection, which occurs when the change in the predicted growth rate changes from increase to decrease. It has been reported that in the case of $m<1$, the point of change is undefined (Brown *et al*., 1976; Nadarajah *et al*., 1984; Perotto *et al*., 1992; Beltran *et al*., 1992). In other words, it indicates that the point of change hasn't occurred.

In this study, the parameters A, B, k, R^2 and MSE obtained in the Morkaraman model were 46.62, 2.42, 0.018, 0.998 and 0.83, respectively, in the Logistic model, which showed the best agreement in the growth of Morkaraman male lambs from birth to 135 days of age. Bilgin *et al*. (2003) reported that the best model in their study of Morkaraman Lambs was the Brody model and the parameters A, B, k and MSE predicted by this model were 51.86, 0.921, 0.1370 and 0.47, respectively. Another study reported that Gompertz and Bertalanffy were the best models in Morkaraman lambs (Topal *et al*., 2004). They estimated Gompertz model's A, B, k, R^2 and MSE parameters as 41.4, 2.06, 0.012, 0.98 and 3.0 respectively, Bertalanffy Model A, B, k, R^2 and MSE parameters as 42.5, 0.52, 0.010, 0.98 and 3.0 respectively.

Conclusion: Growth models provide valuable information on mature weight and growth rate during growth periods and are likely to be useful for selection purposes with regard to achieving the intended body weight in lamb industry. Especially by taking advantage of the relationship between the mature weight and the rate of growth, it seems possible to change the mature live weight of lambs in the preferred direction. Richards and Logistic models explained the weight-age (birth-135 days of age) change in Morkaraman male lambs, which were subject to different feeding regimes following the weaning. The harmony of the parameters of different feeding regimes and the slaughter age of Morkaraman male lambs was acquired using the Logistic model in Group 2.

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