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COMPARISON OF NONLINEAR MODELS TO DESCRIBE THE GROWTH OF TUJ AND ROMANOV X TUJ (F1) LAMBS

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Abstract: This study aimed to identify the most suitable model for explaining weight changes in purebred Tuj (n=35) and Romanov x Tuj (RoxTuj) (F1) (n=25) lambs using non-linear models. Single-born lambs of both breeds and genders were included in the evaluation. Five different non-linear growth models were compared: Brody, Gompertz, Logistic, Richards, and Weibull. The best model for describing growth was chosen based on four criteria: coefficient of determination (R^2), mean square error (MSE), Akaike information criterion (AIC), and Bayesian information criterion (BIC). Models with the highest R^2 and the lowest MSE, AIC, and BIC values were considered the best fit for the data. It was observed that the Brody model had the highest R2 and lowest MSE, AIC and BIC values for Tuj and RoxTuj (F1) female and male lambs. The Gompertz, Logistic, and Richards models exhibited similar predictive performance. In contrast, the Weibull model produced significantly different results compared to the other models when predicting weight changes. Therefore, the Brody model was identified as the most effective model for explaining growth patterns in both Tuj and RoxTuj (F1) lambs.

Keywords: Growth curves, Non-parametric models, Tuj, Romanov

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1. Introduction

In the context of animals, growth refers to the dynamic changes in weight and volume that occur during specific developmental stages based on age. These changes are influenced by a multitude of environmental factors acting upon the genetic potential, resulting in a complex and intricate process (Yakupoğlu, 1999). Growth curves, also known as age-growth curves, depict the trajectory of growth over a defined time period. They provide insights into the inherent capacity of animals to grow and develop, as well as the interplay between this capacity and environmental conditions throughout their lifespan (Efe, 1990).

The primary purpose of growth curves is to predict an Individual's growth at later ages, enabling the selection of animals with favourable growth traits at an early stage (Efe, 1990; Tekel, 1998). Interpretation of changes in values across different age points and data summarization with fewer parameters is key objectives. Summarization involves estimating growth curve parameters through statistical modeling (Akbaş, 1995; Bilgin et al., 2004 Esenbuga et al., 2000; Kopuzlu et al., 2014).

While the shape of growth curves may vary based on species, breed, sex, and environmental conditions, linear models can describe growth until adult weight in sheep. However, since growth rates exhibit a sigmoidal pattern in later stages, linear increase is not sufficient. Consequently, non-linear models have been developed to capture the temporal changes (Akbaş, 1995; Esenbuga et al., 2000; Kopuzlu et al., 2014).

The use of growth curves in animal husbandry originated with Brody's estimation of various growth characteristics using growth models and gained prominence through the work of Richards. Commonly employed growth curve models include Gompertz, Logistic, Brody, and Richards, which facilitate the prediction of growth traits in animal husbandry (Bilgin et al., 2004).

The objective of this study is to identify the most effective model for predicting the growth of female and male lambs from the Tuj and RoxTuj (F1) crossbreeds, utilizing age-body weight data and employing certain nonlinear models.

2. Materials and Methods

The animal material for this study comprises 35 pure Tuj lambs and 25 Romanov x Tuj (RoxTuj) (F1) crossbred female and male lambs (single-born), which were reared at the Sheep Farm of Atatürk University Food and Livestock Application and Research Center. Within the first 24 hours of birth, each lamb's weight was meticulously measured using scales accurate to 20 grams, and they were individually identified with plastic earrings. At an average age of 75 days, weaning was carried out, and the lambs were then transferred to pasture. The same care and feeding practices were maintained for all lambs on the farm.

Following birth, lambs were weighed every 15 days to track their live weight changes. The study utilized body weight data collected at 15-day intervals from birth up to 24 weeks of age to analyze growth curves. Various nonlinear models (Table 1), including Brody, Gompertz, Logistic, Richards, and Weibull, were employed to describe growth over time. By evaluating coefficients of determination (R^2), mean square error (MSE), Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC), the most suitable growth model for Tuj and RoxTuj (F1) crossbred lambs were identified. The coefficient of determination (R^2) serves as a measure of how much variation in the data set can be explained by the generated growth curve model, ranging between 0 and 1. In the calculation of AIC values, the formula "AIC=n*ln(SSE/n)+2k" is used, while for BIC values, the formula "BIC=n*ln(SSE/n)+k*ln(n)" is employed. Here, n represents the number of observations, k denotes the number of model parameters, and SSE represents the sum of squared errors.

From a biological perspective, the parameters derived from different functions have specific interpretations. Yt represents the observed weight at age t. The parameter A signifies the weight at maturity, which is the weight limit as age (t) approaches infinity. B corresponds to the initial weight, and k denotes the growth rate. These parameters were estimated using the Levenberg-Marquardt iteration method via the NLIN procedure in the SPSS program.

Table 1. Growth curve models

Growth Model	
Brody	$\boldsymbol{Y_t} = \boldsymbol{A}[\mathbf{1} - \mathrm{B} * \mathbf{exp}(-\boldsymbol{k} * \boldsymbol{t})]$
Gompertz	$\boldsymbol{Y_t} = \boldsymbol{A} * \mathbf{exp}[-\mathrm{B} * \mathbf{exp}(-\boldsymbol{k} * \boldsymbol{t})]$
Logistic	$\boldsymbol{Y_t} = \boldsymbol{A}\,[\mathbf{1} + \mathrm{B} * \mathbf{exp}(\,-\boldsymbol{k} * \boldsymbol{t})]^{-1}$
Richards	$\boldsymbol{Yt} = \boldsymbol{A}[\mathbf{1} - \mathrm{B} * \mathbf{exp}(-\boldsymbol{k} * \boldsymbol{t})]\mathrm{m}$
Weibull	$\boldsymbol{Yt} = \mathrm{A} - \mathrm{B} * \mathbf{exp}\,(-\boldsymbol{k} * \boldsymbol{t}\,\mathrm{m})$

3. Results and Discussion

The growth curve parameters for Tuj and RoxTuj (F1) lambs, as estimated by nonlinear models, are displayed in Table 2. When Table 2 ve 3 is examined, the A parameter in Tuj female and male lambs is highest with the Richard model and lowest with the Weibull model; In RoxTuj (F1) lambs, the highest was determined by the Brody model and the lowest was determined by the Logistic model. The B parameter was determined to be highest with the Weibull model and lowest with the Brody and Richard model for both genotypes in males and females. The k parameter was determined as the highest by the Logistic models and the lowest by the Richard and Brody models. The m parameter was determined as the highest in males and females by the Richard model, and the lowest by the Weibull model.

In this study, the parameter values estimated from all models except the Richards model were found in Akbaş et al. (1999) Kıvırcık and Dağlıç breeds; In Esenbuga et al. (2000) İvesi, Morkaraman and Tuj breeds; Köyceğiz (2003) in İvesi and Morkaraman male and female lambs; Bilgin et al. (2004) in Awasi and Morkaraman breeds; Aytekin and Zülkadir (2013) in Malya sheep; It was found to be lower than the values reported by Kopuzlu et al. (2014) in Hemşin breed male and female lambs. The values reported by Yaldızbaş (2016) for the A parameter in Romanov lambs were observed to be higher than the values obtained from all models in this study.

Table 2. The estimated parameter values, and their standard errors for Tuj and RoxTuj (F1) male lambs with nonlinear growth models

Models		A	B	k	m
Brody	Female	45.73±2.29	0.95±0.007	0.040±0.004	-
	Male	48.73±3.13	0.94±0.008	0.04±0.004	-
Gompertz	Female	35.15±2.85	2.15±0.076	0.093±0.007	-
	Male	37.78±4.32	2.17±0.072	0.087±0.006	-
Lojistik	Female	33.44±2.28	5.02±0.29	0.125±0.005	-
	Male	34.37±1.22	5.31±0.47	0.137±0.006	-
Richard	Female	108.82±12.23	0.95±0.008	0.028±0.005	1.97±0.71
	Male	99.23±14.25	0.94±0.008	0.030±0.005	1.91±0.71
Weibull	Female	29.02±11.28	26.49±2.02	0.12±0.009	1.35±0.12
	Male	31.96±11.07	28.35±1.95	0.08±0.009	1.65±0.13

Table 3. The estimated parameter values, and their standard errors for RoxTuj (F1) male lambs with nonlinear growth models

Models		A	B	k	m
Brody	Female	135.27±20.19	0.99±0.007	0.006±0.006	-
	Male	152.73±25.25	0.99±0.008	0.006±0.008	-
Gompertz	Female	27.22±2.76	2.23±0.06	0.06±0.007	-
	Male	31.08±3.22	2.20±0.07	0.06±0.003	-
Lojistik	Female	23.34±2.08	5.89±0.19	0.25±0.004	-
	Male	24.28±2.12	6.03±0.27	0.37±0.006	-
Richard	Female	71.13±11.54	0.94±0.008	0.03±0.004	1.95±0.56
	Male	85.27±16.36	0.94±0.008	0.03±0.004	2.20±0.71
Weibull	Female	30.12±10.58	23.56±1.85	0.09±0.01	1.54±0.34
	Male	36.27±11.07	29.62±1.72	0.10±0.01	1.73±0.61

In Table 4, the Weibull model exhibited the highest MSE values for both female and male lambs of the Tuj and RoxTuj (F1) breeds, while the Brody model had the lowest MSE values. Regarding R^2, the Brody model yielded the highest values for both males and females, whereas the Weibull model had the lowest R^2 values. Additionally, AIC and BIC values were highest in male and female lambs with the Weibull model, while the lowest values were detected in the Brody model.

In both genotypes, the Brody model demonstrated the best fit with the highest R^2, lowest MSE, AIC, and BIC values for both male and female lambs. Conversely, the Weibull model exhibited the poorest fit. The deviation in predictions by the Weibull model is clearly observed in Figures 1 and 2. Furthermore, upon analyzing the figures, it is evident that the Logistic model provides close predictions to the observed values in Tuj lambs, while in RoxTuj (F1) crossbreds; it tends to overestimate the observed values.

Similar to our study, Lambe et al., (2006), Malhado et al., (2009), Daskiran et al. (2010), Özdemir and Dellal (2009) determined the Brody, Logistic and Gompertz models as the best models. Unlike our study, Mohammadi et al., (2019) reported that the Logistic model was the model that showed the worst fit. Bilgin et al. (2004), Kopuzlu et al., (2014) and Nimase et al., (2018) reported that the Brody model can be recommended because it has fewer parameters than other models and is easy to interpret.

As a conclusion, it was observed that all five models describe growth well except for weibull. However, the Brody model was the model that best described the growth as it had the highest R^2 value in both Tuj and RoxTuj (F1) male lambs.

Table 4. Goodness of fit criteria (MSE, R^2, AIC ve BIC) results for models değerleri

Models		Tuj				RoxTuj (F1)			
		MSE	R^2	AIC	BIC	MSE	R^2	AIC	BIC
Brody	Female	2.74	99.4	13.09	15.96	3.23	99.7	12.96	15.28
	Male	3.51	99.7	18.24	21.33	3.91	99.8	17.32	19.64
Gompertz	Female	3.89	97.7	15.24	17.56	4.23	99.3	16.98	19.3
	Male	4,02	97.5	21.75	24.07	4.96	99.5	20.13	22.45
Lojistik	Female	3.81	96.1	16.21	18.53	4.85	99.0	18.51	20.83
	Male	3.77	96.9	19.99	22.89	4.65	99.1	19.95	22.27
Richard	Female	3.96	96.3	16.57	19.06	3.99	96.2	17.82	20.91
	Male	4.51	96.9	24.76	27.08	4.23	97.5	22.14	25.23
Weibull	Female	8.44	90.5	16.82	19.82	9.28	89.2	19.82	22.91
	Male	12.27	91.2	25.34	28.34	13.44	90.3	21.95	25.04

MSE= mean square error; R^2= coefficients of determination; AIC= akaike ınformation criterion; BIC= bayesien ınformation criterion; RoxTuj: Romanov x Tuj crossbreed.

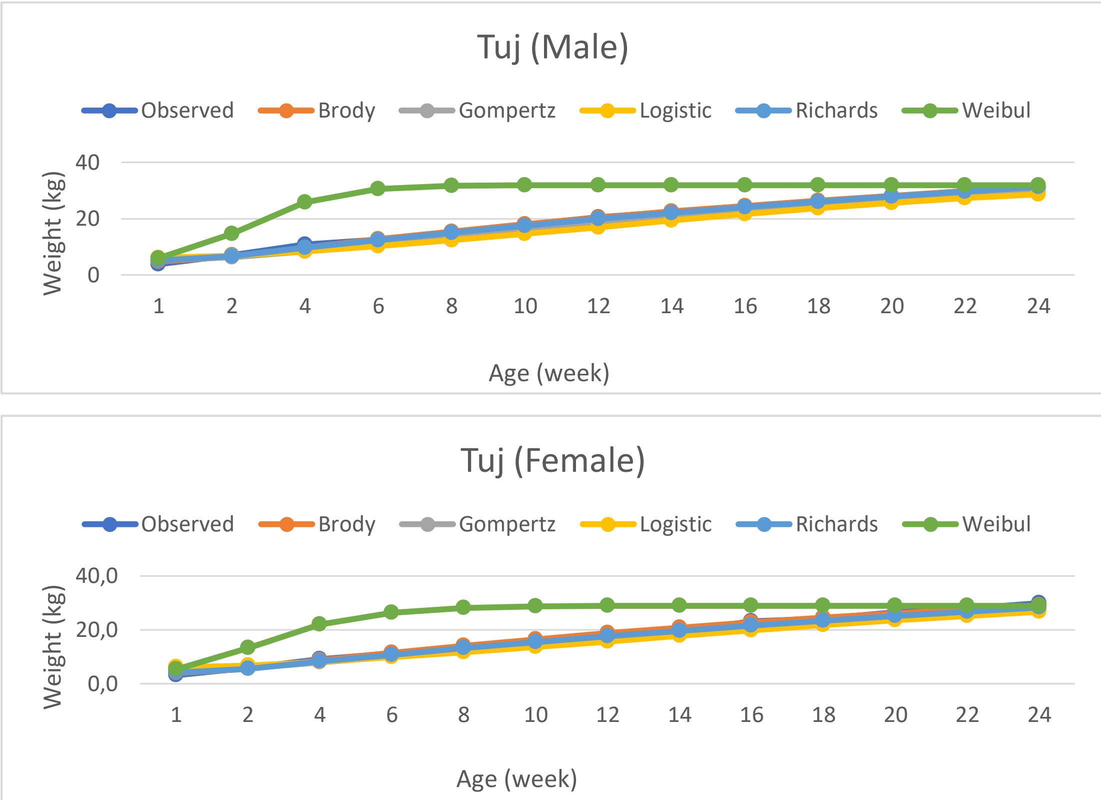

Figure 1. Growth curves of Tuj female and male lambs observed and estimated by different nonparametric models

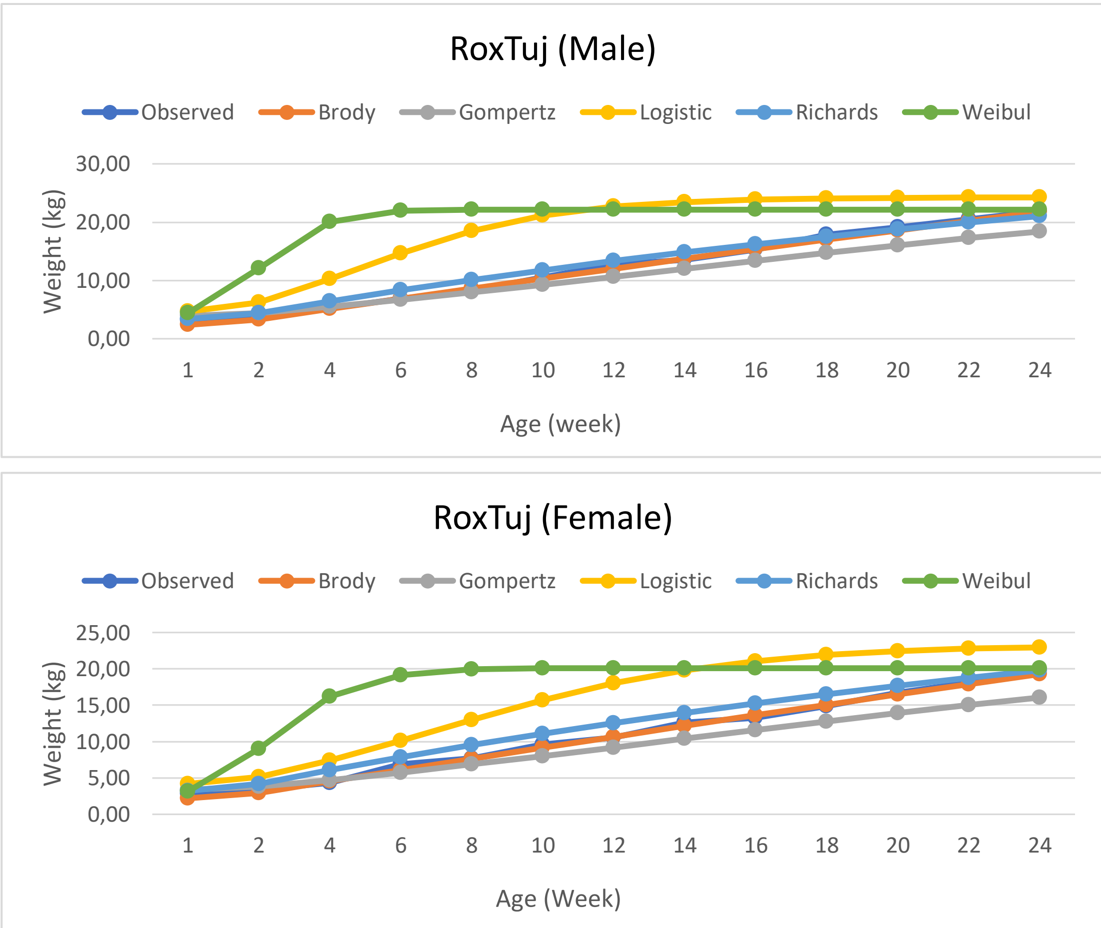

Figure 2. Growth curves of RoxTuj (F1) female and male crossbred lambs

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	Ü.D.	N.E.
C		100
D	25	75
S		100
DCP	50	50
DAI	25	75
L	50	50
W	50	50
CR	50	50
SR	75	25
PM	25	75

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

The study was approved by The Local Animal Care and Ethics Committee of Atatürk University, Erzurum, Türkiye (approval date: May 29, 2018, protocol code: 2018/64).

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