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Possibilities of using cubic spline function and yield-density models in estimation of live weight of kıvırcık lambs fed with different silage types

[*Possibilidades de uso da função spline cúbica e de modelos de densidade de produção na estimativa do peso vivo de cordeiros kıvırcık alimentados com diferentes tipos de silagem*]

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ABSTRACT

In this study, the possibilities of using Cubic Spline functions and some yield-density models in the estimation of live weights of Kıvırcık lambs fed with different silage types were investigated. In the experiment, 40 male Kıvırcık lambs aged 2.5-3 months were used and the animals were fattened for 56 days. To assess the predictive performance of the fitted models, model fit statistics such as the coefficient of determination (R^2), adjusted R^2, mean square error (MSE), and Akaike Information Criterion (AIC) were determined. The Cubic Spline model was discovered to be the best model for quantifying Kıvırcık lambs live weight, with the highest R^2 and adjusted R^2 values, as well as the lowest MSE and AIC values. Cubic Spline functions were applied as live weight estimation model in lambs fed with silage containing 5 different ratios of corn and sunflower (100% sunflower silage, 75% sunflower + 25% corn silage, 50% sunflower + 50% corn silage, 25% sunflower + 75% corn silage, 100% corn silage). As a result, Cubic Spline functions have been found to be effective in estimating the live weight of fattened lambs.

Keywords: Kıvırcık lamb, silage types, live weight, cubic spline

RESUMO

Neste estudo, foram investigadas as possibilidades de usar funções de spline cúbica e alguns modelos de densidade de produção na estimativa de pesos vivos de cordeiros Kıvırcık alimentados com diferentes tipos de silagem. No experimento, foram usados 40 cordeiros Kıvırcık machos com 2,5 a 3 meses de idade e os animais foram engordados por 56 dias. Para avaliar o desempenho preditivo dos modelos ajustados, foram determinadas as estatísticas de ajuste do modelo, como o coeficiente de determinação (R2), o R2 ajustado, o erro quadrático médio (MSE) e o critério de informação de Akaike (AIC). O modelo de spline cúbica foi considerado o melhor modelo para quantificar o peso vivo de cordeiros Kıvırcık, com os valores mais altos de R2 e R2 ajustado, bem como os valores mais baixos de MSE e AIC. As funções de spline cúbica foram aplicadas como modelo de estimativa de peso vivo em cordeiros alimentados com silagem contendo 5 proporções diferentes de milho e girassol (100% de silagem de girassol, 75% de girassol + 25% de silagem de milho, 50% de girassol + 50% de silagem de milho, 25% de girassol + 75% de silagem de milho, 100% de silagem de milho). Como resultado, verificou-se que as funções de spline cúbica são eficazes na estimativa do peso vivo de cordeiros engordados.

Palavras-chave: cordeiro Kıvırcık, tipos de silagem, peso vivo, spline cúbica

INTRODUCTION

In contrast to linear models, the employment of more complicated non-linear models is not only useful but also vital during periods of variable growth rates. Non-linear models have the additional benefit of being the foundation for an impartial method that can evaluate an organism's capacity for development and sustainable output (Fekedulegn *et al.*, 1999). The basic link between crop yield and plant population (Farazdaghi and Harris, 1968) and the equations for the plant growth models (Paine *et al.*, 2012) provide the groundwork for the employment of reciprocal yield-density functions. Reciprocal equations are

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generally acknowledged as being superior for precisely and meaningfully providing a true asymptotic or parabolic fit to data (Bleasdale, 1984). The relationship between crop yield and density was mathematically first described by Shinozaki and Kira (1956), but it was Holliday's (1960a, 1960b) study (conducted independently of Shinozaki and Kira's) that empirically proved the existence of the relationship (Willey and Heath, 1969). Various methods are used to create a live weight estimation model in all living things and accordingly to estimate live weight at certain ages, one of these methods is Cubic Spline functions. Examining the point distributions of dependent and independent variables by separating them from certain points (knots) is called Cubic Spline function or Piecewise regression. In Cubic Spline functions, all point distributions are expressed using interval functions instead of a single function (Şahin, 2009).

Cubic Spline functions are not yet well known by researchers working in the field of animal husbandry, and therefore they are little used. The difficulty of choosing the models suitable for some point distributions obtained or having to choose the best one among the existing models, causes researchers to ignore the relationships to be obtained with these distributions most of the time. Especially when the shape of point distributions cannot be explained by known models, the ability to obtain functions with high fit perfection with appropriate knots increases the interest and need for Cubic Spline functions. Some studies on this subject are listed below; Çağlar (1993) examined the solutions of multi-point linear boundary value problems using spline functions and compared the results with the finite difference method. Wheatley and Gerald (1994) theoretically examined the creation of Cubic Spline functions and the coefficient equations of interval functions. Comets *et al*. (1999) studied *octreotide* absorption in rabbits with non-parametric models and used Restricted Cubic Piecewise regressions to model individual absorption profiles. White *et al*. (1999) used Cubic Piecewise regression and Restricted Cubic Piecewise regression models for modeling lactation curves in dairy cattle. In their study, the researchers compared the results obtained from Cubic Piecewise and Constrained Cubic Piecewise regressions with the results obtained with the Wilmink model and recommended the use of Piecewise regression models because they are more flexible. Huisman *et al*. (2002) used Cubic Piecewise and Polynomial regressions to examine the relationship between age, live weight gain and heredity, using data records from pigs. Druet *et al*. (2003) investigated genetic parameter estimation and modeling of lactation curves from first lactation dairy records in Holstein cattle with different models such as polynomial, Ali and Schaffer, Wilmink and Piecewise regression. Degroot (2004) used Cubic Piecewise regression in modeling the lactation curve and estimating genetic parameters in Holstein cattle given Somatotropin hormone. Iwaisaki *et al*. (2005) used Linear Piecewise regression method to estimate maternal genetic parameters in the early stages of growth in beef cattle. Cubic Piecewise regressions were used for the change in measurement values of the otoliths used in age determination in fish based on time (Black *et al*., 2005), modeling of lactation yields in Holstein cattle and estimation of genetic parameters (Degroot *et al*., 2007). In another study, Cubic Spline regression was used to model lactation curves using milk yield records from cattle (Şahin and Efe, 2010).

The goal of this study was to use cubic spline and yield-density models to model the live weights of lambs fed corn and sunflower silage in 5 various ratios from birth to 140 days, as well as to estimate live weight on days without measurement.

MATERIAL AND METHODS

In the study, 40 Kıvırcık male lambs, aged 2.5-3 months with an average live weight of 23-25 kg, were used in 5 separate treatment groups, each with 8 animals. The fattening lambs were housed in individual compartments during the experiment and individual feeding was applied to the animals during the 56-day fattening period. This study was carried out in a semi-open barn in a sheep farm belonging to Bursa Uludağ University Agricultural Application and Research Center. During the trial period, the live weights and feed consumptions of the lambs were determined individually and in 2-week periods.

During the experiment, lambs were fed 5 different silages (100% sunflower silage, 75%

sunflower + 25% corn silage, 50% sunflower + 50% corn silage, 25% sunflower + 75% corn silage, 100% corn silage) as pure and mixed. Lambs housed in individual chambers consumed the silage mixtures of their groups *ad libitum*. In addition to the silage mixtures consumed by the lambs, 700 g of concentrate feed per animal was given in the first 4 weeks of the experiment. Later, this amount was increased to 900 g for 4 weeks, and to 1400g in the last 2 weeks of the experiment, considering the daily nutrient needs of the lambs. Fresh and clean drinking water was always available in front of the lambs. During the fattening period, the live weights of the lambs were determined by control weighing made every 14 days.

The Farazdaghi−Harris rational model is expressed as follows (Chiolerio and Adamatzky, 2021).

$$y = \frac{1}{a + bx^c}$$

Here a, b and c are parameters. In conclusion, depending on the value of c, the model either reflects asymptotic or parabolic yield-density behavior. Asymptotic behavior persists if c = 1, and parabolic behavior appears if c > 1 (Panik, 2014). An asymptotic current flow (a), a resistance (b), and a non-dimensional scale parameter (c) can all be related with a fit parameter.

Holliday (1960a) identified two distinct specifications for the fundamental relationship between crop yield and plant population: one in which yield depends on a crop's growth in the reproductive phase (Hudson, 1941); and another in which yield results from the growth in the vegetative phase (Donald, 1951). Here, the equation

$$y = \frac{1}{a + bx + cx^2}$$

can be used to determine the approximate quadratic live weight for animals. Here, Y stands for weight and X represents animal population.

The Gaussian model is provided by and fits peaks (MathWorks, 2023).

$$y = \sum_{i=1}^{n} a_i \exp\left(-\left(\frac{x - b_i}{c_i}\right)^2\right)$$

where a is the amplitude, b is the centroid (location), c is related to the peak width, n is the number of peaks to fit, and $1 \leq n \leq 8$.

The Spline expression was first used by Schoenberg (1946) and she worked on the use of spline functions in differential equations and spline theory (Schoenberg, 1946; Walkley, 1999).

Splines are k-order Piecewise polynomials. The joining points of the parts are knots. In deciding the knots, the function values and the first k-1 derivative should be known. Cubic spline (k=3) is sufficient for solving practical problems. Because it is sometimes seen that a low-order polynomial produces a poor fit to the data, and increasing the order of the polynomial somewhat improves the situation. The inability of the residual sum of squares to stabilize or residual plots with inexplicable structure are symptoms of this. This issue can arise when the function performs differently in different portions of the x range. Transformations on x and/or y can sometimes solve this problem. The conventional strategy, on the other hand, is to divide the x range into parts and fit a suitable curve in each segment. Spline functions are a convenient approach to accomplish piecewise polynomial fitting. A Cubic Spline function with h number of knots $(t_1 < t_2 < \cdots < t_h)$ with continuous first and second order derivatives can be written as follows (Montgomery *et al.*, 2012).

$$S(x) = \sum_{j=0}^{3} \beta_{0j} x^j + \sum_{i=1}^{h} \beta_i (x - t_i)_+^3 \quad (1)$$

Here, $(x - t_i)_+$

$$(x - t_i)_+ = \begin{cases} (x - t_i) & if\ x - t_i > 0 \\ 0 & if\ x - t_i \leq 0 \end{cases} \quad (2)$$

is defined as (Smith, 1979). If the positions of the knots are the parameter to be estimated, the resulting problem is a nonlinear one. Equation (1) is an application of linear least squares when the positions of the knots are known. In a Cubic Spline (1) model, if all (h+1) polynomial parts are of 3[rd] order then it is a Cubic Spline model without continuity constraints.

$$S(x) = \sum_{j=0}^{3} \beta_{0j} x^j + \sum_{i=1}^{h} \sum_{j=0}^{3} \beta_i \quad (3)$$

Here $(x - t)_+^0$ equals 1 if $x > t$ and if $x \leq t$ (Montgomery *et al.*, 2012).

A Cubic Spline model with one knot at t and no continuity constraint can be expressed as follows (Montgomery *et al*., 2012). Interval functions for equation (2) is expressed as:

$$S(x) = \begin{cases} \beta_{00} + \beta_{01}x + \beta_{02}x^2 + \beta_{03}x^3, \quad x \leq t \\ \beta_{00} + \beta_{01}x + \beta_{02}x^2 + \beta_{03}x^3 + \beta_{10} + \beta_{11}(x-t) + \beta_{12}(x-t)^2 + \beta_{13}(x-t)^3, x > t \end{cases}$$

(Freund and Wilson, 2006; Harrell, 2017).

The following goodness of fit criteria were calculated to compare the prediction performance of models used in the study (Liddle, 2007; Gupta *et al*., 2009):

1. Coefficient of Determination

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

2. Adjusted Coefficient of Determination

$$Adj.R^2 = 1 - \frac{\frac{1}{n-k-1}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}{\frac{1}{n-1}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$$

3. Mean-square error (MSE) given by the following formula:

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

4. Akaike Information Criteria (AIC):

$$AIC = n\ ln\ (MSE) + 2k$$

RESULT AND DISCUSSION

The values of the live weight averages of the lambs fed with different silage types on different days are given in Table 1.

Birth weight, 84, 98, 112, 126 and 140. Day live weights were used to create the Cubic Spline function of the experimental groups. Cubic Spline function models were investigated for different types of silage (pure or mixed). The coefficient of determination (R^2) was calculated as 0.9999 in all of these models evaluated for silage types. It has been possible to make the best estimation by creating node values with the Cubic Spline function. Cubic Spline functions of Kıvırcık lambs fed with silage containing corn and sunflower in different ratios from birth to 140 days are summarized as follows.

All comparison criteria for fed 100% corn silage in live weight modeling in lambs are presented in Table 2. As seen in Table 2, the coefficient of determination (R^2) values of the models was found to be very high in the range of 0.9892-0.9995. Similarly, Adj. It was also valid for R^2 and remained in the range of 0.9820-0.9992.

Table 1. Live weights of lambs fed with different silage types and at different rates according to the age groups

Days	1st group	2nd group	3rd group	4th group	5th group
0	4.10	3.97	4.56	4.38	4.15
84	24.29	24.23	25.10	24.41	23.65
98	25.16	25.18	26.76	24.85	25.23
112	29.06	29.96	30.33	28.95	29.53
126	33.75	34.05	34.09	32.46	33.11
140	37.44	37.36	37.38	35.94	36.25

1st group: 100% corn silage, 2nd group: 75% corn + 25% sunflower silage, 3rd group: 50% corn + 50% sunflower silage, 3rd group: 25% corn + 75% sunflower silage, 5th group: 100% sunflower silage.

Table 2. Live weight obtained for fed 100% corn silage; Mean Squared Error, Coefficients of Determination and Akaike Information Criteria values of all models

Models	R^2	Adj. R^2	MSE	AIC
Holliday	0.9965	0.9942	0.000043	-54.3259
Farazdaghi-Harris	0.9962	0.9936	0.859	5.0881
Gaussian	0.9892	0.9820	2.4524	36.1688
Cubic Spline	0.9995	0.9992	0.000024	-57.8247

The highest R^2 and Adj. The model with R^2 values is the Cubic Spline method. When examined in terms of MSE statistics, it was seen that the largest value was obtained in the Gaussian model (2.4524), while the Cubic Spline and Holliday models had very small values such as 0.000024 and 0.000043, respectively. While the Gaussian model has the largest AIC value with the value of 36.1688, the AIC statistics of the cubic spline and Holliday models are very small values such as -52.8247 and -54.3259, respectively. Therefore, these two models showed a very good fit. In general, when all the goodness-of-fit statistics are evaluated, it is seen that the most suitable model is the Cubic Spline. Cubic Spline functions were applied for the model showing the growth of Kıvırcık lambs fed with 100% corn silage and these functions are given below:

$$f(x_1) = -0.0001\,(x-0)^3 + 0.0079\,(x-0)^2 + 4.1 \qquad 0 \le x < 84$$
$$f(x_2) = 0.0006\,(x-84)^3 - 0.0073\,(x-84)^2 + 0.0554\,(x-84) + 24.29\,,\ \ 84 \le x < 98$$
$$f(x_3) = -0.0006\,(x-98)^3 + 0.0160\,(x-98)^2 + 0.1774\,(x-98) + 25.16\,,\qquad 98 \le x < 112$$
$$f(x_4) = 0.0011\,(x-112)^3 - 0.0103\,(x-112)^2 + 0.2572\,(x-112) + 29.06, 112 \le x < 126$$
$$f(x_5) = -0.0046\,(x-126)^3 + 0.0372\,(x-126)^2 + 0.6346\,(x-126) + 33.75, 126 \le x < 140$$

At any time (days) desired to be estimated in these functions, the live weight estimation of lambs can be calculated as follows. For example, the Cubic Spline function can be used to estimate the live weight of a lamb at day 90.

$$f(x_2) = 0.0006\,(x-84)^3 - 0.0073\,(x-84)^2 + 0.0554\,(x-84) + 24.29\,,\ \ 84 \le x < 98$$

Because the calculation of the live weight estimation for the 90. day is suitable for the definition range of this function. By replacing the 90 value in this function, the live weight estimation value can be calculated approximately.

$$f(x_2) = 0.0006\,(90-84)^3 - 0.0073\,(90-84)^2 + 0.0554\,(90-84) + 24.29\,,\ \ 84 \le x < 98$$
$$f(x_2) = 0.0006\,(6)^3 - 0.0073\,(6)^2 + 0.0554\,(6) + 24.29\,,\ \ 84 \le x < 98$$
$$f(x_2) = 0.0006\,(6)^3 - 0.0073\,(6)^2 + 0.0554\,(6) + 24.29$$
$$f(x_2) = 0.0006 * 216 - 0.0073 * 36 + 0.0554 * 6 + 24.29 = 24.30$$

Similarly, the Cubic spline function is used to estimate body weight at day 110.

$$f(x_3) = -0.0006\,(x-98)^3 + 0.0160\,(x-98)^2 + 0.1774\,(x-98) + 25.16\,,\qquad 98 \le x < 112$$

X=110 is put in the function and calculated as follows.

$$f(x_3) = -0.0006\,(110-98)^3 + 0.0160\,(110-98)^2 + 0.1774\,(110-98) + 25.16,\qquad 98 \le x < 112$$
$$f(x_3) = -0.0006\,(12)^3 + 0.0160\,(12)^2 + 0.1774\,(12) + 25.16\,,\qquad 98 \le x < 112$$
$$f(x_3) = -0.0006 * 1728 + 0.0160 * 144 + 0.1774 * 12 + 25.16 = 28.39$$

For X=120,

$$f(x_4) = 0.0011\,(x-112)^3 - 0.0103\,(x-112)^2 + 0.2572\,(x-112) + 29.06\,,\qquad 112 \le x < 126$$

The Cubic Spline function is used.

$$f(x_4) = 0.0011\,(120-112)^3 - 0.0103\,(120-112)^2 + 0.2572\,(120-112) + 29.06\,,\qquad 112 \le x < 126$$
$$f(x_4) = 0.0011\,(8)^3 - 0.0103\,(8)^2 + 0.2572\,(8) + 29.06\,,\qquad 112 \le x < 126$$
$$f(x_4) = 31.78$$

was calculated as.

The estimated live weight of lambs every 10 days can also be calculated, fed on silages containing all different proportions of corn and sunflower in the 10-140 day range. As shown in Figure 1, the closest estimates to the actual live weight were observed in Cubic Spline and Holliday models, respectively.

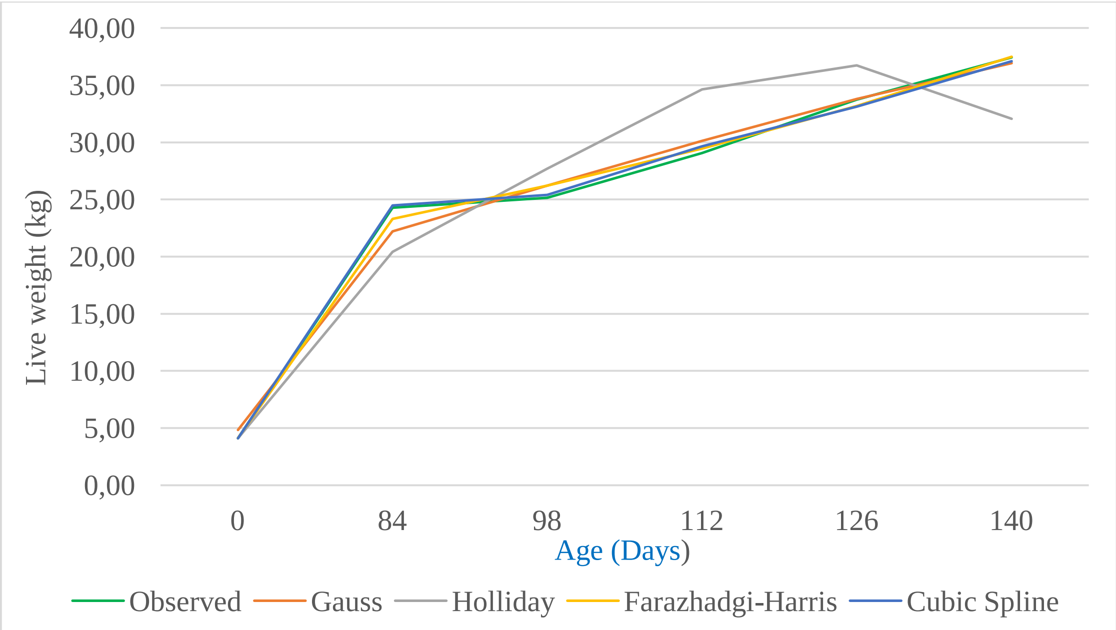

Figure 1. Live weights of lambs in the 1st group during the fattening period.

All comparison criteria for fed 75% corn+25% sunflower silage in live weight modeling in lambs are presented in Table 3.

Table 3. Live weight obtained for fed 75% corn+25% sunflower silage; mean squared error, coefficients of determination and akaike information criteria values of all models

Models	R^2	Adj. R^2	MSE	AIC
Holliday	0.9968	0.9947	0.0025	-29.9488
Farazdaghi-Harris	0.9962	0.9937	0.891	5.3075
Gaussian	0.9918	0.9855	1.9182	9.9083
Cubic Spline	0.9996	0.9993	0.00031	-42.4736

As seen in Table 3, the coefficient of determination (R^2) values of all models are above 0.99. adj. R^2 values were in the range of 0.9855-0.9993. The highest R^2 and Adj. The model with R^2 values is the Cubic Spline method. When examined in terms of MSE statistics, it was seen that the largest value was obtained in the Gaussian model (1.9182), while the Cubic Spline and Holliday models had very small values such as 0.00031 and 0.0025, respectively. When the AIC values are examined, the Gaussian model has the largest value with the value of 9.9083, while the Cubic Spline and Holliday models have very small values such as -42.4736 and -29.9488, respectively. Therefore, these two models showed a very good fit. In general, when all the goodness-of-fit statistics are evaluated, it is seen that the most suitable model is the Cubic Spline. A model describing the growth of Kıvırcık lambs fed with 75% corn+25% sunflower silage was created using the Cubic Spline function. Obtained Cubic Spline functions are as follows:

$$f(x_1) = -0.0001\,(x-0)^3 + 0.0081\,(x-0)^2 + 3.97 \qquad 0 \le x < 84$$
$$f(x_2) = 0.0007\,(x-84)^3 - 0.0076\,(x-84)^2 + 0.0411\,(x-84) + 24.23\,, \quad 84 \le x < 98$$
$$f(x_3) = -0.0009\,(x-98)^3 + 0.021\,(x-98)^2 + 0.2283\,(x-98) + 25.18\,, \quad 98 \le x < 112$$
$$f(x_4) = 0.0014\,(x-112)^3 - 0.0178\,(x-112)^2 + 0.2736\,(x-112) + 29.96, \quad 112 \le x < 126$$
$$f(x_5) = -0.0046\,(x-126)^3 + 0.0395\,(x-126)^2 + 0.578\,(x-126) + 34.05, 126 \le x < 140$$

The graph of live weights is presented in Figure 2.

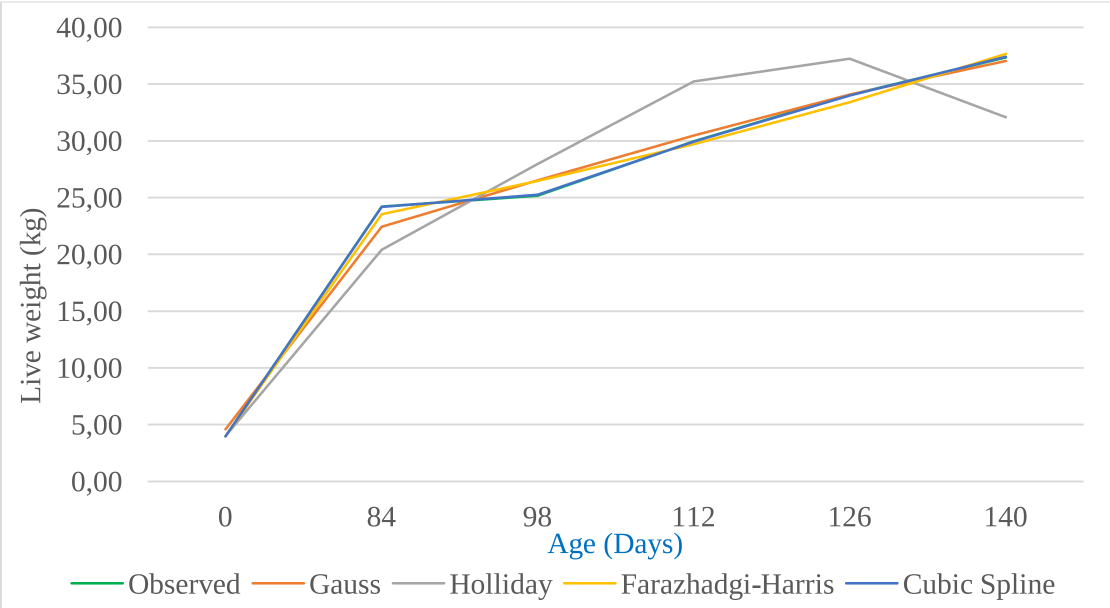

Figure 2. Live weights of lambs in the 2nd group during the fattening period.

All comparison criteria for fed 50% corn+50% sunflower silage in live weight modeling in lambs are presented in Table 4.

Table 4. Live weight obtained for fed 50% corn+50% sunflower silage; Mean Squared Error, Coefficients of Determination and Akaike Information Criteria values of all models

Models	R^2	Adj. R^2	MSE	AIC
Holliday	0.9970	0.9950	0.0035	-28.0193
Farazdaghi-Harris	0.9989	0.9981	0.2520	-2.2700
Gaussian	0.9936	0.9893	1.4472	8.2178
Cubic Spline	0.9997	0.9993	0.00023	-44.2646

As seen in Table 4, the coefficient of determination (R^2) values of all models were above 0.99 and were found to be very high in the range of 0.9936-0.9997. Adj. R^2 values were in the range of 0.9893-0.9993. The highest R^2 and Adj. The model with R^2 values is the Cubic Spline method. When examined in terms of MSE statistics, it was seen that the largest value was obtained in the Gaussian model (1.4772), while the Cubic Spline and Holliday models had very small values such as 0.00023 and 0.0035, respectively. When the AIC values are examined, the Gaussian model has the largest value with the value of 8.2178, while the Cubic Spline and Holliday models have very small values such as -44.2646 and -28.0193, respectively. R^2 and Adj. of the Farazdaghi-Harris model. R^2 values were found to be 0.9989 and 0.9981, respectively, and have the highest value after the Cubic Spline model. Therefore, other models except the Gaussian model showed very good agreement with the observed values. However, when evaluated in general, it was seen that the most suitable model was the Cubic Spline. Live weight function of Kıvırcık lambs fed 50% corn+50% sunflower silage was determined by Cubic Spline function as follows:

$$f(x_1) = -0.0001\,(x-0)^3 + 0.0073\,(x-0)^2 + 4.56 \qquad 0 \le x < 84$$
$$f(x_2) = 0.0004\,(x-84)^3 - 0.0059\,(x-84)^2 + 0.1187\,(x-84) + 25.10\,, \quad 84 \le x < 98$$
$$f(x_3) = -0.0006\,(x-98)^3 + 0.0118\,(x-98)^2 + 0.201\,(x-98) + 26.76\,, \qquad 98 \le x < 112$$
$$f(x_4) = 0.0012\,(x-112)^3 - 0.012\,(x-112)^2 + 0.1979\,(x-120) + 30.33, \qquad 112 \le x < 126$$
$$f(x_5) = -0.0045\,(x-126)^3 + 0.0392\,(x-126)^2 + 0.5782\,(x-126) + 34.09, \quad 126 \le x < 140$$

The graph of the live weights in the 3rd group is presented in Figure 3.

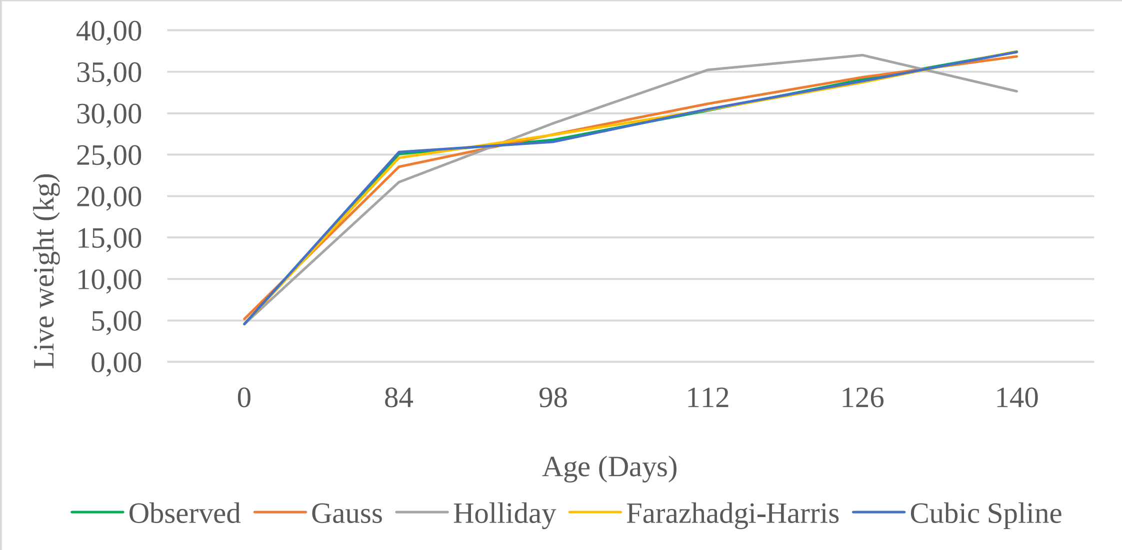

Figure 3. Live weights of lambs in the 3rd group during the fattening period.

As shown in Figure 3, the closest estimates to the actual live weight were observed in Cubic Spline and Farazdaghi-Harris models, respectively.

All comparison criteria for fed 25% corn+75% sunflower silage in live weight modeling in lambs are presented in Table 5.

Table 5. Live weight obtained for fed 25% corn+75% sunflower silage; Mean Squared Error, Coefficients of Determination and Akaike Information Criteria values of all models

Models	R^2	Adj. R^2	MSE	AIC
Holliday	0.9964	0.9939	0.00004	-4.1266
Farazdaghi-Harris	0.9959	0.9931	0.8501	5.8376
Gaussian	0.9884	0.9806	2.3932	8.1972
Cubic Spline	0.9996	0.9990	0.000028	-4.8833

As seen in Table 5, the coefficient of determination (R^2) values of all models were found to be very high in the range of 0.9884-0.9996. Adj. R^2 values were in the range of 0.9806-0.9990. The highest R^2 and Adj. The model with R^2 values is the Cubic Spline method. When examined in terms of MSE statistics, it was seen that the largest value was obtained in the Gaussian model (2.3932), while the Cubic Spline and Holliday models had very small values such as 0.000028 and 0.00004, respectively. When the AIC values are examined, the Gaussian model has the largest value with the value of 8.1972, while the Cubic Spline and Holliday models have very small values such as -4.8833 and -4.1266, respectively. R^2 and Adj. of the Farazdaghi-Harris model. R^2 values were calculated as 0.9959 and 0.9931, respectively. When evaluated in general, it was determined that the most suitable model was the Cubic Spline. The live weight function of Kıvırcık lambs fed 25% corn+75% sunflower silage was explained by the Cubic Spline function as follows:

$$f(x_1) = -0.0001\,(x-0)^3 + 0.0084\,(x-0)^2 + 4.38 \qquad 0 \le x < 84$$
$$f(x_2) = 0.0007\,(x-84)^3 - 0.0082\,(x-84)^2 + 0.012\,(x-84) + 24.41\,, \quad 84 \le x < 98$$
$$f(x_3) = -0.0009\,(x-98)^3 + 0.0206\,(x-98)^2 + 0.1855\,(x-98) + 24.85\,, \quad 98 \le x < 112$$
$$f(x_4) = 0.0015\,(x-112)^3 - 0.0182\,(x-112)^2 + 0.2189\,(x-120) + 28.95\,, \quad 112 \le x < 126$$
$$f(x_5) = -0.0047\,(x-126)^3 + 0.0433\,(x-126)^2 + 0.5697\,(x-126) + 32.46, \quad 126 \le x < 140$$

The graph of the live weights in this group is presented in Figure 4.

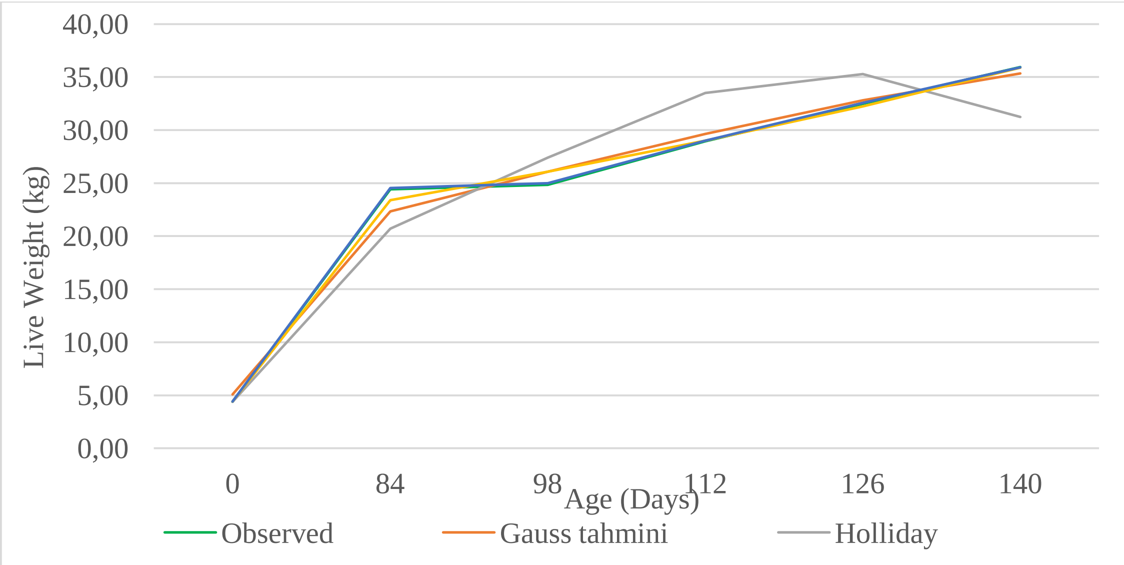

Figure 4. Live weights of lambs in the 4th group during the fattening period.

All comparison criteria for fed 100% sunflower silage in live weight modeling in lambs are presented in Table 6. As seen in Table 6, the coefficient of determination (R^2) values of all models were found to be very high in the range of 0.9948-0.9998, being over 0.99. Adj. R^2 values were also above 0.99 and were calculated in the range of 0.9914-0.9995. The highest R^2 and Adj. The model with R^2 values is the Cubic Spline method.

Table 6. Live weight obtained for fed 100% sunflower silage; Mean Squared Error, Coefficients of Determination and Akaike Information Criteria values of all models

Model	R^2	Adj. R^2	MSE	AIC
Holliday	0.9972	0.9953	0.000033	-55.9140
Farazdaghi-Harris	0.9981	0.9966	0.4400	1.0741
Gaussian	0.9948	0.9914	1.1194	6.6768
Cubic Spline	0.9998	0.9995	0.000019	-59.2264

When examined in terms of MSE statistics, it was seen that the largest value was obtained in the Gaussian model (1.1194), while the Cubic Spline and Holliday models had very small values such as 0.000019 and 0.000033, respectively. When the AIC values are examined, the Gaussian model reaches the largest value with the value of 6.6768, while the cubic spline and Holliday models have very small values such as -59.2264 and -55.9140, respectively. R^2 and Adj. of the Farazdaghi-Harris model. R^2 values were calculated as 0.9981 and 0.9966, respectively. When evaluated in general, it was determined that the most suitable model was the Cubic Spline. The live weight function of Kıvırcık lambs fed with 100% sunflower silage is explained by the Cubic Spline function as follows:

$$f(x_1) = -0.0001\,(x-0)^3 + 0.0072\,(x-0)^2 + 4.15 \qquad 0 \le x < 84$$
$$f(x_2) = 0.0005\,(x-84)^3 - 0.0061\,(x-84)^2 + 0.094\,(x-84) + 23.65\,, \quad 84 \le x < 98$$
$$f(x_3) = -0.0008\,(x-98)^3 + 0.0161\,(x-98)^2 + 0.2353\,(x-98) + 25.23\,, \quad 98 \le x < 112$$
$$f(x_4) = 0.0014\,(x-112)^3 - 0.0169\,(x-112)^2 + 0.2249\,(x-120) + 29.53\,, \quad 112 \le x < 126$$
$$f(x_5) = -0.0046\,(x-126)^3 + 0.0404\,(x-126)^2 + 0.5538\,(x-126) + 33.11, \quad 126 \le x < 140$$

The graph of the live weights in this group is presented in Figure 5.

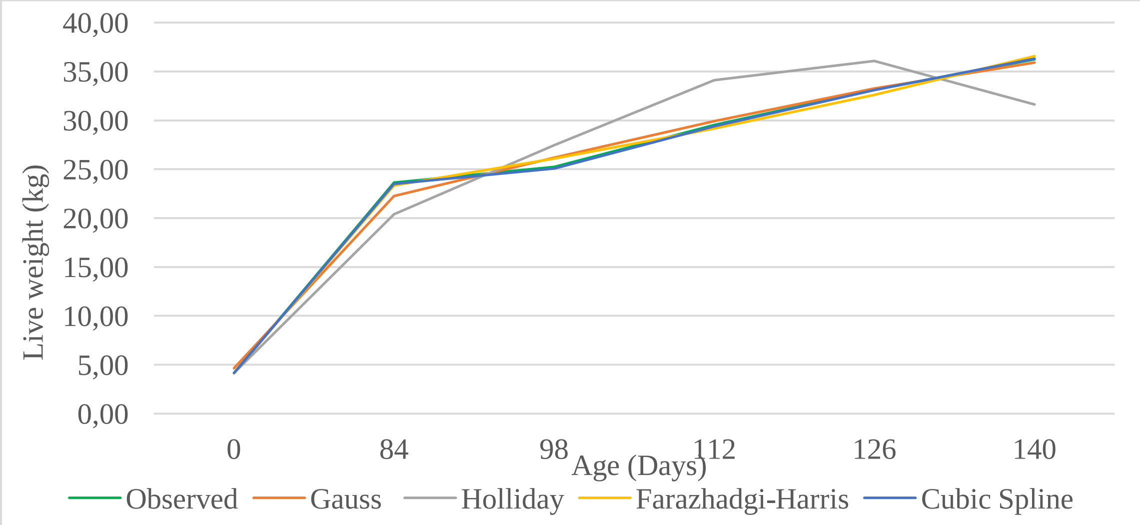

Figure 5. Live weights of lambs in the 5th group during the fattening period.

Estimated live weights at 10-day intervals for all experimental groups in the 10-150-day age range are presented in Table 7 and Figure 6.

Lambs fed with 100% corn silage had higher live weight gain at both the measured and estimated ages. In lambs fed with 75% corn+25% sunflower silage, it was observed that the live weight gain was higher after the 100. day. Lambs fed 50% corn+50% sunflower, 25% corn+75% sunflower and 100% sunflower silages showed a faster increase in live weight from the 110th day compared to other periods.

Table 7. Estimated live weights for different age periods

Days	1st group	2nd group	3rd group	4th group	5th group	Max. weight	Min. weight
10	7.85	7.69	7.94	8.34	7.36	Group 4	Group 5
20	11.24	11.05	11.06	11.90	10.31	Group 4	Group 5
30	14.26	14.07	13.90	15.05	13.01	Group 4	Group 5
40	16.92	16.72	16.49	17.78	15.47	Group 4	Group 5
50	19.22	19.03	18.84	20.06	17.72	Group 4	Group 5
60	21.15	20.98	20.95	21.90	19.70	Group 4	Group 5
70	22.72	22.58	22.83	23.28	21.49	Group 4	Group 5
80	23.91	23.83	24.49	24.18	23.07	Group 3	Group 5
90	24.30	24.11	25.57	24.60	23.95	Group 3	Group 5
100	25.56	25.71	27.18	25.29	25.74	Group 3	Group 4
110	28.39	29.23	29.77	28.32	28.90	Group 3	Group 4
120	31.78	32.48	32.52	31.09	31.72	Group 3	Group 4
130	34.97	35.01	35.09	33.36	33.99	Group 3	Group 4
150	38.65	40.04	39.31	39.61	39.07	Group 2	Group 1

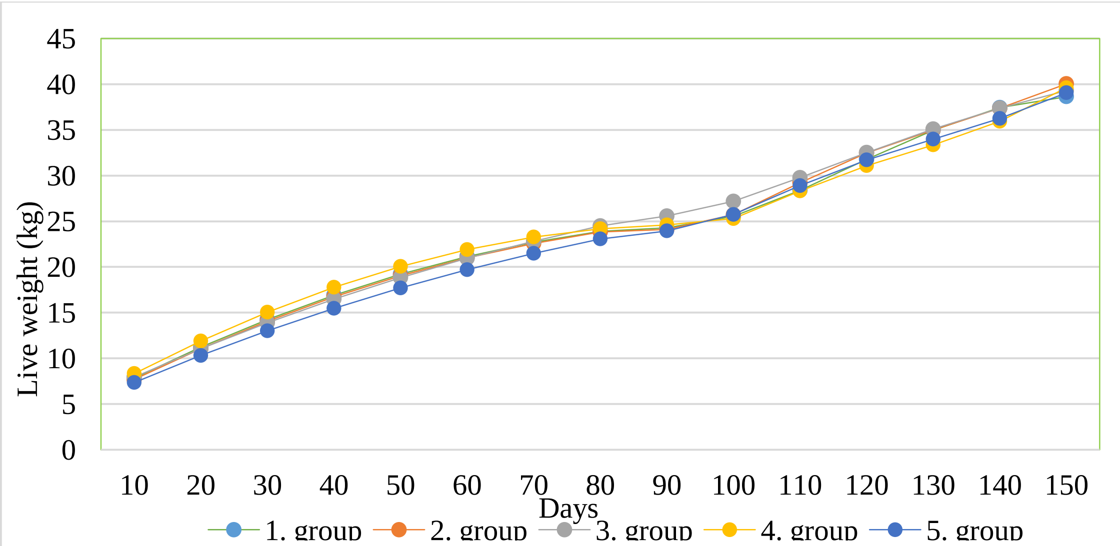

Figure 6. Live weight estimates of the lambs of the experimental groups.

Except for the measurement days (between 10-150 days), live weight gains were calculated using the estimated live weight values at 10-day intervals between days and are given in Table 8.

As seen in Table 8, the highest live weight gain in lambs fed with 100% corn silage was on the 20. - 120. days (3.39kg) and 130. day (3.19kg), while the lowest body weight gain was on the 90. (0.39kg) and 80. days (1.19kg). In lambs fed 75% corn + 25% sunflower silage, the highest live weight gains were 3.36, 3.52 and 3.25kg on the 20., 110. and 120. days, respectively, while the lowest weight gains were 0.28kg on the 90. day and 1.25kg on the 80. day. The highest live weight gains of lambs fed with 50% corn + 50% sunflower silage were 3.12, 2.84 and 2.75kg on the 20., 30. and 120. days, respectively, while the lowest weight gain was 1.08 kg on the 9. day. The highest body weight gain values were determined as 3.56, 3.15 and 3.67kg on the 20., 30. and 150. days, respectively, in the lambs fed with 25% corn + 75% sunflower silage, and the lowest weight gain was 0.42kg on the 90. day and 0.69kg on the 100. day. In lambs fed 100% sunflower silage, the highest body weight gain was 2.95, 3.16 and 2.82kg on the 20., 110. and 120. days, respectively, and the lowest 0.88 kg on the 90. day.

Table 8. Values of the live weight gains of the lambs belonging to the experimental groups

Days	1st group	2nd group	3rd group	4th group	5th group
20	3.39	3.36	3.12	3.56	2.95
30	3.02	3.02	2.84	3.15	2.70
40	2.66	2.65	2.59	2.73	2.46
50	2.3	2.31	2.35	2.28	2.23
60	1.93	1.95	2.11	1.84	2.0
70	1.57	1.6	1.88	1.38	1.79
80	1.19	1.25	1.66	0.9	1.58
90	0.39	0.28	1.08	0.42	0.88
100	1.26	1.60	1.61	0.69	1.79
110	2.83	3.52	2.59	3.03	3.16
120	3.39	3.25	2.75	2.77	2.82
130	3.19	2.53	2.57	2.27	2.27
140	2.47	2.35	2.29	2.58	2.26
150	1.21	2.68	1.93	3.67	2.82

In general, the lowest body weight gain was estimated at 90. day in all experimental groups. The highest live weight gains were determined on the 20. and 120. days, and it was determined that the said increases were seen in the first and last days of the fattening period. The graph showing the change in live weight gains according to the days is presented in Figure 7.

There are noticeable differences in live weight gain in different groups. Tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk) were applied for weight gain. The data showed a normal distribution (Table 9).

Since the data showed normal distribution, analysis of variance (ANOVA) was applied (Table 10). According to the results of variance analysis, the difference in live weight gain between groups was found to be insignificant (F=0.034 and p>0.05).

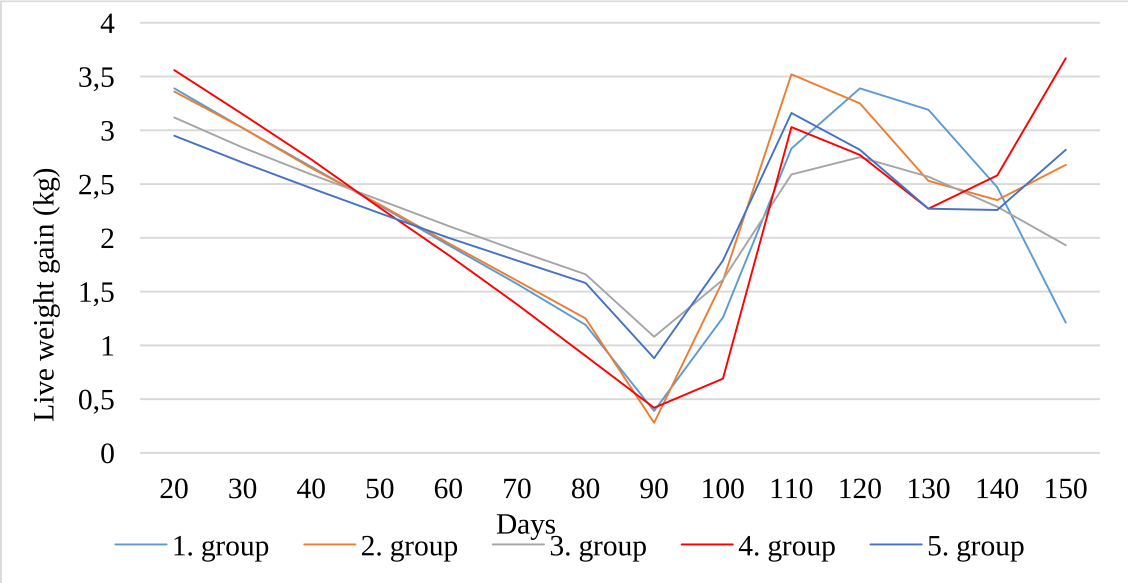

Figure 7. Live weight gain estimates of the lambs of the experimental groups.

Table 9. Tests of normality for weight gain

	Kolmogorov-Smirnov			Shapiro-Wilk		
Groups	Statistic	df	p	Statistic	df	p
1	0.124	14	0.200	0.935	14	0.361
2	0.143	14	0.200	0.952	14	0.593
3	0.150	14	0.200	0.972	14	0.896
4	0.157	14	0.200	0.940	14	0.423
5	0.120	14	0.200	0.959	14	0.700

df: Degrees freedom

Table 10. ANOVA test results

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.095	4	0.024	0.034	0.998
Within Groups	45.841	65	0.705		
Total	45.936	69			

Some findings of different researchers regarding live weight and live weight gains in lambs are as follows; Yakan *et al*. (2012) reported the 180. day live weights of Akkaraman, Awassi and Kıvırcık breeds as 37.88, 36.65 and 33.86kg, respectively. Average live weight of different genotypes showed differences according to breeds. Alarslan and Aygün, (2019) determined the birth weight, 30., 60., 90., 120., 150. and 180. days live weights of Kıvırcık lambs as 4.49, 8.69, 1.94, 21.50, 28.58, 33.68 and 37.60kg, respectively. In the study, they found significant the effect of maternal age and birth type on the birth weight of lambs, the effect of birth type on live weights on the 60. and 90. days, and the effect of gender on the live weights on the 90., 120., 150. and 180. days. Öztürk *et al*. (2012) determined the birth weight and average live weight of 30., 60., 90., 120. and 150. days of Kıvırcık x pure (F_1) (Hybrid) lambs to be 4.25, 8.76, 14.40, 21.72, 26.69 and 35.85 kg, respectively. In the study, the effect of age on body weight was found to be significant. In another study, Demir *et al*. (2001), reported the 56th day live weight of Kıvırcık lambs as 28.81 - 28.86 kg. Akbaş *et al*. (1999) investigated the live weights of Kıvırcık and Dağlıç male lambs with different mathematical growth models. Among these models, Brody, Negative Exponential, Gompertz, Logistik and Bertalanffy models showed a good fit to the weight-age data of lambs. Yıldız *et al*. (2009) determined the growth curves of Merinos x Kıvırcık hybrid lambs using the Gompertz and Logistic models. In the Gompertz model, the determination coefficient (R^2) was 0.986 for female lambs and 0.990 for male lambs, whereas in the Logistic model, it was 0.982 for both male and female lambs.

In research, the live weights of 278 Romanov lambs were estimated using Cubic Spline, Logistic, Gompertz, and Richard models. The lambs' weights were tracked from birth to day 180. The results revealed that the mean square error for the male lambs ranged from 0.295 to 0.995, while the mean square error for the female lambs ranged from 0.995 to 2.659. The R^2 adj. values for the male and female lambs, respectively, were between 0.971 and 0.997. The male lambs' AIC values ranged from -37.12 to 0.094, and the female lambs' values ranged from -0.196 to 122.12. Considering the MSE, R^2 adj., AIC and Durbin-Watson values of the female lambs (0.295, 0.997, -37.12, 2.23, respectively) and male lambs (0.995, 0.993, -122.12, 2.31, respectively), the Cubic Spline model was determined to be the best model, while the Richard model was determined to be the worst fitting model both for the female (0.95, 0.971, 0.094, 2.41) and male (1.85, 0.969, -0.196, 2.79) lambs (Tahtalı *et al*., 2020). To determine the growth curves of Malya sheep, Aytekin and Zülkadir (2013) employed the Gompertz, Logistic, and Cubic Spline models. They discovered that the determination coefficients for the Gompertz, Logistic, and Cubic Spline models were 0.915, 0.912, and 0.921, respectively. Therefore, they found that the Cubic Spline model was more suitable. It is consistent with the results of this study in terms of the most appropriate model for describing growth. In this study, the Cubic Spline method was determined as the best model among the 4 models used in the body weight modeling of Kıvırcık lambs. The outcomes of this investigation could not be compared to the body of literature because there aren't any yield-density models in this area.

CONCLUSION

In this study, the change of live weight of Kıvırcık lambs fed with corn and sunflower silage in 5 different ratios (pure and mixed) according to time was investigated. Several comparison statistics were used to compare the results, including coefficient of determination (R^2), adjusted coefficient of determination (Adj. R^2), mean-square error (MSE), and Akaike Information Criteria (ACI). In terms of performance, the models were ranked in the following order: Cubic Spline > Holliday > Farazdaghi-Harris > Gaussian (best to worst). Cubic spline functions have been applied to better describe growth by examining growth periods separately. That is, 5 different Cubic Spline functions were obtained for 5 different time intervals, 0-84, 84-98, 98-112, 112-126 and 126-140 days. According to the Cubic Spline function formed according to these time intervals, the live weight estimation on any day could be made.

As a result, it has been seen that Cubic Spline functions, which are little used in agricultural areas and are not known much by researchers working on this subject, can be used successfully in the estimation of live weight of lambs. The obtained results revealed that the Cubic Spline functions and yield-density models will make an important contribution to the research on animal husbandry.

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