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**Original Research Article**

# Identification of Best Growth Curve Model for Anatolian Black Cattle

**Key words**

Anatolian Black cattle;
live weight;
growth curve;
non-linear models

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**Abstract:** The aim of this study was to identify the model that best describes the growth trajectory from birth to 24 months of age in Anatolian Black Cattle (ABC) raised for conservation purposes. A total of 493 weight records of 113 animals at birth, 3, 6, 12, 18, and 24 months were collected. Six different non-linear models were used to describe the growth curve of animals: 2nd degree polynomial, 3rd degreee polynomial, Logistic, Brody, Von Bertalanffy, and Gompertz models. In the study, $R^2$ values of the models were: 0.997, 0.999, 0.953, 0.979, 0.924, and 0.862; corel values (correlation between the observed and estimated curves) were 0.994, 0.998, 0.989, 0.993, 0.961, and 0.703; Residual Standard Deviations (RSD) were 3.216, 1.388, 11.533, 3.561, 14.736, and 27.141, respectively. Given these values, it was found that the 3rd degree polynomial model was the best to describe the growth curve of ABC. As a result of the analyses, it was noticed that the values predicted by this model deviated by 1-3 kg from the observed values in all periods and in all environmental factors examined (sex, dam age, parity, birth year and birth, season). It was found that these differences increased up to 4-5 kg only in the 18-month period. The results also showed that ABC continued to grow after 24 months of age. As a result, traits such as age at sexual maturity, breeding age, and slaughter age can be easily predicted by identifying the model that best describes growth and development in herds.

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## Introduction

Cattle breeding has an important place in Turkey's animal husbandry; while there are around 18 million cattle in Turkey, approximately 8% of this is local breeds (1). Domestic cattle breeding is important in terms of rural employment and development, rural sociology and the use of poor pasture areas. Anatolian Black Cattle (ABC) is one of the breeds that is most widely grown and spread among the domestic breeds in Turkey. This breed is grown especially in the Central Anatolian Region of Turkey and is mostly grown for meat and milk yield by breeders living in rural areas. It has adapted to these conditions since it has grown in unfavourable conditions in this region for many years. They have gained resistance to harsh winters, drought, hunger, thirst, and diseases (2, 3). Growth and development values in Turkey's domestic cattle breeds are generally slower than those of developed cattle breeds. In studies conducted with the ABC breed in Turkey, live weights at birth, 3, 6 and 12 months of age were found to be 14.85 kg, 49.37 kg, 81.22 kg, and 97.29 kg, respectively (2). In other studies with the same breed, live weights from birth to 12 months of age were the following: 16.97- 21.35 kg, 63.21 - 68.18 kg, 101.04 - 110.33 kg, and 152.16 kg- 184.57 kg, respectively (3, 4, 5).

Growth in cattle is a function that continues throughout the life of the animal, from embryonic stages to adulthood, and can be explained mathematically by growth curve models (6). The change in any of the examined features over a certain period is defined as the growth curve (7). The growth curve shows the statistical relationship between the weight and time or age of animals, which is shaped under the influence of genetic potential and environmental factors (8). The growth of living organisms does not progress at a


**Figure 1a**: Anatolian Black cows and calves


**Figure 1b**: Animal weighing

constant rate throughout their lives (9). In the case of constant growth, linear models are used, and when the growth rate occurs at different times depending on age, nonlinear models (such as Negative Exponential, Brody, Logistics, Gompertz, Bertalanffy, Richards, and Weibull) are used (6, 10). The fact that living things have different growth rates in some periods necessitated the use of nonlinear models, which were more comprehensive models (8). There is still a need to investigate whether the most commonly preferred non-linear models are sensitive to the length of the growth period prior to truncation of the data (11).

The aim of this study was to evaluate non-linear models of the growth curve in ABC cattle taken at individual weights from birth to 24 months and to determine the model that best explains growth. For this purpose, 2nd degree polynomial, 3rd degree polynomial, Logistic, Brody, Von Bertalanffy, and Gompertz models were analysed.

## Materials and methods

### *Animals*

The animal material of this study consisted of Anatolian Black Cattle (ABC) grown in the "International Center for Livestock Research and Training" (39°97' N, 33°10' E; elevation 826 m) located in Ankara. This breed has been conserved within the scope of the project "Conservation of Domestic Genetic Resources and Sustainable Use" conducted by the General Directorate of Agriculture Research and Policies. The study was carried out on a total of 113 heads of ABC born between 2015 and 2020.

ABC calves were raised with their dams from birth, and they were allowed to suckle their dams freely. The cows were not milked on the farm. Feeding of ABC bred cows was two meals a day, morning and evening, ad libitum in the form of total mixed feed. ABC cows were given 80% barley bales and 20% dry meadow grass as roughage.

**Table 1:** Descriptive statistics of body weight at different ages in Anatolian Black Cattle

| Statistics | BW | 3MW | 6MW | 12MW | 18MW | 24MW |
|---|---|---|---|---|---|---|
| N | 113 | 93 | 96 | 98 | 35 | 58 |
| Minimum (kg) | 13.00 | 37.00 | 52.50 | 89.00 | 144.00 | 178.00 |
| Maximum (kg) | 30.00 | 99.00 | 153.00 | 283.00 | 332.00 | 444.00 |
| Female (kg) | 17.25 | 61.70 | 90.42 | 144.30 | 188.65 | 225.34 |
| Male (kg) | 19.55 | 67.66 | 103.08 | 162.75 | 245.50 | 303.90 |
| Mean (kg) | 18.57 | 65.10 | 98.33 | 155.60 | 217.89 | 264.64 |
| Standard Error | 0.312 | 1.340 | 2.120 | 3.830 | 7.970 | 7.910 |
| Coefficient of Variation (CV%) | 17.86 | 19.88 | 21.17 | 24.40 | 21.64 | 22.78 |

Notes: BW=birth weight, 3MW=3 month weight, 6MW=6 month weight, 12MW=12 month weight, 18MW=18 month weight, 24MW=24 month weight.

**Table 2:** Non-linear models used to describe the growth of Anatolian Black Cattle

| Model | Equation | Reference |
|---|---|---|
| 2nd Degree Pol. | $y_t=\beta_0 + \beta_1 t + \beta_2 t^2$ | 12 |
| 3rd Degree Pol. | $y_t=\beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3$ | 12 |
| Logistic | $y_t=A(1 + be^{-kt})^{-1}$ | 13 |
| Brody | $y_t=A(1 - be^{-kt})$ | 14 |
| Von Bertalanffy | $y_t=A(1 - be^{-kt})^3$ | 15 |
| Gompertz | $y_t=A\exp(-be^{-kt})$ | 16 |

yt = observed BW at age t (kg); $\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$: regression coefficients of 2nd and 3rd degree polynomial models; A: the asymptotic limit of the BW when age t approaches infinity (kg); b: the integration constant, related to the initial weights of the animal and without a well-defined biological interpretation; k: ratio of the relative intensity of growth (maturation rate); t: time (month).

Figure 1a shows Anatolian Black cows and calves, while Figure 1b shows the weighing of an animal.

### *Data set*

In this study, birth weight, 3, 6, 12, 18, and 24 month live weights of 113 calves born between 2015 and 2020 were used. These values were determined by weighing them with precision scales up to 200 g. The characteristics of the data are presented in Table 1. In addition, information on sex, dam age, parity, birth year, and month was also recorded.

### *Predicting the growth curve*

In the study, six different non-linear models were used in the estimation of growth curves, and these models are presented in Table 2.

In the study, $R^2$ (coefficient of determination), RSD (Residual Standard Deviation), and corel (correlation) between the observed and estimated growth curves were used to compare the models.

### *Statistical analysis*

Statistical analyses were carried out using the Proc Nlin in SAS (17). Growth curve models were fitted for each animal separately, and then the best-fitted model parameters and the other phenotypic data were analyzed using the Proc Glm in SAS (17). For analysis, sex (female, male), age of dam (2-3, 4-7, 8-10, 11+), parity (1, ...7), birth year (2015, ... 2020), and birth season (winter, spring, summer, autumn) were included in the model, and these were taken as fixed effects in the GLM analyses. To determine the differences between groups, the Tukey test was used.

## Results and discussion

The growth curve parameters as derived from 6 different models using 493 weight records for ABC are presented in Table 3. The 3rd degree polynomial model showed the highest $R^2$ and corel and lowest RSD, indicating the best goodness of fit. On the other hand, the Gompertz model was the least fitted to estimate the ABC weight based on its lowest value of $R^2$. That is, the 3rd degree polynomial model with four parameters ($\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$), which has the highest $R^2$ and smallest RSD value, best explains the change in live weight

**Table 3:** Model comparison for growth of Anatolian Black Cattle

| Model | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $R^2$ | RSD | corel |
|---|---|---|---|---|---|---|---|
| 2nd degree polynomial | 21.80±0.619 | 0.44±0.0132 | 0.01±0.001 | - | 0.997 | 3.216 | 0.994 |
| 3rd degree polynomial | 18.72±0.361 | 0.33±0.099 | 0.01±0.002 | 0.01±0.001 | 0.999 | 1.388 | 0.998 |
| | **A** | **b** | **k** | **$t_i$** | | | |
| Logistic | 206.09±8.417 | - | -1.79±1.788 | 8.84±8.839 | 0.953 | 11.533 | 0.989 |
| Brody | 225.56±15.625 | 0.83±0.027 | 0.01±0.001 | - | 0.979 | 3.561 | 0.993 |
| Von Bertalanffy | 169.96±15.650 | -0.19±0.124 | 0.01±0.005 | - | 0.924 | 14.736 | 0.961 |
| Gompertz | 129.05±4.530 | 2.751±0.079 | 0.40±0.000 | - | 0.862 | 27.141 | 0.703 |

$\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$: regression coefficients of 2nd and 3rd degree polynomial models; A: the asymptotic limit of the BW when age t approaches infinity (kg); b: the Integration constant, related to the initial weights of the animal and without a well-defined biological interpretation; k: ratio of the relative intensity of growth (maturation rate); t: time (month).

$R^2$: coefficient of determination; RSD: Residual Standard Deviation; corel: correlation between observed and estimated growth curves

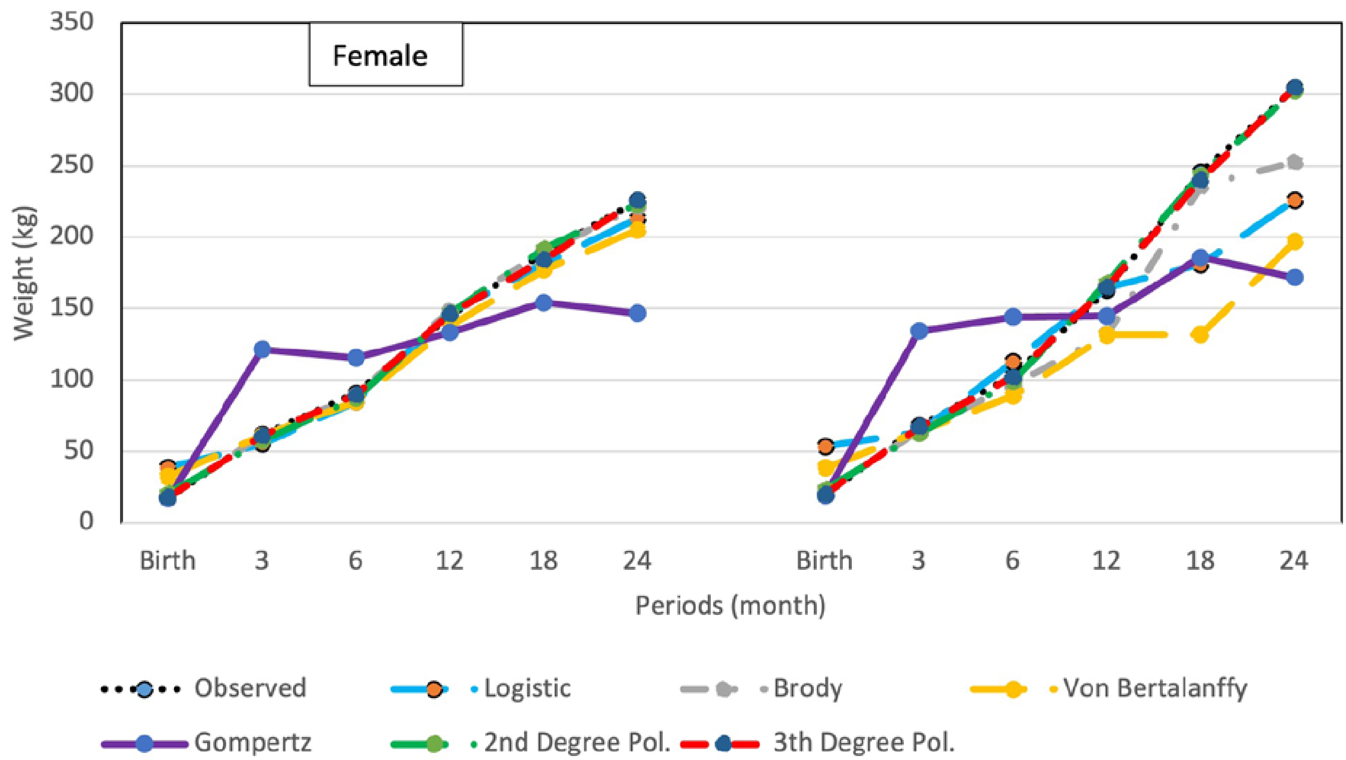


**Figure 2:** Observed and estimated growth curve of females and males by the models and sex of animals

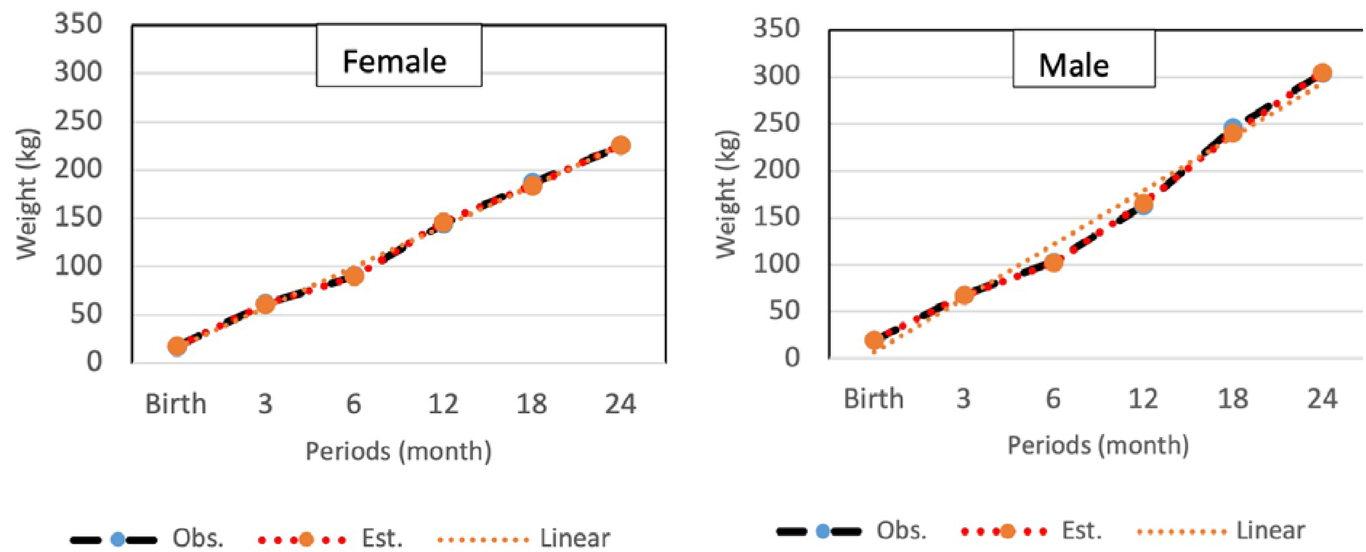


**Figure 3:** Growth curve with 3rd degree polynomial model by sex

according to age in ABC. In Figure 2, the growth curve of the observed weights by gender and estimated according to the models is presented. As can be seen in Figure 2, the model most compatible with the values observed in ABC from birth to 24 months is the 3rd degree polynomial model.

In similar studies, the 3rd degree polynomial model was determined to be the most suitable model in the Holstein breed by Heinrichs and Hargrove (12); in the Ayrshire, Brown Swiss and Shorthorn breeds by Heinrichs and Hargrove (18); and in the Holstein and Brown Swiss breeds by Akbulut (19). On the other hand, the most suitable models were the Gompertz and Von Bertalanffy model ($R^2$=0.70) in Madura breed by Hartati and Putra (6); Richards model ($R^2$=0.999) in Holstein by Tutkun (10);the Logistic model in the pre-weaning period; the Gompertz and Richards models in the post-weaning period in the Holstein breed by Koşkan and Özkaya (20); Richards model ($R^2$=0.968, 0.960) in Brown-Swiss and Holsteins by Bayram and Akbulut (21); the Richards model ($R^2$=0.976) in Anatolian Buffaloes by Şahin et al. (22). The most suitable models differ in studies conducted with different breeds and environmental conditions. In practice,

**Table 4:** Least square means and standard errors (SE) of the 3rd degree polynomial model parameters by different environmental factors

| Factor | Group | n | $\beta_0$±SE | $\beta_1$±SE | $\beta_2$±SE | $\beta_3$±SE |
|---|---|---|---|---|---|---|
| **Sex** | Female | 48 | 17.61±0.608 | 0.01±0.182 | 0.011±0.0028 | 0.0009±0.0004 |
| | Male | 65 | 20.25±0.573 | 0.35±0.171 | 0.005±0.0027 | 0.0005±0.0003 |
| **Dam Age** | 2-3 | 31 | 21.18±1.773 | -0.52±0.530 | 0.006±0.0083 | -0.0006±0.0011 |
| | 4-7 | 46 | 17.45±0.797 | 0.80±0.238 | 0.002±0.0037 | 0.0006±0.0005 |
| | 8-10 | 17 | 18.12±1.037 | 0.17±0.310 | 0.006±0.0048 | 0.0007±0.0006 |
| | 11+ | 19 | 18.99±0.979 | 0.26±0.293 | 0.019±0.0046 | 0.0020±0.0006 |
| **Parity** | 1 | 29 | 14.40±1.704 | 0.92±0.510 | 0.010±0.0080 | 0.0023±0.0010 |
| | 2 | 24 | 18.00±0.985 | -0.45±0.295 | 0.016±0.0046 | 0.0012±0.0006 |
| | 3 | 19 | 19.95±0.995 | -0.34±0.297 | 0.018±0.0046 | 0.0008±0.0006 |
| | 4 | 15 | 19.48±1.084 | -0.39±0.324 | 0.012±0.0050 | -0.0001±0.0007 |
| | 5 | 12 | 20.90±1.189 | 0.13±0.355 | 0.003±0.0055 | -0.0002±0.0007 |
| | 6 | 8 | 20.33±1.511 | 0.63±0.452 | -0.002±0.0071 | 0.0001±0.0009 |
| | 7 | 6 | 19.47±1.683 | 0.73±0.503 | -0.002±0.0079 | 0.0005±0.0010 |
| **Year** | 2015 | 18 | 17.81±1.026 | 0.49±0.307 | 0.003±0.0047 | 0.0005±0.0006 |
| | 2016 | 23 | 19.03±0.876 | 0.15±0.262 | 0.007±0.0041 | 0.0001±0.0005 |
| | 2017 | 17 | 18.39±0.967 | 0.17±0.289 | 0.003±0.0045 | -0.0001±0.0006 |
| | 2018 | 24 | 19.70±0.784 | 0.21±0.234 | 0.008±0.0036 | 0.0011±0.0005 |
| | 2019 | 10 | 19.27±1.147 | -0.10±0.343 | 0.012±0.0054 | 0.0016±0.0007 |
| | 2020 | 21 | 19.39±1.041 | 0.14±0.311 | 0.013±0.0047 | 0.0009±0.0006 |
| **Season** | Winter | 17 | 17.49±0.960$^{b}$ | -0.15±0.287 | 0.179±0.0044$^{a}$ | 0.0019±0.001 |
| | Spring | 55 | 19.78±0.696$^{ab}$ | 0.37±0.208 | 0.002±0.0032$^{b}$ | 0.0002±0.000 |
| | Summer | 26 | 20.58±0.777$^{a}$ | 0.41±0.232 | 0.004±0.0036$^{b}$ | 0.0001±0.000 |
| | Autumn | 15 | 17.88±1.038$^{b}$ | 0.08±0.310 | 0.008±0.0048$^{b}$ | 0.0006±0.001 |

$^{a,b}$ The means with the different superscripts within the factor in the same column are different (P<0.05).

$\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$: regression coefficients of 3$^{rd}$ degree polynomial model

determining the weight-age relationship of cattle requires a lot of expense and time (21). In order to make reliable estimations in different regions and different breeds and to use the obtained parameters for selection purposes, first the identification of the appropriate model is necessary.

In the rest of this paper, the results of the 3$^{rd}$ degree polynomial model were presented since this model was determined to be the best fitted to real measurements obtained from animals. Table 4 reflects the least square means and their corresponding standard errors of $\beta_0$, $\beta_1$, $\beta_2$, $\beta_3$ parameters by environmental factors. As a result of the analysis, $\beta_0$ values vary between 17.45-21.18 (except for parity 1) in all environmental factors. The differences between these values were found to be statistically significant only in the seasonal group (P<0.05). In addition, $\beta_2$ values

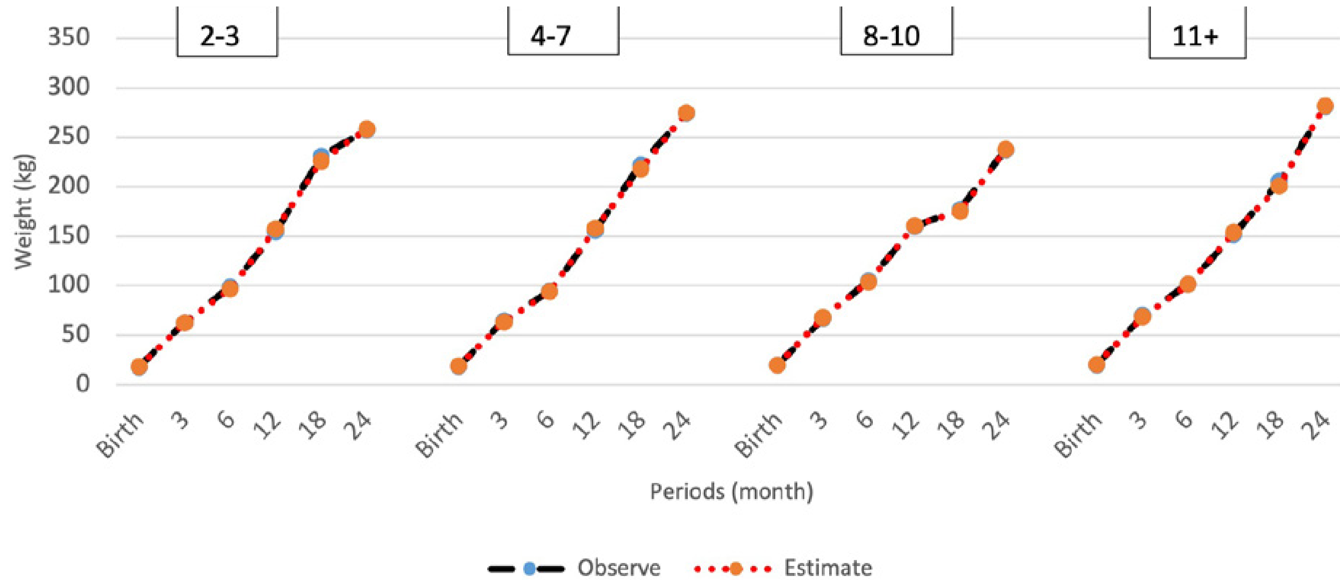


**Figure 4:** Growth curve with 3rd degree polynomial model by age of dam

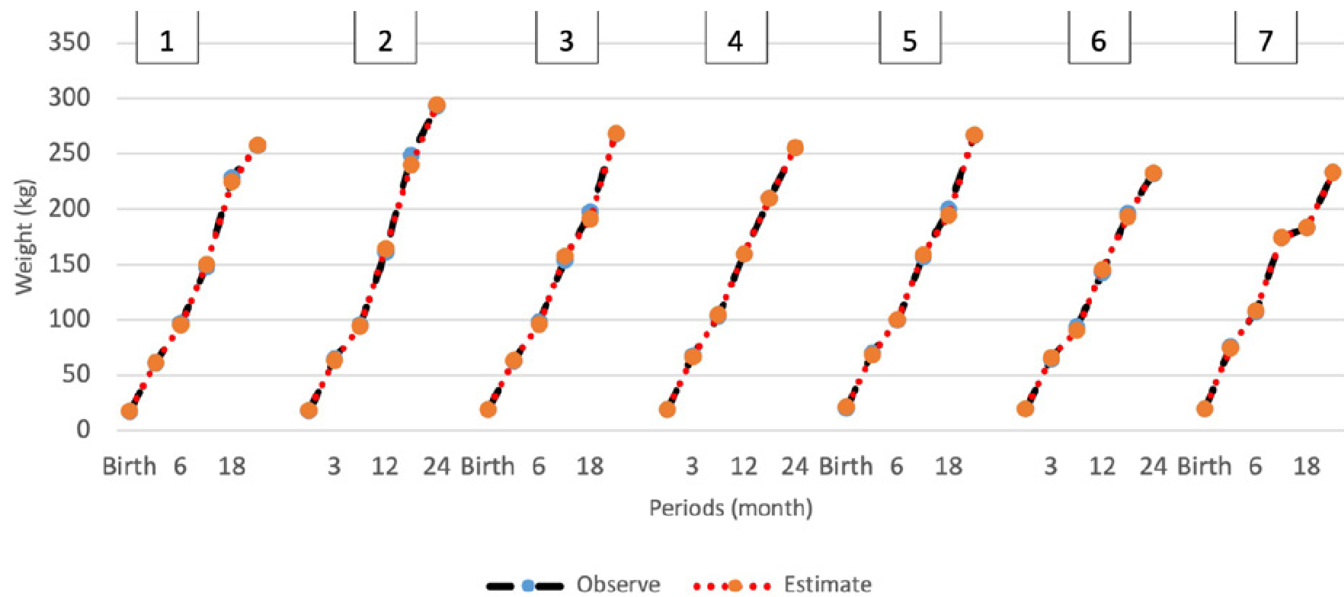


**Figure 5:** Growth curve with 3rd degree polynomial model by parity

were found to be statistically significant between seasons (P<0.05).

In Figures 3, 4, 5, 6, and 7, the growth curves of animals according to sex, dam age, parity, birth year, and birth season are presented using the 3rd degree polynomial model. As Figure 3 is examined, it has been determined that males have a higher weight than females in both observed and predicted values in all periods. Sahin et al. (22) found that adult live weight was higher in males in all models (Logistic, Gompertz, Richards, Brody) examined in Anatolian buffaloes. Hartati and Putra (6) reported that the animals had similar growth characteristics in all models (Logistik, Gompertz, Von Bertalanffy) which were examined in both sexes in Madura cattle. Growth in both males and females in the study continued until the age of 24 months, which can be clearly seen in the linearly plotted growth curve in Figure 3. Akbulut (19), using the 3rd degree polynomial model, determined that the growth in Holstein and Brown Swiss breeds continued linearly up to 18 months.

When Figures 4 and 5 were examined, the differences according to dam age and parity became more pronounced after 18 months of age. According to the chosen model, it was estimated that calves from the 11+ dam age group had higher live weights in periods BW, 3M, and 24M. It was also estimated that the 8-10 dam age group had higher live weights in periods 6M and 12M, while the 2-3 dam age group had higher live weights in the 18M period. When live weights measured in different periods were examined according to parity, it was determined that the animals born from the 5th parity cows had a higher live weight in the birth

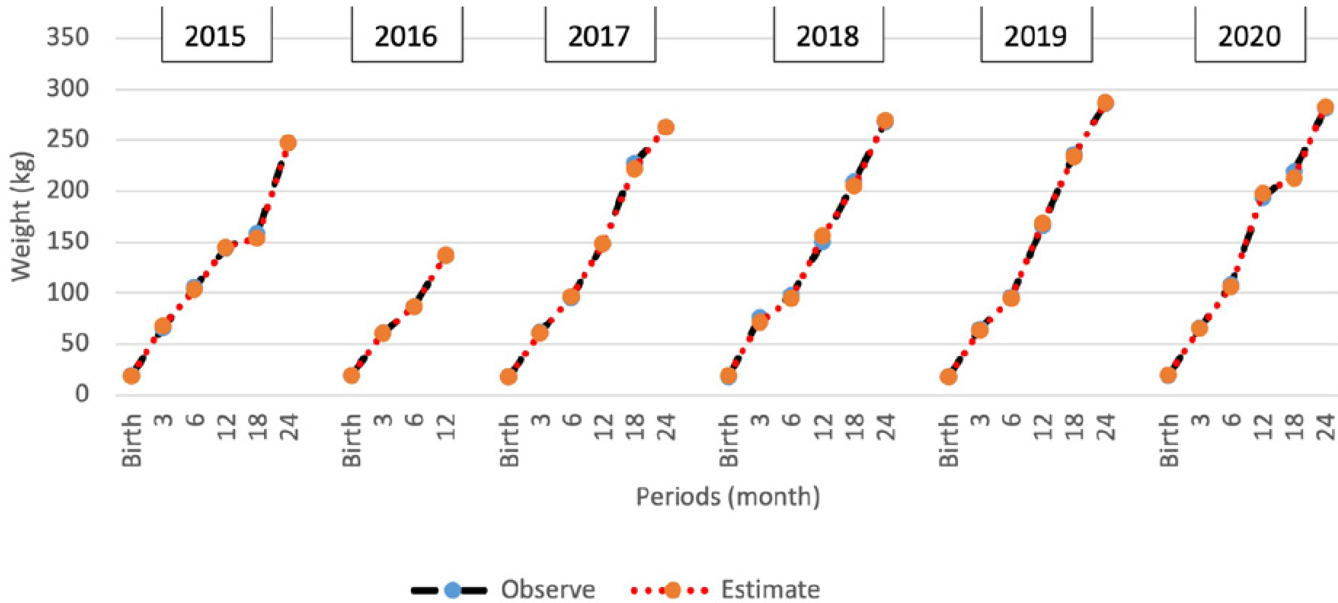

**Figure 6:** Growth curve with 3rd degree polynomial model by birth year

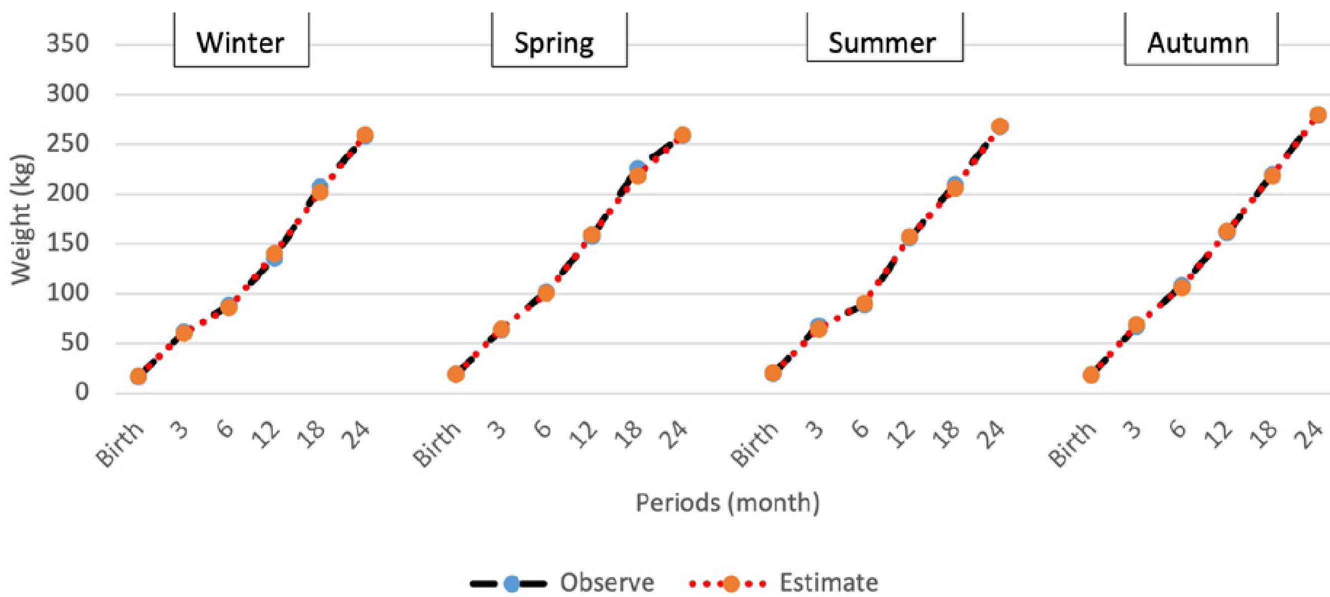

**Figure 7:** Growth curve with 3rd degree polynomial model by birth season

period. In addition, while the animals born from the 7th parity cows had a higher live weight in the 3M, 6M, and 12M periods, the animals born from the 2nd parity cows had a higher live weight in the 18M and 24M periods.

When Figures 6 and 7 are examined, the differences according to the year of birth and season of birth begin to appear mostly in 6M. While studying the differences in live weights by years, it was observed that the calves born in 2020 had higher live weights at birth, 6M, and 12M periods. Additionally, those born in 2018 had higher live weights in the 3M period, and those born in 2019 had higher live weights in the 18th and 24M periods. When the differences in live weights according to the seasons were examined, it was found that the animals born in the summer season had higher weights at birth and 3M periods. It was also observed that while the animals born in the spring season had higher live weights at the 6M and 12M periods, the animals born in the autumn season had higher live weights at the 18M and 24M periods.

According to this model, the estimated values showed a deviation of around 1-2 kg in female and male animals at all periods compared to the observed values, while in males they showed a deviation of 3-5 kg only in the 12M and 18M periods (Figure 3). In other graphs (Figure 4-7), the differences between the generally estimated values and the observed values are between 1-3 kg, and the differences were found to be around 4-5 kg only in 18M periods. This indicates that the 3rd degree polynomial model is the most appropriate model for the growth values of ABC.

Monitoring the growth and development of animals during some periods in the growth process will be of great benefit to the farms in terms of herd management, care, and feeding regulation (22). In order to obtain reliable estimates of the growth curve parameters, it may be necessary to collect growth data until the point when the growth curve starts to flatten or the growth rate slows down (11). Changes in body weight in animals reflect the influence of environmental factors and management systems, particularly nutrition (23). In addition, by monitoring the growth of the animals, early intervention can be made for animals that have a problem in their development.

## Conclusions

According to the results of the study, the 3rd degree polynomial model was determined to be the most suitable model in ABC according to the $R^2$, RSD, and corel values. By using the 3rd degree polynomial model on the farm, the general growth and development of the animals can be followed, and conditions such as sexual maturity age, breeding age, and appropriate slaughter age can be easily predicted. Examining the growth curve is important for breeders to decide on the optimum body weight of the animals, the appropriate age, and the ideal weight. Growth curve parameters can be successfully applied to animals and may benefit the development and design of selection strategies.

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The author of the study kindly declares no competing interest.

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# Določitev najboljšega modela krivulje rasti za anatolsko črno govedo

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**Izvleček:** Namen te študije je bil določiti model, ki najbolje opisuje potek rasti od rojstva do 24 mesecev starosti anatolskega črnega goveda (ABC), vzrejenega za namene ohranjanja. Zbranih je bilo 493 podatkov o telesni teži 113 živali ob rojstvu ter pri 3, 6, 12, 18 in 24 mesecih starosti. Za opis krivulje rasti živali je bilo uporabljenih šest različnih nelinearnih modelov, in sicer polinom 2. stopnje, polinom 3. stopnje, logistični model ter modeli Brody, Von Bertalanffy in Gompertz. V študiji so bile vrednosti $R^2$ modelov naslednje: 0,997, 0,999, 0,953, 0,979, 0,924 in 0,862; vrednosti correl (korelacija med opazovanimi in ocenjenimi krivuljami) so bile 0,994, 0,998, 0,989, 0,993, 0,961 in 0,703; ostanki standardnih odklonov (RSD) so bili 3,216, 1,388, 11,533, 3,561, 14,736 in 27,141. Glede na te vrednosti je bilo ugotovljeno, da je polinomski model 3. stopnje najbolje opisal krivuljo rasti ABC. Na podlagi analiz je bilo ugotovljeno, da so vrednosti, ki jih je napovedal ta model, za 1-3 kg odstopale od ugotovljenih vrednosti v vseh obdobjih in pri vseh preučevanih okoljskih dejavnikih (spol, starost matere, paritleta, leto rojstva in sezona rojstva). Ugotovljeno je bilo, da so se te razlike povečale na 4-5 kg le v 18-mesečnem obdobju. Rezultati so tudi pokazali, da se je ABC še naprej povečevala po 24 mesecih starosti. Posledično je mogoče lastnosti, kot so starost ob spolni zrelosti, plemenska starost in klavna starost, enostavno napovedati z določitvijo modela, ki najbolje opisuje rast in razvoj v čredah.

**Ključne besede:** anatolsko črno govedo; živa teža; krivulja rasti; nelinearni modeli