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Fitting different non-linear models to describe growth pattern in Zandi sheep

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ABSTRACT

The objective of this study was to describe the growth pattern in Zandi sheep using non-linear models. In total 21640 body weight records from birth to yearling were analyzed. The data set were used in this study, obtained from the Animal Breeding Center of Iran during 1992–2013. In this study growth pattern parameters (mature weight, growth rate and mature rate) estimated using four nonlinear regression model (Brody, Gompertz, logistic and Bertalanfy). Growth models were compared with coefficients of determination (R^2), adjusted coefficient of determination (R^2_{adg}), Means square error (MSe) and Akaike's information criterion (AIC). logistic model provided the best fit of growth curve due to the generally greater values of R^2 and R^2_{adg} and lower values of MSe and AIC than other models. In logistic model the estimated amount of mature weight (A), growth rate (B) and maturation rate (K) were 34.48±0.09, 7.61±0.28 and 0.027±0.0004, respectively. This amount for Brody model were 36.52±0.17, 0.9±0.004 and 0.009±0.0002 respectively. For Gompertz model this amount were 35.12±0.11, 2.25±0.04 and 0.017±0.0002 respectively. In von Bertalanfy model the estimated amount of parameters A, B and K were 35.48±0. 12, 0.53±0.006 and 0.014±0.0002 respectively.

Introduction

The main aim of sheep rearing is producing meat. Hence sheep farmers pay special attention to growth traits (Bahreini Behzadi, 2015). Zandi sheep is one of the Iranian native races. This race is raised in Tehran, Qom and Markazi provinces. This sheep race is adapted to feeding difficult situations, poor and highland pastures, having small body and is a proper race for nomadic rearing system (Kalantar, 2005). The most important traits in livestock from economic view are traits related to growth (Keskin and Daskiran, 2007). Owing to effective role of growth traits on amounts of products in animal husbandries, attention has been paid to them from ranchers and researches (Rashidi et al. 2008). Growth is a necessary trait of biological systems, which means increase in body size per time unit and described as genetic and environmental influences combined together (Carrijo and Duarte, 1999). Knowing relationship between variables and that how changing one or some variables causes changing in other variables is important and have a lot of usages especially in biological sciences scope (Bahreini Behzadi, 2010).

Growth models can be used to measurement and prediction the effects of various factors on animal performance such as weight increasing. In fact, growth models are non-linear regression functions that can predict growth in different times during anima life (Bahreini Behzadi, 2015). The changes of these models that occur during times can create a growth curve function (Karakus et al. 2008). In fact, growth curves describe regular changes related to live weight along increasing animal age that typically is as sigmoid (Nikkhah et al. 2010).

Non-linear models provide useful information related to management problems, appropriate age for slaughtering, adjusting diet and especially maturity time in sheep rearing (Keskin and Daskiran, 2007; Kucuk and Eyduran, 2010).

Various non-linear growth models have been used on animals such as sheep and quail (Bathaei and Leroy, 1998; Gurcan et al. 2012). According to having meaningful parameters from physiology aspect, non-linear regression models preferred over linear models (Ghadiryan et al. 2011). There are many regression models that used to describe of sigmoid growth patterns and trying to specify temporary growth of livestock in order to predict and comparisons (Naghous et al. 2012). Brody, Gompertz, logistic and Bertalanfy and various types of generalized functions are important and common functions. Common part of these functions is their sigmoid property and typically curve is S-shaped or sigmoid (Malhado et al. 2009).

Three main phases of growth are recognizable on the graphs: quick growth phase, linear phase and slow growth phase comes to maturity (Nikkhah et al. 2010)[9]. Term of growth defines increasing in number and size of body cells, but unfortunately it's not possible to measure growth trend constantly. So it is necessary to evaluate growth trends by modeling mathematical functions (Amirabadi et al. 2011).
Many researches were conducted to fitting growth curves and increasing weight. Growth curve of body weight, carcass components and combined carcass 102 of ram and ewe from birth day to 720th day was investigated using non-linear functions (Goliomytis et al. 2006). In order to investigating growth curves in Santa Ines sheep, Brody, Gompertz, Richards logistic and Bertalanfy functions were fitted (Silva,

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2012). Also, in a study that investigated non-linear functions in Moroccan and Qpersik sheep, Gompertz function was reported as the best growth model (Eyduran et al. 2008).

There is no study that evaluated growth models in Zandi sheep. The aim of this study was predict growth in Zandi sheep using non-linear growth models (Brody, Gompertz, logistic and Bertalanfy) and determine the best model.

Materials and methods

In this research, 21640 records of Zandi sheep (body weight from birth to one year old) collected by Livestock Breeding Center of Iran from 1991 to 2013, were used. Zandi sheep breeding station (where considered Zandi sheep were kept) is located in Tehran. This place has relatively good pastures and station's sheep grazing nearly all year and complementary feeding may only be needed in very cold days, breeding season and late gestation period. Lambs were kept along their mothers in first 15 days and only kept separately at nights. After one month from birth, lambs were fed with complementary feeding. In this station, ewes were mated at 18 months of age. Mating began in October and continued for about a month. Ewes were selected a month earlier and after grouping and identifying estrus by rams, mated by these rams randomly. Sheep giving birth between February to March, and sometimes continued until April (Asefi, 2012).

Data includes animal number, animal's parents, animal gender, birth type, mother's age in giving birth and records related to weight body traits at different ages. Table 1 shows data structure and pedigree information of herd.

Table 1. Data structure and pedigree information of herd.

Items	Number	Items	Number
Animals in total	8282	Non base animals	7706
Inbred animals	2205	Non base sirs	221
Sires in total	258	Non base dams	1507
Dams in total	2046	Grand parents	1294
Animals with progeny	2804	Grand sires	214
Animals without progeny	5978	Grand dams	1080
Base animals	576	Great grand parents	839
Base sires	37	Great grand sires	163
Base dams	539	Great grand dams	676

Microsoft Excel 2013 was used to storage, edition and preparation of data,. After revision, data related to animals that have unknown number were erased.

Parameters of growth curve were estimated based on weight body at different ages using SAS 9.1 and NLIN procedure. Table 2. shows primary values determined to start estimating. It should be mentioned that primary values how defined that intended function meet convergence.

Table 2. Primary values determined to start estimating growth parameter.

Parameter	Primary values	Steps of model
A	30-90	5
B	0.1-5	0.5
K	0.01-5	0.5

Brody, Gompertz, logistic and Von Bertalanfy models used to fitting growth traits are shown in Table 3. These models fit growth traits by Gauss-Newton method.

Gauss-Newton method is widely used to estimate least-squares of parameters in non-linear regression.

In the above functions, exp is Euler's number equal to 2.71828. After estimating intended parameters of non-linear functions, average of least-squares and coefficient of determination (R^2) calculated and based their values, the best non-linear function for growth traits of Zandi sheep was selected. Intended indicators to identify the best non-linear function are shown in Table 4.

Table 3. Functional forms of equations used to describe the growth curve of Zandi sheep.

Model	Equation	No. of Parameter
Von Bertalanfy	$w_t = A^*(1 - B^* \exp(-K^* t))^3$	3
Gompertz	$W_t = A^* \exp(-K^* t)$	3
logistic	$W_t = A/(1 + B^* \exp(-K^*)$	3
Brody	$W_t = A^*(1 - B^* \exp(-K^* t))$	3

Table 4. Intended indicators to identify the best non-linear function.

Symbol	Criteria
R_2	Coefficient of determination
R^2_{adg}	Adjusted coefficient of determination
MSE	Mean square error
AIC	Akaike information criterion

Results and discussion

The models were compared by using residual mean square error (MSE) and Akaike's information criterion (AIC; Akaike, 1974). By using the NLMIXED procedure for fitting fixed and mixed effect growth models, the AIC values obtained from the MIXED and the NLMIXED (fixed and mixed models) procedures can be compared. The model with the smallest MSE and AIC values was chosen to be the best for fitting growth data. AIC = −2log L + 2 p Where, -2logL is the minus two times the maximized log-likelihood and p is the number of parameters in the model. The MSE calculated by dividing the residual sum of square by the number of observations, which represents the estimator of the maximum likelihood of the residual variance. AIC is a criterion for model selection based on the likelihood function.

Intended traits, least-squares and standard error are shown in Table 5. According to this Table, average body weight at birth, weaning, 6 months of age, 9 months of age and 12 months of age were 4, 21.4, 33.08, 33.45 and 34.45, respectively. Also, minimum and maximum body weights at different age are shown in Table 5.

Estimated values for parameters of non-linear functions are provided in Table 6. In this study, parameter A is mature weight. This parameter estimated for Brody, Gompertz, logistic and Bertalanfy models as 36.52, 35.12, 34.48 and 35.48, respectively. Value of A usually considered as a part that have maximum structure and cell aggregation (Owens and Dubeski, 1993). According to Table 6, parameter A has the highest value (36.52) and the lowest value (34.48) in Brody and logistic models, respectively. It is similar with the

Table 5. Intended traits, least-squares and standard error.

Body weight	Number	CV	Mean	Minimum	maximum
Birth weight	7687	4±0.008	14.59	1.5	7.3
Weaning weight	6131	21.41±0.05	14.83	10.5	43.3
6 month weight	3414	33.08±0.09	11.92	14.5	50
9 month weight	2698	33.45±0.11	11.11	16.7	50
12 month weight	1680	34.45±0.15	12.83	18.5	58

Table 6. Estimated values of nonlinear functions parameters in Zandi sheep.

Functions	Parameter	Estimated value	Standard error	Confidence interval 95%	
				Max	Min
Brody	A	36.52	0.17	36.85	36.19
	B	0.90	0.004	0.91	0.89
	K	0.009	0.0002	0.009	0.009
Gompertz	A	35.12	0.11	35.34	34.9
	B	2.25	0.04	2.32	2.18
	K	0.017	0.0002	0.018	0.017
Logistic	A	34.48	0.09	34.66	34.29
	B	7.61	0.28	8.15	7.06
	K	0.027	0.0004	0.028	0.026
von Bertalanffy	A	35.48	0.12	35.72	35.23
	B	0.53	0.006	0.54	0.52
	K	0.014	0.0002	0.015	0.0138

results of growth curve modeling in Shall sheep using functions with three parameters (A, B and K) that indicated parameter A had the highest value (40.31) and the lowest value (36.17) in Brody and logistic models, respectively (Hossein Zadeh, 2015). Parameter B stand for growth rate from birth to maturity. With the same primary weight, animals that have higher maturity degree reach maturity earlier. Parameter B in Brody, Gompertz, logistic and Bertalanfy models were 0.9, 2.25, 7.61 and 0.53, respectively.

Parameter of maturity degree (K) specify age of animal in maturity. With increasing this parameter, animals reach their maturity at lower age. In the current study, value of this parameter (K) in Brody, Gompertz, logistic and Bertalanfy models were estimated 0.009, 0.017, 0.027 and 0.014, respectively. In a study, growth pattern in Lori-Bakhtiari sheep was investigated, and the results were similar with the present study (Bahreini Behzadi, 2015). Estimated values for mature weight, weight and maturity degree in Lori-Bakhtiari sheep reported for Gompertz model as 56.57, 2.20 and 0.012, for Brody model as 65.98, 0.94 and 0.005, for Bertalanfy model as 58.26, 0.54 and 0.01, and for logistic model as 54.06, 5.93 and 0.018, respectively (Bahreini Behzadi, 2015). In logistic model as the best model, mature weight was lower in the current study in comparison with Lori-Bakhtiari sheep reported in (Bahreini Behzadi, 2015). Lori-Bakhtiari sheep have larger body than Zandi sheep and it could be reason for this difference. In another study, values of A, B and K parameters of Gompertz model in Mangali sheep were reported 36.92, 2.04 and 0.01 (Tariq et al. 2011).

Table 7 shows genetic correlations between the parameters (A, B and K) of different non-linear functions that used in this study. Genetic correlation between mature weight and mature rate in all four models were negative. There were important biological relationships between mature weight and mature rate.

This negative interaction indicates that sheep with lower mature weight, become mature faster. In other words, sheep with higher mature weight typically have lower growth rate compare to sheep with lower mature weight (Silva et al. 2012).

Coefficient of determination (R^2), adjusted coefficient of determination (R^{2adg}), mean square error (MSE) and Akaike information coefficient (AIC) were the criteria that used to determine the most appropriate model. Values of these criteria for all non-linear models that used in this study are shown in Table 8. Value of MSE for Brody, Gompertz, logistic and Bertalanfy models were 25.61, 24.39, 23.78 and 24.75, respectively. Also, R^2 values for Brody, Gompertz, logistic and Bertalanfy models were 0.968, 0.969, 0.971 and 0.969, respectively. According to Table 8, logistic model owing to having the highest values of R^2 and R^{2adg} and the lowest values of MSE and AIC was selected as the best model. Gompertz model was second best model owing to having the second highest R^2 value and the second lowest error criteria.

In a study, non-linear models were fitted to describe growth pattern in Anglo-Nubian goat, and reported that logistic model was the best describing model (Oliveira et al. 2009). In another study, the results showed logistic and Gompertz models were the best models between non-linear functions (Brody, Gompertz, Richards, logistic and Bertalanfy) to describe growth pattern in crossbred sheep (Malhado et al. 2009). Growth pattern of Santa Ines sheep was studied and reported that Richards model had some problems in convergence and logistic model was the best

Table 7. Correlation coefficient between parameters of growth models.

	Correlation		
Model	rAB	rAK	rBK
Brody	-0.0393570	-0.8438589	0.2488279
Gompertz	-0.1343539	-0.5879628	0.6848080
Logistic	-0.1385122	-0.3831919	0.8746841
von Bertalanffy	-0.1114335	-0.6800601	0.5531407

rAB: correlation between mature weight and growth rate, rAK: correlation between mature weight and maturity rate, rBK: correlation between growth rate and maturity rate

Table 8. Various criteria for comparing nonlinear function.

Functions/Criteria	R^2	R^2_{adg}	MSE	AIC
Brody	0.9683367	0.9683261	25.61	71295.539
Gompertz	0.9698430	0.9698329	24.39	71004.460
Logistic	0.9705989	0.9705890	23.78	70852.873
Bertalanfy	0.9694020	0.9693917	24.75	71091.157

model (Silva et al. 2012). Also, logistic model was reported as an appropriate model to describe growth pattern of Angus cattle (Hassen et al. 2004).

But some researchers reported results that are different to what we observed in our study. In a research on Baluchi sheep, It was reported that Gompertz, and Bertalanfy models had the highest precision and the lowest error in comparison with other models (Bahreini Behzadi, 2010). In another study, R^2 value of Gompertz function for male and female Murakami sheep and male and female Qpersik sheep were reported 0.997, 0.987, 0.992 and 0.993, respectively. It was resulted that Gompertz function is a useful tool to describe growth pattern (Eyduran et al. 2008).

In different literature, there are many estimates of growth curve parameters of sheep and they were so variable. This difference in reports depends on various factors. For instance, according to having small body size, mature weight in Baluchi sheep was estimated 40.25 by Brody model, but mature weight of Mehraban sheep that is a heavy race was reported 70.02 (Bathaei and Leroy, 1996; Molaei, 2013). Also, growth rate and maturity degree in Baluchi sheep (0.89 and 0.007 respectively) and Mehraban sheep (0.95 and 0.119 respectively) were reported.

Conclusions

According to results, logistic model owing to having the highest precision and the lowest error between other models (Brody, Gompertz, Bertalanfy) was selected as the best model to describe growth pattern in Zandi sheep. This model provides a descriptive comparison and can be used to estimate growth rate during times. As a result, this model can be used in order to improving growth, applying proper feeding methods, determine appropriate age to slaughter. Values of growth pattern parameters obtained in this study was different with other sheep races. This estimates were obtained by different models and methods, and in different age and environmental situations. Using growth models can improve the efficiency of livestock production by determine appropriate age to slaughter. Also, these models can be used to determine feeding system and management problems in herd.

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