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Research Article

Non-Linear Models for Growth Curves in Large White Turkeys

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Abstract: The present work aimed to model the growth curves of male and female turkeys with respect to their live weight-age relationships and to determine a non-linear model explaining their growth curve better. For this purpose four different non-linear models were used to define growth curves of turkeys, namely Gompertz, Logistic, Morgan-Mercer-Flodin (MMF), and Richards. The coefficients of determination for these models were 0.9975, 0.9937, 0.9993, and 0.9966 for females and 0.9974, 0.9933, 0.9993, and 0.9969 for males, respectively. Considering model selection criteria, Gompertz, Logistic and Richards models seen to be suitable models for explaining Large White turkey growth.

Key Words: Large White turkeys, growth curves, non-linear models

Ağır Beyaz Hindilerde Büyüme Eğrilerinin Tanımlanmasında Non-Linear Modeller

Özet: Bu araştırma, erkek ve dişi hindilerde canlı ağırlık-yaş ilişkileri dikkate alınarak büyüme eğrilerinin modellenmesi ve büyümeyi daha iyi açıklayan non-linear modelin saptanması amacıyla yapılmıştır. Bu amaçla, büyüme eğrilerinin tanımlanmasında dört farklı non-linear model (Gompertz, Logistic, Morgan-Mercer-Flodin (MMF) ve Richards) kullanılmıştır. Bu modellere ait determinasyon katsayıları sırasıyla; dişiler için 0,9975, 0,9937, 0,9993 ve 0,9966; erkekler için 0,9974, 0,9933, 0,9993 ve 0,9969 olarak saptanmıştır. Model seçme kriterleri bakımından Gompertz, Logistic ve Richards modeller ağır beyaz hindilerde büyüme olgusunu matematiksel olarak açıklamada yeterli bulunmuştur.

Anahtar Sözcükler: Ağır beyaz hindi, büyüme eğrileri, non-linear modeller

Introduction

Growth is defined as an increase in both the number and length of cells (1). In general, growth is a measure of live weight associated with an increasing size of animals. Ricklefs (2) associates the studies towards definition of growth with those approaches investigating growth trends and curves based on live weights.

The size of an individual changes during growing. Because of the differential growth of the particular body parts, the shape of an organism (its proportions) changes as well. Unfortunately, one cannot measure continuously most of these growth processes. Therefore, it is preferable to model measurements by mathematical functions. This gives one the opportunity to interpolate to non-observed intervals. Measurements of growth can be analyzed with respect to time (age) or to body weight.

Growth trend defines periodic changes in the underlying characteristic. This change is affected by some environmental factors namely temperature, feeding pattern, and diseases etc., along with the genetic structure and sex.

There have been quite a few studies undertaken toward the determination of growth trend in birds. These studies have been conducted on broilers, egg layers, and quails mostly. The literature on poultry and other animals traditionally defines the age-live weight relationship as a non-linear S-shaped function. Ricklefs (2) defined the growth trend in Japanese quails using the Gompertz model, which is a non-linear growth model. On the other hand, there have been similar studies undertaken towards poultry using some non-linear models such as logistic saturation kinetics, Von Bertalanffy, Brody, and Richards (3-13).

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Growth trend parameters are highly heritable and are used successfully in selection studies (14-17). In the selection studies conducted on quails growth trend parameters, genetic correlations associated with these parameters, and heritability were estimated (18,19). In their study, they have found differences among growth parameters calculated for quails of six different genetic lines.

Growth parameters are important not only as selection criteria but also in terms of feed management techniques used during the production period and slaughter weight.

This study aimed to estimate growth rate curves and their parameters using different growth models to determine the age-live weight relationship in male and female large white turkeys.

Materials and Methods

A total of 288 one-day-old male and female white turkey poults, 144 of each sex, were used in the study. These turkeys were kept indoors for 18 weeks using the littered floor system. Poults were placed into 24 unit pens at the end of the second week. Pens allowed to be 0.33 m^2 per bird as the stocking density. Males and females were grown separately during the experiment period. Wood shavings were used as litter. The turkeys were provided with feed and water on an ad libitum basis. Beak trimming was done at 9 days old. Turkeys were fed using feed materials containing 28% crude protein with 2800 kcal/kg ME in the first four week-period, 26% crude protein with 2900 kcal/kg ME during 5-8 weeks, 22% crude protein with 3000 kcal/kg ME during 9-12 weeks, and 19% crude protein with 3100 kcal/kg ME during 13-18 weeks. The experiment was undertaken from May to October. In the first 4-week period the lighting was set on for 23.5 hours a day and from this period forward 18 hours light 6 hours dark periods were followed. Live weights of turkeys were recorded individually on a weekly basis.

In this research widely known non-linear growth models, Gompertz, Logistic, Morgan-Mercer-Flodin (MMF), and Richards, were fit to estimate the age-live weight relationship. The rationality behind the use of these models lies in the fact that these models have some important parameters enabling to comment on the biological growth process. The mathematical relations of these models are as follows:

Gompertz : $y = A \, . \, e^{B.e^{C.x}}$,

Logistic : $y = A/(1 + B.e^{C.x})$,

MMF : $y = (A.B + C.x^D)/(B + x^D)$,

Richards : $y = 1/(A + B.e^{C.x})^D$,

It relates weight (y) to age (x), where, A, B, C and D are models parameters.

Non-linear regression procedure and Levenberg-Marquardt method (20) of SPSS was used to estimate the parameters of all the models. The non-linear models used were from general forms of the equations (21). Examining for accuracy of the model used the fitting criteria were coefficient of determination (R^2), Durbin-Watson statistics, standard error of prediction (S_{yx}), which is square root residual variance, and A parameter values (22). Coefficient of determination (R^2) is a measure of the proportion of the total variation accounted for by the explanatory variable. The Durbin-Watson statistics can be used to test for a correlation (non-randomness) of the residuals. Durbin-Watson statistics are given by the following formula.

$$DW = \sum_{t=2}^{n} (e_t - e_{t-1})^2 \Big/ \sum_{t=1}^{n} e_t^2$$

$$e_t = y_t - \hat{y}_t$$

where e_t shows t^{th} error term value for t = 1, 2,...,n.

y_t is t^{th} observed value and $\hat{y}_t$ shows i^{th} expected value.

The model with smallest standard error of prediction (S_{yx}) is assumed to have the best fit to the data, in order that A parameter (asymptotic weight) values offered the best opportunity to make direct comparisons among all models (23).

Results

The growth curves of male and female turkeys are given in Figures 1 and 2. As seen in these figures fit lines from all models are very close to the observed values.

Table 1 shows the model parameters and their determination coefficients (R^2) values. All models have considerably high R^2 values. The models may be ranked according to their R^2 values as MMF (0.9993), Gompertz

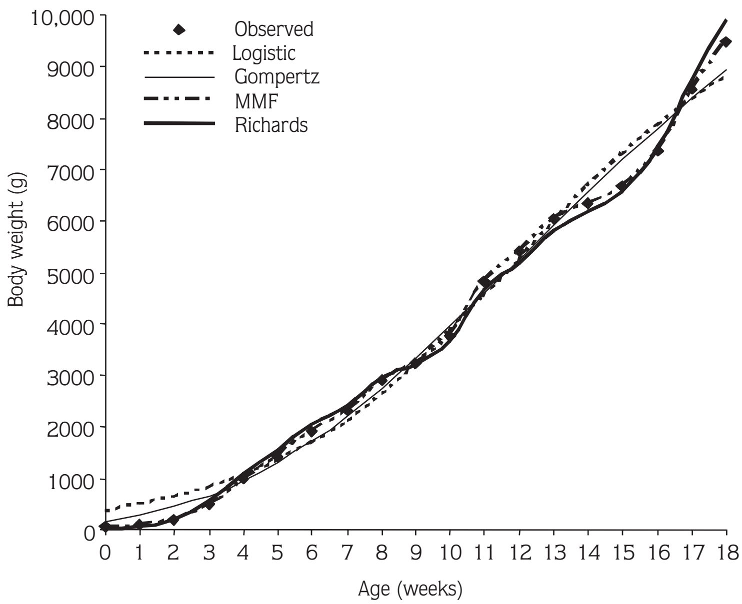

Figure 1. Growth curves of male turkeys.

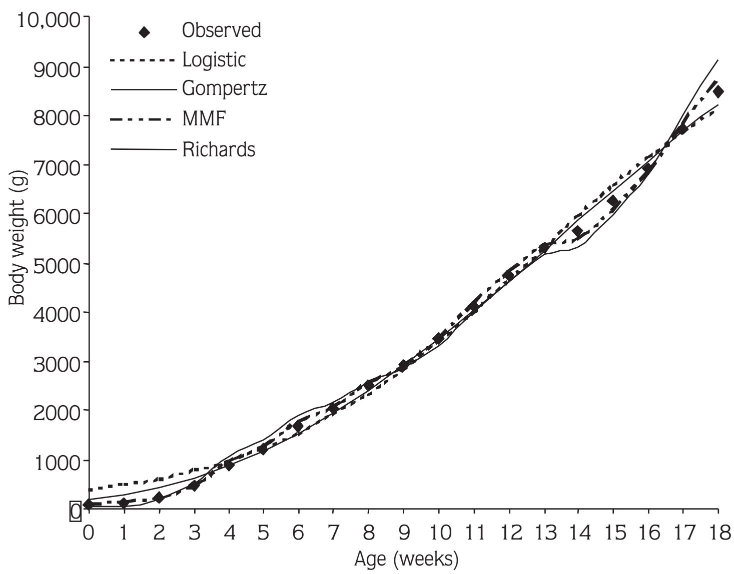

Figure 2. Growth curves of female turkeys.

(0.9975), Richards (0.9969) and Logistic model (0.9937) for females and males.

The model parameters shown in Table 1 were substituted into the formula to estimate live weights in each model for males and females as given in Tables 2 and 3, respectively.

Discussion

A parameters of Gompertz, Logistic, Richards and MMF models for male turkeys were estimated as 14,620.90, 10,468.42, 10,819.75 and 49.77, respectively. Likewise for female turkeys the A parameters of Gompertz, Logistic, Richards and MMF

Table 1. Coefficients of determination (R^2) and parameter values of non-linear models.

Model	Sex	Parameters				R^2	S_{yx}	DW
		A	B	C	D			
Gompertz	Male	14,620.90	-4.44	-0.12	-	0.9974	146.88	0.7328
	Female	15,157.56	-4.44	-0.11	-	0.9975	134.88	0.6242
Logistic	Male	10,468.42	26.89	-0.27	-	0.9933	244.79	0.4419
	Female	10,100.50	27.50	-0.26	-	0.9937	220.39	0.4025
MMF	Male	49.77	369.37	25,486.46	1.83	0.9993	125.69	1.0250
	Female	46.90	484.79	33,980.68	1.74	0.9993	109.21	0.9298
Richards	Male	10,819.75	-0.46	0.18	0.10	0.9969	258.88	0.5225
	Female	10,370.21	-0.56	0.17	0.09	0.9966	246.84	0.4706

DW: Durbin-Watson statistics ($P < 0.05$) S_{yx}: Error of prediction

Table 2. Observed and predicted (Pred.) body weights (BW), and residual values for non-linear models relating growth by age for male turkeys.

Age (weeks)	Observed mean BW (g)	Gompertz		Logistic		MMF		Richards	
		Pred.	Resd.	Pred.	Resd.	Pred.	Resd.	Pred.	Resd.
0	59	172	-113	375	-316	68	9	29	-30
1	114	287	-173	488	-375	110	-4	58	-56
2	250	451	-201	634	-383	207	-43	198	-52
3	526	673	-147	818	-293	497	-29	550	24
4	935	959	-24	1051	-116	976	41	1086	151
5	1352	1312	40	1341	11	1405	53	1548	196
6	1838	1732	107	1697	141	1915	77	2058	220
7	2284	2213	70	2125	159	2298	14	2407	123
8	2866	2750	116	2628	238	2913	47	2961	95
9	3320	3333	-13	3205	116	3242	-78	3213	-107
10	3878	3951	-74	3846	32	3756	-122	3649	-229
11	4725	4593	132	4536	189	4832	107	4662	-63
12	5322	5248	75	5251	72	5398	76	5190	-132
13	5951	5904	47	5965	-14	6024	73	5815	-136
14	6424	6554	-129	6653	-229	6337	-87	6169	-255
15	6897	7187	-290	7292	-394	6656	-241	6573	-324
16	7567	7799	-233	7865	-298	7376	-191	7422	-145
17	8454	8384	70	8365	89	8540	86	8759	305
18	9225	8938	287	8790	436	9486	261	9915	690

Pred.=Predicted value; Resd.=Residual value (observed minus predicted)

Table 3. Observed and predicted (Pred.) body weights (BW), and residual values for non-linear models relating growth by age for female turkeys.

Age (weeks)	Observed mean BW (g)	Gompertz		Logistic		MMF		Richards	
		Pred.	Resd.	Pred.	Resd.	Pred.	Resd.	Pred.	Resd.
0	59	178	-119	354	-295	71	12	29	-30
1	107	283	-176	456	-349	97	-10	49	-58
2	236	429	-193	584	-348	192	-44	187	-49
3	482	622	-140	746	-264	449	-33	502	20
4	877	868	9	949	-72	940	63	1045	168
5	1206	1169	37	1199	7	1246	40	1381	175
6	1658	1528	130	1505	153	1750	92	1885	227
7	2026	1941	85	1873	153	2045	19	2150	124
8	2515	2405	110	2306	209	2546	31	2596	81
9	2926	2914	12	2804	122	2861	-65	2840	-86
10	3468	3461	7	3365	103	3412	-56	3319	-149
11	4116	4038	78	3976	140	4154	38	4000	-116
12	4728	4635	93	4622	106	4808	80	4614	-114
13	5296	5245	51	5282	14	5360	64	5161	-135
14	5647	5859	-212	5935	-288	5469	-178	5303	-344
15	6239	6470	-231	6558	-319	6053	-186	5965	-274
16	6905	7071	-166	7135	-230	6782	-123	6818	-87
17	7708	7657	51	7653	55	7784	76	7989	281
18	8467	8222	245	8106	361	8699	232	9116	649

Pred.=Predicted value; Resd.=Residual value (observed minus predicted)

models were estimated as 15,157.56, 10,100.50, 10,370.21 and 46.90, respectively. The Gompertz model gives a higher estimate than other models for the A parameter. A parameter values only are higher in females than in males for the Gompertz model. Considering male and female turkeys the B parameters were found to be similar. However, parameters obtained with the other three models are different for male and female turkeys. This difference may be related to the sexual dimorphism on growth trend as reported for chickens (24). Differences between growth rates of male and female quails have also been observed (25).

Stephan et al. (8) have calculated the R^2 values for Logistic and Gompertz models for ad libitum fed broilers and they found 0.979 and 0.980 for the Logistic and Gompertz models, respectively. This research had higher values of R^2 for the Logistic and Gompertz models.

Knizetova et al. (10) used the Richards model for chickens and they found higher values of R^2 for males than those for females, which ranged from 0.9986 to 0.9995 and from 0.9972 to 0.9988, respectively. The lower values of R^2 in females could have been caused by high fat accumulation during the later stage of growth. One-year-old hens from the meat-type line fed ad libitum showed higher abdominal fat deposition, which represented 7.6% of live weight while it amounted to only 2.1% in cockerels. Knizetova et al. (11,12) have conducted research on ducks and geese. They determined the similar value of R^2 (0.9994) for both sexes in ducks. However, in geese they reported a higher R^2 value of 0.9901 for males than a value of 0.9880 for females. Therefore, with the exception of ducks, higher R^2 values were found for males than for females.

Many authors (3-13) found similar results using the models outlined in this study or different models. Models used here, in general, explain significant relationship between age and weight.

Errors are the differences between observed and expected values and they are assumed to be zero. Standard error (S_{xy}) the least prediction method gives a good indication of the adequacy of the model. Among ours, the MMF model has the lowest, followed by the Gompertz, Logistic, and Richards models. From this study we can say that the prediction obtained from MMF with the lowest expected errors outperforms the other models. In this paper males were found to have slightly higher S_{yx} values than females in all models studied.

Goodness-of-fit was determined by Durbin-Watson statistics. Durbin-Watson statistics show a positive autocorrelation for males and females in all models.

MMF model results, which had lowest prediction error and highest R^2 value, indicated that parameter A had no meaning explaining turkey growth. Gompertz seemed to be a better model explaining large white turkey regarding model selection criteria. Additionally the Logistic and Richards models performed well in this study.

The non-linear investigation of the growth process has some advantages in not only mathematically explaining of growth but also estimating the relationship between feed requirements and live weight, which plays a crucial role in animal husbandry. Furthermore, non-linear estimation techniques may contribute to determining of the economic information and marketing strategies in animal-based enterprises.

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