

COMPARISON OF THREE NONLINEAR MODELS TO DESCRIBE THE GROWTH CURVE OF HOLSTEIN-FRIESIAN BULLS RAISED UNDER EGYPTIAN CONDITIONS

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SUMMARY

The current study aimed to estimate the growth curve parameters through three non-linear models (Logistic, Gompertz and Richards) to determine which model best fits the data. Live weight records of 102 Holstein-Friesian bulls collected between 2017-2019 from a Holstein-Friesian herd that belongs to the Association of Livestock Development (EL- Lahhamy farm), located thirty kilometers west of Fayoum Governorate. In this work, the parameters of the studied models, asymptotic weight (A), constant of integration (b) and the maturation rate (K) ranged from 626.15 kg to 879.82 kg, 2.708 to 11.08, and 0.0035 to 0.008, respectively. According to the studied parameters of growth functions, Gompertz reached the highest numerical estimated value for (A) and the Logistic function had the lowest value. Parameter (K) estimate by the Gompertz model was similar to that obtained by the Richards model; both values were lower than those attained through the Logistic model (0.008). The inflectionpoint traits, time at Point of inflection (IPT) and weight at point of inflection (IPW) estimates ranged from 300.64 kg to 314.59 kg and 323.92 days to 336.14 days, respectively. The Richards model has the highest estimates of IPW and IPT compared to the other models, also it had the best adjustment according to model goodness of fit criteria, by having the lowest values for Akaike information criterion (AIC), Schwarz Bayesian information criterion (BIC), Mean square error (MSE) and highest coefficient of determination (R^2 , 0.14489, 0.14510, 0.31737 and 0.9983) followed by the Gompertz, and logistic functions.

Keywords: Growth curves, Gompertz, Richards, Logistic, Holstein-Friesian bulls

INTRODUCTION

Growth, a combination of hereditary and environmental factors, is an essential physiological process in animal production which can be defined as a relationship between live weight and age or an increase in body size per time unit (Lawrence and Fowler, 2002). The aggregating importance of the Holstein breed as a source of beef beside milk requires information about growth parameters (Calo *et al.*, 1973). Non-linear functions that relate the animal weights and ages have been primarily used in the study of the cattle growth curve (Souza *et al.*, 2010). Fitting of nonlinear models presents a chance for summarizing the information included in the whole sequence of weight-age points into a small set of parameters which can be interpreted from a biological point of view as (A) Asymptotic weight (b) is a scaling parameter related with initial body weight and (k) is the maturing rate. These parameters are eventually used to find other growth traits. Also, by investigating the relationship between parameter K and the asymptotic weight (A), the heaviest animals can be identified at younger ages (Freitas, 2005). Many studies conducted on non-linear equations indicated that the Richards model was the best to describe the growth curve of cattle (Selvaggi *et al.*, 2017 and Yin and König, 2020). Although Richards has more computational

difficulties as it is a four-parameter model, it was found to be the most suitable one due to its accuracy in predicting mature weight, which is considered an important selection goal (Selvaggi *et al.*, 2017). The Gompertz and logistic mathematical models were found among the most frequently used functions for describing cattle growth (Duarte, 1975 and Wada *et al.*, 1983). So, the present study aimed to compare the potential of three non-linear models (Logistic, Gompertz, and Richards) to detect which model best fits the data of Holstein bulls.

MATERIALS AND METHODS

Herd management:

Live weight records of 102 Holstein-Friesian bulls collected between the years 2017 and 2019 from a Holstein-Friesian herd cattle that belongs to The Association of Livestock Development (EL-Lahhamy farm), a dairy farm located about thirty kilometers west of Fayoum Governorate. Shaded open yards with a cool spraying system during the high atmospheric temperature were constructed for animal housing. Calves were weaned at the 3rd month of age. Three different rations were formulated and provided ad libitum to the bulls considering the average live weights obtained from the monthly weights. The three rations were as follows: (from weaning to 150kg), from 150 to 300kg

and from 300kg to the end) which contained of 19%, 16%, and 14% crude protein, respectively. The total digestible nutrients (TDN%) was 69 for all of them.

Statistical analysis:

Model parameters were analyzed using the procedure of nonlinear models (PROC NLIN) of

SAS software (SAS, 2011). Nonlinear functions used for the description of the growth curve were Gompertz, Richards, and Logistic to fit the Holstein-Friesian male growth curve. These functions are presented in Table (1).

Table 1. Non-linear functions used for modeling the growth curves and the inflection point traits formula for each as cited by (Selvaggi *et al.*, 2017)

Models	Functions formula
Gompertz	$W_t = A * \exp(-b * \exp(-k * t))$ (Gompertz 1825)
IPT	$\ln(b)/k$
IPW	A/e
Richards	$W_t = A * (1 + b * \exp(-k * t))^{-1/d}$ (Richards 1959)
IPT	$-1/k * \ln d/b $
IPW	$A/(d + 1)1/d$
Logistic	$W_t = A * (1 + b * \exp(-k * t))^{-1}$ (Verhulst 1838)
IPT	$\ln(b)/k$
IPW	$A/2$

W_t is body weight (BW, kg) of the animal at age t , day; (A) is predicted final weight or asymptotic weight, kg; (b) Constant of integration; (k) is growth parameter indicates the maturing rate; (d) is shape parameter in Richards model; e is the base of the natural logarithm ($\sim 2.71828...$); IPT: time at point of inflection; IPW: weight at point of inflection.

Goodness-of-fit criteria:

The goodness-of-fit criteria to compare the studied functions that explain the growth are as follows:

- Determination Coefficient, $R^2 = 1 - (SSE/SST)$
- Mean Square Error, $MSE = SSE / (n - k)$
- Akaike's Information Criteria, (AIC; Akaike 1973)
 $= n \cdot \ln(SSE/n) + 2k$
- Schwarz Bayesian Information Criterion, (BIC; Schwarz, 1978)
 $= n \cdot \ln(SSE/n) + k \cdot \ln(n)$

Where: SST the total sum of squares, SSE is the sum of square errors, n is the number of observations, and k the number of parameters. The best model should have the lowest values for AIC, BIC, MSE, and highest R^2 .

RESULTS AND DISCUSSION

Means \pm standard errors for observed live weight of Holstein-Friesian bulls are presented in Table 2. According to the data obtained, the averages of weight at birth and final live weight at 17 months of age were found to be 34.87 ± 0.84 kg and 580.00 ± 7.98 kg, respectively. As the animals get older, the standard error values for body weights become higher. Coefficient of variation (CV %) had the highest values at ages of 120, 150 and 180 days compared with other different ages.

In this study, the averages of live body weights are in agreement with the previous study of Tutkun (2019).

Table 2. Observed means and standard errors of Holstein bulls weights by age

Age (days)	Mean (kg)	SE	CV%
Birth	34.87	1.50	3.86
30	51.43	3.05	8.08
60	77.50	3.21	9.25
90	105.52	3.29	11.81
120	141.55	3.39	12.23
150	172.79	3.98	12.47
180	201.72	4.10	12.50
210	232.43	4.21	11.80
240	269.22	4.49	11.18
270	303.13	4.86	9.75
300	338.81	5.01	9.15
330	384.76	5.33	9.28
360	411.38	5.68	9.39
390	459.50	5.95	10.58
420	598.50	6.21	11.21
450	530.50	6.57	11.54
480	555.00	7.12	10.78
510	580.00	7.98	11.05

In this study, the parameters of studied models, A, b, and K ranged from 626.15 kg to 879.82 kg, 2.708 to 11.08, and 0.0035 to 0.008, respectively (Table 3). According to the studied growth functions, Gompertz reached the highest numerical estimated value for the asymptotic weight (A) and the Logistic function had the lowest value. Although the Gompertz model had the highest asymptotic weight value, the Richards model was the best to fit the data depending on the goodness of fit criteria and a similar trend was found by Selvaggi *et al.*, (2017). The estimated maturity rate parameter (K) by the Gompertz model was similar to that obtained by the Richards model; both values were lower than those attained through the Logistic model (0.008). The estimates of asymptotic weight (A) and maturity rate (K) in this work are in line with the previously reviewed studies with Holstein bulls. Velásquez *et al.* (2013) estimated the values of A and K (795 kg and 0.0047, respectively) for the Gompertz model. Furthermore, the values of asymptotic weight (A), the maturity rate (K), and the integration constant (b) as shown in (Table 3) did not considerably differ, compared with other studies with Holstein-Friesian bulls. Tutkun (2019) estimated A, K, and b values of 986.44, 0.004 and 3.354 for the Gompertz model and 1110.24, 0.003, 0.299 for the Richards model and 672.94, 0.008 and 13.76 for the Logistic model. There is an antagonistic genetic correlation between parameters A and K (Silva *et al.*,

2002). Several factors can affect estimates of growth parameters such as the mother's age (Silva *et al.*, 2002), season (Nuru *et al.*, 1981), year of birth (Quaas, 1983) in addition to mature weight and maturity rate (McLaren *et al.*, 1982). In this study, Parameters A and k showed a distinct converse relationship, where animals with heavier asymptotic weight (A) values presented the slowest maturity rate (k) values. On the other hand, animals that grew with fast maturity rates were lighter at maturity. Hence, there was an inversed relationship between mature weight and maturity rate (Bullock *et al.*, 1993 and Perotto *et al.*, 1994).

The IPT and IPW estimates of the Holstein-Friesian bulls are presented in Table 3. In this study, the parameters of studied models, IPT, and IPW estimates ranged from 300.64 to 314.59 and 323.92 to 336.14, respectively. The Richards model has the highest estimates of IPW and IPT compared to the other models. Tutkun (2019) calculated IPT and IPW estimates of 306.75 days and 362.89 kg for the Gompertz model, 400.14 days, 545.01 kg for the Richards model and 327.72 days and 336.47 kg for the Logistic model for Holstein-Friesian bulls. Regarding studied growth models, the inflection point estimates in this study were lower than those estimated by Tutkun (2019). The estimates of the growth function parameters are presented in Table 3.

Table 3. Estimated parameters and their standard error (\pm SE) of growth models and inflection point traits

Parameter	Gompertz	Richards	Logistic
A	879.82 \pm 2.78	660.18 \pm 6.85	626.15 \pm 1.03
B	3.33 \pm 0.01	2.708 \pm 0.001	11.08 \pm 0.08
K	0.004 \pm 0.0004	0.0035 \pm 0.0001	0.008 \pm 0.0005
D	-	1.092 \pm 0.048	-
IPT	300.74	314.59	300.64
IPW	323.92	336.14	328.07

SE: standard error, A: asymptote weight, b: scale parameter, k: relative growth rate, d: shape parameter, IPT: point of inflection time (days), and IPW: point of inflection weight (kg).

The goodness of fit for the different growth functions are presented in Table 4. Based on the goodness of fit criteria, the AIC, BIC, R², and MSE criteria can determine how well the models fit a database. The estimates for the three studied growth functions were equivalent and have considerably high and similar R² values (close to 1) which ranged from 0.9978 to 0.9983 indicating that all models had a good performance (fitting) in describing live weight changes related to age in Holstein-Friesian bulls. High R² estimates have been reported by many authors (Velásquez *et al.*, 2013, Koşkan and Özkaya, 2014 and Tutkun, 2019). According to model goodness of fit criteria, the Richards model had the best adjustment, having the lowest values for AIC, BIC, MSE, and highest R² 14489.18, 14510.6, 317.37, and 0.9983, respectively, followed by the Gompertz, and logistic functions (Table 4). Several studies reported that Richards model was the best for describing growth pattern in cattle (Tjørve and Tjørve, 2010; Velásquez *et al.*, 2013; Goldberg and

Ravagnolo, 2015; Gano *et al.*, 2016 and Tutkun, 2019). The logistic function was found to be the least accurate based on AIC and BIC (Forni *et al.*, 2009, Gano *et al.*, 2016 and Selvaggi *et al.*, 2017). The estimates of AIC and BIC showed wide range reported by many authors (42.05 to 201857 and 41.43 to 201889, respectively) for the Gompertz model (Velásquez *et al.*, 2013, Goldberg and Ravagnolo, 2015 and Gano *et al.*, 2016) ranging from 183379 to 189150 and 183560 to 189189, respectively for Richards model and ranging from 184623 to 206277 and 184749 to 206309, respectively for Logistic model (Goldberg and Ravagnolo, 2015 and Gano *et al.*, 2016).

The tested models showed a very similar trend regarding their ability to fit throughout the study periods (Figure 1). The difference between actual and predicted values was very similar among the evaluated models (Figure 1), indicating that the observed weight of the animal was identical to predicted by the models through the time

Table 4. The goodness of fit criteria for fitted growth functions

Criterion	Growth functions		
	Gompertz	Richards	Logistic
R ²	0.9981	0.9983	0.9978
MSE	355.05	317.37	336.12
AIC	14548.78	14489.18	14553.63
BIC	14570.21	14510.60	14580.41

R²:coefficient of determination, MSE: mean square error, AIC: Akaike information criterion, and BIC: Schwarz Bayesian information criterion.

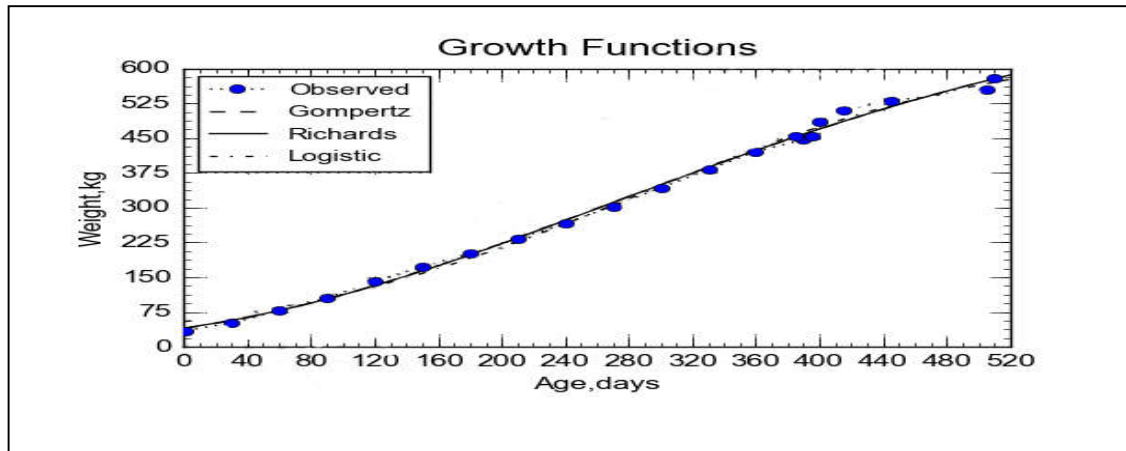


Figure 1. Growth curves of Holstein-Friesian bulls according to logistic, Gompertz, and Richards models in comparison to the observed data.

CONCLUSION

According to model goodness of fit criteria, the Richards model was the best to fit the data of Holstein-Friesian bulls by having the lowest values for (AIC), (BIC), (MSE), and highest value for (R²) followed by the Gompertz, and logistic functions.

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مقارنة ثلاثة نماذج غير خطية لوصف منحنى النمو لذكور الفريزيان المرباة تحت الظروف المصرية

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هدفت الدراسة الحالية إلى تقدير معاملات منحنى النمو من خلال ثلاثة نماذج غير خطية (لوجستية، جومبيرتز وريتشاردز) لتحديد النموذج الأنسب لتمثيل البيانات. تم استخدام سجلات وزن حي لـ ١٠٢ ثور هولشتاين-فريزيان تم جمعها بين عامي ٢٠١٧ و ٢٠١٩ من قطع هولشتاين-فريزيان ينتمي إلى جمعية تنمية الثروة الحيوانية (مزرعة ألبان اللحامي) تقع على بعد حوالي ثلاثين كيلومترًا غرب محافظة الفيوم. في هذا البحث تراوحت معاملات النماذج المدروسة والوزن المقارب (A) وثابت التكامل (b) ومعدل النضج (K) من ٦٢٦.١٥ كجم إلى ٨٧٩.٨٢ كجم ومن ٢.٧٠٨ إلى ١١.٠٨ ومن ٠.٠٠٣٥ إلى ٠.٠٠٨ على التوالي. وفقًا لمعايير نماذج النمو المدروسة، وصلت Gompertz إلى أعلى قيمة تقديرية رقمية لـ (A) وكانت للدالة اللوجستية أقل قيمة. كان تقدير القيمة (K) بواسطة نموذج Gompertz مشابهًا لتلك التي حصل عليها نموذج Richards؛ كلا القيمتين كانت أقل من تلك التي تم الحصول عليها من خلال النموذج اللوجستي (٠.٠٠٨). تراوحت تقديرات صفات نقطة الانقلاب حيث تراوح الوقت عند نقطة الانقلاب (IPT) والوزن عند نقطة الانقلاب (IPW) من ٣٠٠.٦٤ كجم إلى ٣١٤.٥٩ كجم و ٣٢٣.٩٢ يومًا إلى ٣٣٦.١٤ يومًا على التوالي. يحتوي نموذج ريتشاردز على أعلى تقديرات IPW و IPT مقارنة بالنماذج الأخرى، كما أنه كان لديه أفضل تطابق وفقًا لمعايير ملاءمة النموذج، من خلال الحصول على أدنى قيم (AIC)، (BIC)، متوسط الخطأ التربيعي (MSE) والأعلى في معامل التحديد: {0.9983 (R2)، 14489.18، 14510.6، 317.37 and 0.9983 (R2)}، على التوالي، تليها دالة Gompertz، والدالة اللوجستية.