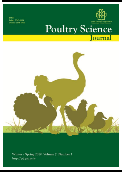

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Comparison of Some Nonlinear Functions for Describing Broiler Growth Curves of Cobb500 Strain

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Abstract

This study was conducted to compare some nonlinear functions to describe the broiler growth curve of the Cobb500 strain. A flock of fifty one-day-old chicks were randomly selected from a henhouse of 2500 chicks. Our goal was to establish a growth curve using weighting data using mathematical solutions of time-dependent differential functions. In total, six equations were subjected to a statistical calibration by a sequential quadratic programming under the non-linear regression procedure of the SPSS program. The results showed that the heterogeneity rate between individuals of the same batch increases with the age of the chicks, from more than 10% an early age to less than 30% at the slaughter age. The goodness of fit for six dynamic models showed that the number of iterations required increases with the number of parameters of the model. However, the three parameter models were the best model for describing growth curve (the greatest efficiencies and the lowest error components). The asymptomatic values (3500g to 7500g) and their estimation errors (2% to 12%) are relatively acceptable for the three-parameter models compared to those of four parameters (more than 8000g and up to 100% error). Finally, the comparison between actual and predicted values by models shows that the Gompertz model was the most suitable till up to the four weeks of age. After 1 month of age, the Gompertz has a lower precision and the logistics, Von Bertalonffy and WLS models accurately described the growth curve.

Introduction

Poultry is the animal production sector, which has recorded the most remarkable development in Algeria in recent years. For the poultry meat industry, production levels reached more than 300 thousand tons per year with a turnover of 160 billion dinars (1.4 billion dollars). This represents an important part of the national agricultural wealth, providing income in return to large segments of the population. According to industry professionals, this sector employs about 350,000 peoples (Mahmoudi *et al.*, 2015). The cost price of poultry meat is 80% related to the cost of food. Algeria imports the crop materials for the manufacture of poultry feed, corn and soybeans, whose import value is in the order of 1.08 billion US dollars, or 13% of the total of Algerian agro-food imports, estimated at 8.6 billion dollars (CNIS, 2011; Kaci and Cheriet, 2013).

The broiler industry often works with birds that serve two purposes: fast growth with optimal weight in the shortest time and better carcass quality (Al-Samarai, 2015; Prince, 2002). Several livestock studies have been interested in the analysis of the growth curve. These practical applications help breeders to improve breeding conditions and increase production levels and consequently farm incomes (Abbas *et al.*, 2014). To correctly predict the different effects of nutrients on quantitative traits such as weight, level of consumption and feed conversion efficiency; the adoption of adequate models was the concern of several poultry nutrition researchers'

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(Cangar *et al*., 2006; Simiz *et al*., 2013). Mathematical models derived from the resolution of time-dependent differential equations are often used to describe body weight growth (Fatten, 2015). In broiler chicken, the literature reports several functions derived from differential equations such as Gompertz, Richards, Logistic, Weibull, Von Bertalanffy, Logistic, Exponential, and others type models (Yang *et al*., 2006; Topal and Bolukbasi, 2008; Eleroglu *et al*., 2014; Moharrery and Mirzaei, 2014; Mohammed, 2015; Narinç *et al.,* 2017).

Broiler breeders aim, through the use of mathematical models, to obtain optimal growth rates by sex and strain and to estimate the body composition of birds. Thus, mathematical models are also used to estimate the nutritional requirements of birds and help to reduce production costs by rationalizing the use of food and defining the optimal market age (Marcato *et al.,* 2008). In fact, the cumulative consumption of food from birth to slaughter, which is an index of economic efficiency, often depends on growth rates but also on the shape of the growth curves (Knitztova *et al.,* 1995).

The objective of the present study was to choose the optimal nonlinear function to describe the growth curve of Cobb500 broilers under the Algerian farming conditions.

Materials and Methods

Experimental birds and management

This experiment, conducted in 2017, involved 50 chicks randomly selected from a henhouse of 2500 one-day-old chicks in the province of Mila in eastern of Algeria. Firstly, chicks are isolated by a fence and identified by the tights numbered on the feet. Indeed, chicks are raised on the ground, on mulched litter in buildings with windows, whose ventilation is static. Feeding was provided by two types of foods presented in the form of flour according to the periods of growth (Table 1). Feed and water were distributed ad libitum but the consumed values were estimated. The chicks were weighed individually once a week at a fixed time as mentioned by Barbato (1991) from the first day to 49 days (slaughter age) using an electronic scale.

Table 1. Composition of starter, grower and finisher diet

Ingredients	Starter	Grower	Finisher
Yellow Corn (%)	59.3	62.6	67.1
Soybean meal (%)	35.2	32.0	27.5
Wheat Bran (%)	2.3	2.5	2.5
Total Phosphorus (%)	1.7	1.7	1.4
$CaCO_3$ (%)	1.2	0.8	0.7
Premix (%)	0.25	0.25	0.25
Calculated Composition			
Energy Kcal EM/kg	2870	2960	3043
Crude Protein	20.8	19.4	17.7
Crude Cellulose	3.9	3.8	3.7
Methio&Cyst (%)	0.85	0.8	0.7
Lysine (%)	1.13	1.01	0.9
P (%)	0.66	0.64	0.58
Ca (%)	1.04	0.98	0.91
Vit A	12500	12500	12500
Vit D3	2000	2000	2000
Vit E	20	20	15

Broiler were divided into three groups depending on the slaughter weight (Table 2); Light class whose average weight is less than 2.5 kg; Middle class with a weight between 2.5 and 3kg and at the end the heavy class where the average weight is greater than 3kg. Indeed, the retrospective study shows that the difference in weight between classes was significant (P < 0.001) as early as the 2nd week of age.

Table 2. Chicken class by slaughter weight

		Weight (g)				
		N	%	Min	Mean	Max
Categories	Light Broiler (<=2500g)	7	14.6	2128	2326^{a}	2500
	Moderate Broiler (2500-3000g)	23	47.9	2568	2774^{b}	2990
	Heavy Broiler (>3000g)	18	37.5	3002	3442^{c}	4220

Different letters indicates a significant difference at P < 0.001 (LSD test)

Mathematical models

In total, 6 models were selected and fitted on chicks' growth. The models classified into 2 groups; those with 3 and 4 parameters (Table 3). The "non-linear regression" procedure of the SPSS 23 software (IMB Corp, 2015) was used to estimate the parameters. The number of iterations has not been set. The calculation stops after the stability of the set of parameters. The models are compared using the criteria described in Table 4.

Table 3. Mathematical equations of growth curve models

Type of model	Model	Equation
Model with 3 parameters	Gompertz	$BW_t = a * e^{-b*e^{-k*t}}$
	Logistique	$BW_t = \frac{a}{1 + b * e^{-k*t}}$
	VonBertalonffy	$BW_t = a * (1 - b * e^{-k*t})^3$
	WLS	$BW_t = \frac{a}{1 + e^{-b-k*t}}$
Model with 4 parameters	Richard	$BW_t = a * (1 + b * e^{-k*t})^{\frac{-1}{n}}$
	Weibull	$BW_t = a - b * e^{-k*t^d}$

WLS: Weighted Least Square; BW_t: the recorded body weight at age t; a: asymptote or mature weight; b: shape parameter; k: coefficient of relative growth.

Table 4. The goodness of fit Criteria for Growth Models

Type	Criteria	Mathematical Expression
Efficiency	Efficiency	$R^2 = 1 - \frac{SS_{res}}{SS_t}$
Residuel componets	MSE	$MSE = \frac{SS_r}{n-k}$
	RMSE	$RMSE = \sqrt{MSE} = \sqrt{\frac{SS_r}{n-k}}$
	MAE	$MAE = \frac{\sum\lvert y_i - \hat{y}_i\rvert}{n}$
	AIC	$AIC = nlog(MSE) + 2k$

MSE: Mean square error; RMSE: Root Mean square error; MAE: Mean Absolute Error; AIC: Akaike information criteria; SS: sum of square; n: sample size; k: number of parameters.

Results and Discussion

Description of the study flock

In the studied flock, total average consumption of 7 kg of food was obtained per producing about 3 kg of meat; therefore, the mean feed conversation rate was estimated at 2.4 kg. That is similar to other results in similar conditions (Attou and Hamrani, 2017). There was a continuous increase in the amount of feed consumption per day, so that it varied from 25 g on starting to more than 250 g in finishing. However, the highest consumption index is recorded during the growth period (Table 5).

Table 5. Consumption feed, weight of chickens and Feed consumption rate in the 3 periods of rearing

	Starter (1-12 d)	Grower (12-36 d)	Finisher (36-49 d)	Total period
CQ (g)	300	3000	3600	6900
DCQ (g/d)	25	125	257	140,8
AW (g)	184	1277	2739	2959
FCR	2,24	2,74	2,46	2,37

CQ: Consumed Quantities; DCQ: daily Consumed Quantities; AW: Average Weight; FCR: Feed Conversion Rate

The homogeneity of a flock characterizes the level of production through the absence of the phenomena of competition on the distributed food. The average rate of weight flock homogeneity reported in the literature was about 80%. This rate indicates that more than 80% has a weight range in the mean ± 10%. The homogeneity of the chicks was very high at begin of experiment (> 90%), relatively moderate (70-80%) during the start-up period and lower during the growing period (60-70%). This can be explained by the difference in growth between sexes as a flock is a mixture of males and females.

Evolution of the weight and growth level of chicks

The results of the weight change are shown in the figure 1. The weight of the chicks increases in a continuous manner, the pace of which is of the sigmoid type. The difference between categories begins to appear on the 2nd week and is accentuated with age. About 50% of heavy and medium chicks reach to 1kg at the 3rd week of age; while light chicks were obtaining this weight at the 4th week (Figure 2).

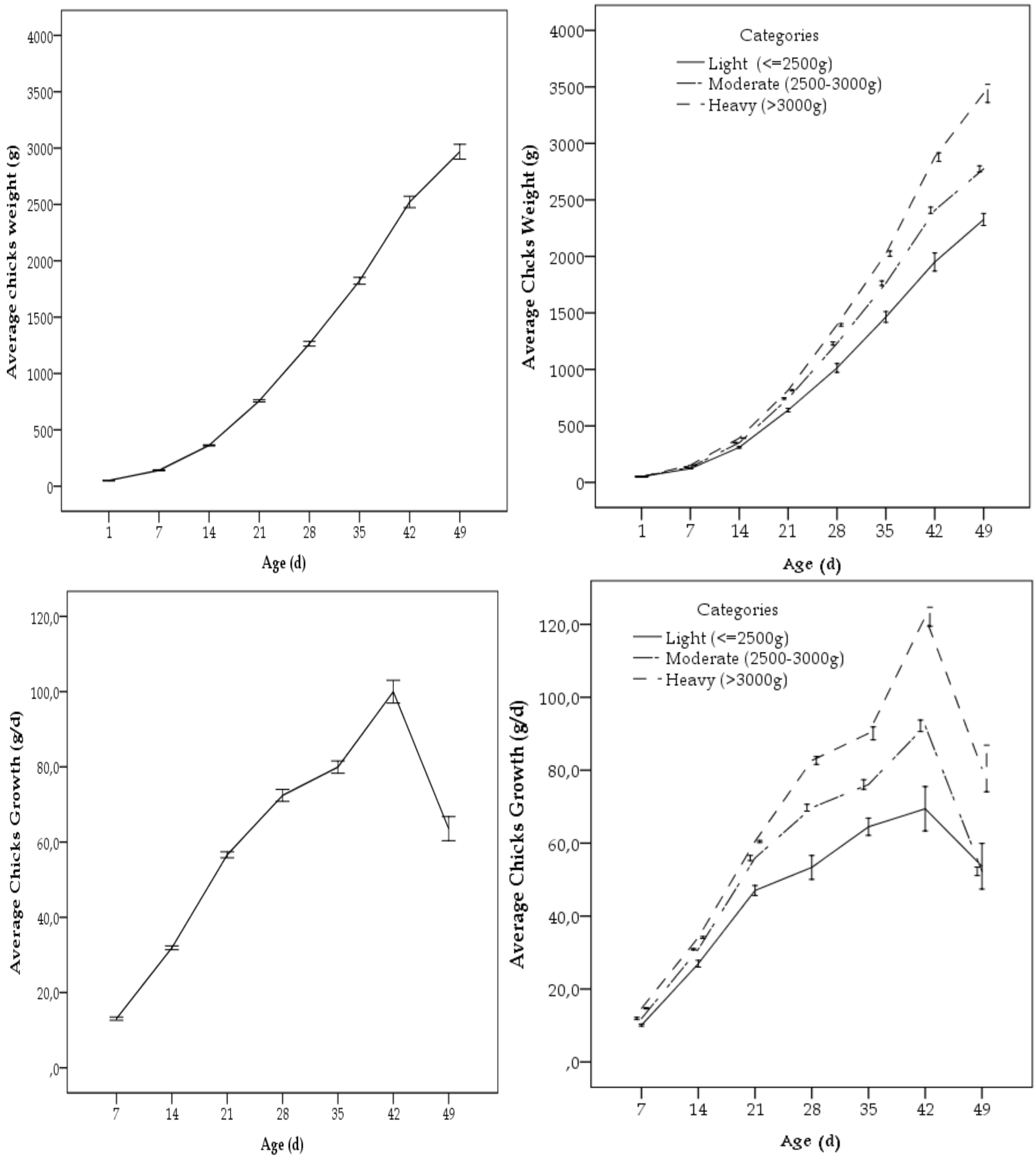

Figure 1. Weight (g) and growth (g/d) of Broiler chicks

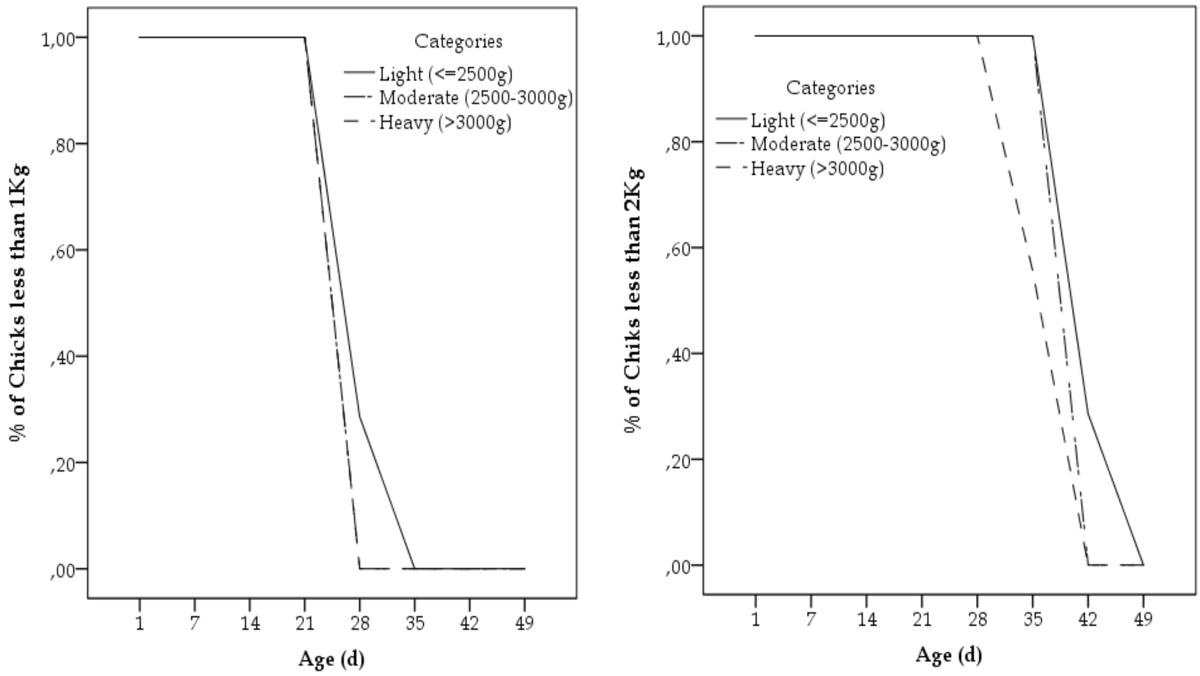

Figure 2. Proportion of broiler less than 1 and 2kg of all categories of chicks

Table 6. Estimated parameters of all models in all, Light, moderate and heavy broiler

Type	Model	Parameter	all		Light Broiler		Moderate Broiler		Heavy Broiler	
			Estimate	SE	Estimate	SE	Estimate	SE	Estimate	ES
Models with 3 parameters	Gompertz	Iteration	19		13		18		23	
		a (g)	5018.3	336.1	3948.4	406.7	4367.7	143.7	6375.9	442.9
		b	5.045	0.197	4.739	0.256	5.056	0.123	5.163	0.171
		k	0.046	0.003	0.045	0.005	0.050	0.002	0.044	0.003
	Logistique	Iteration	23		20		24		27	
		a (g)	3527.6	101.2	2774.4	127.7	3226.7	48.5	4228.1	120.7
		b	38.83	3.39	32.98	4.20	37.59	1.96	42.24	3.30
		k	0.108	0.004	0.104	0.006	0.111	0.002	0.107	0.004
	VonBertalonfy	Iteration	28		22		25		37	
		a (g)	7423.3	937.5	5830.4	1129.7	5957.7	363.8	10371.9	1478.9
		b	0.903	0.022	0.874	0.028	0.9140	0.016	0.907	0.018
		k	0.025	0.003	0.025	0.004	0.029	0.002	0.022	0.002
	WLS	Iteration	14		15		12		15	
		a (g)	3527.6	101.2	2774.4	127.7	3226.7	48.46	4228.1	120.7
		b	-3.66	0.087	-3.50	0.127	-3.63	0.052	-3.74	0.078
		k	0.108	0.004	0.104	0.006	0.111	0.002	0.107	0.004
Models with 4 parameters	Ritchard	Iteration	50		50		50		50	
		a (g)	4067.6	430.2	3279.1	588.5	3643.1	179.8	4564.5	403.7
		b	4.56	5.48	2.91	5.86	4.63	2.97	12.43	12.79
		k	0.072	0.017	0.065	0.025	0.075	0.009	0.085	0.018
		n	0.406	0.267	0.330	0.406	0.409	0.144	0.641	0.278
	Weibull	Iteration	50		50		50		50	
		a (g)	7978.6	3392.5	8011.8	8077.7	7368.8	1945.9	8021.1	2370.2
		b	7949.0	3407.2	7988.1	8097.5	7331.6	1955.0	7978.7	2384.5
		k	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		d	1.850	0.150	1.712	0.234	0.095	0.095	1.998	0.139

WLS: Weighted Least Square; a: asymptote or mature weight; b: shape parameter; k: coefficient of relative growth.

Chick growth was relatively low at first's days of age (13 ± 2g), increased during start-up and growth period, and reached to peak at 6th week of age (100 ± 21g). After, daily growth rate declined significantly (reduction of 37%). Fernandes *et al.*, (2013), report that the maximum growth potential for Cobb500 and

Ross (308 and 508) was between 33 and 35 days independently from the sex. The same rate with different levels was observed in the different categories of chicken. The peak always was on the 42nd day, the values of which are at 69g, 92g and 112g respectively for light, moderate and heavy chickens (Figure 1). Relative growth was greater at start-up (91 ± 6g/kg) and continued regression until slaughter age (21 ± 5g/kg) with fewer differences between categories (5 to 10g).

Broiler Growth Modeling

Parameter Estimation

The results of the estimated parameter are shown in Table 6. For three-parameter models, we find that the number of iterations required for the stability of the parameters varies between 12 and 37. The lowest iteration was for the WLS model and the light chicks. However, the number of iterations increases using the Von Bertalonffy model in heavy broiler. In fact, the Gompertz and Von Bertalonffy models show higher asymptomatic values (5000g and 7500g respectively) compared with the logistic and WLS models whose estimated acceptable values (3500g).

The error of estimated parameter varied from 2.4% to 12.5% of the mean value of the parameter. Only the WLS model has low errors (<3% for all parameters). For the other models, we find high values for at least one parameter (SE: 7% - 12%). According to the final weight, estimation errors for all parameters are higher for heavy and light chickens (14% and 20% respectively) and reduced for moderate-weight broilers (<5% for all parameters).

However, the increase in the number of parameters is often accompanied by an increase in the number of iterations necessary for the stability of the parameters (> 50 iterations per model). The two models are characterized by a relatively high asymptomatic value (8000 g for the Weibull model) and very high estimation errors that exceed 100% of the mean value for several parameters.

Evaluation of goodness of fit for mathematical models

After the parameters are estimated, the models compared to several evaluation methods. A model is considered the best model if it has higher efficiency and low error components. The adjustment values for the models are summarized in Tables 7 and 8. Indeed, we note that the efficiencies are relatively high (> 95%) and identical for all the models. According to the final weight of broiler, higher efficiencies were observed in broiler with moderate final weight (0.99). The residual components analysis shows that the values are also comparable between models, but a superiority of the chickens with average final weight is also observed (RMSE <90 for all the models).

Table 7. The goodness of fit criteria for the 3 parameter models in all, and three classes

Type	Model	Parameter	all	Light Broiler	Moderate Broiler	Heavy Broiler
Models with 3 parameters	Gompertz	R^2	0.954	0.985	0.993	0.987
		MSE	51 645.2	10 665.6	7 131.0	19 915.6
		RMSE	227.3	103.3	84.4	141.1
		MAE	128.18	62.86	56.03	72.55
		AIC	81.96	70.92	68.11	75.29
	Logistique	R^2	0.954	0.983	0.992	0.986
		MSE	52 181.2	11 425.4	7 445.8	20 557.2
		RMSE	228.4	106.9	86.3	143.4
		MAE	140.23	74.13	65.65	91.24
		AIC	82.04	71.41	68.41	75.52
	Von Bertalonfy	R^2	0.954	0.984	0.992	0.986
		MSE	52 420.8	10 989.6	7 992.2	20 840.0
		RMSE	228.9	104.8	89.4	144.4
		MAE	136.69	175.11	90.27	91.78
		AIC	82.07	71.13	68.90	75.61
	WLS	R^2	0.954	0.983	0.992	0.986
		MSE	52 181.2	11 425.4	7 445.8	20 557.2
		RMSE	228.9	106.9	86.3	143.4
		MAE	140.23	74.13	65.65	91.24
		AIC	82.04	71.41	68.41	75.52

WLS: Weighted Least Square; R^2: Efficiency coefficient; MSE: Mean square error; RMSE: Root Mean square error; MAE: Mean Absolute Error; AIC: Akaike information criteria.

Table 8. The goodness of fit criteria for the 4 parameter models in all, and three classes

Type	Model	Parameter	all	Light Broiler	Moderate Broiler	Heavy Broiler
Models with 4 parameters	Ritchard	R^2	0.954	0.984	0.993	0.987
		MSE	51 658.0	10 935.7	6 947.8	20 148.6
		RMSE	227.3	104.6	83.4	141.9
		MAE	67.68	251.63	70.43	162.68
		AIC	83.97	73.09	69.92	77.38
	Weibull	R^2	0.953	0.983	0.991	0.986
		MSE	53 076.6	11 637.5	9 179.4	20 877.1
		RMSE	230.4	107.9	95.8	144.5
		MAE	135.18	68.35	64.41	79.65
		AIC	84.15	73.53	71.87	77.62

R^2: Efficiency coefficient; MSE: Mean square error; RMSE: Root Mean square error; MAE: Mean Absolute Error; AIC: Akaike information criteria.

Comparison of models

Results shows that the Gompertz model was the most calibrated to estimate the weight of chicken Cobb500, according to the evaluation criteria (Figure 3). The Weibull model gives the wrong estimate of the weight of the light and medium chicken. For heavy chicken, the Richard model was not suitable (Figure 4).

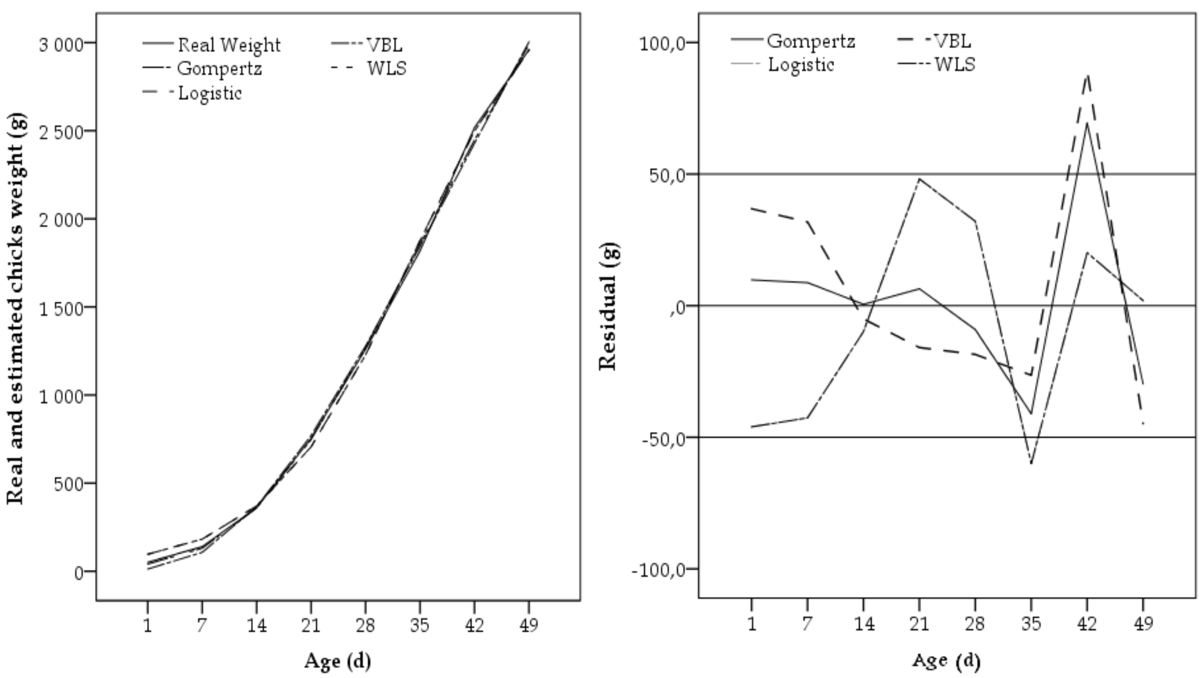

Figure 3. Estimated weight and residual of models with three parameters

The comparison between Real and estimated values shows that before the four weeks of age, the Gompertz model is the most suitable, and the residual average is relatively low (<10 g). After 1 month of age, the Gompertz loses its precision and logistics, Von Bertalonffy and the WLS became relatively more explanatory of the overall shape (Figure 5). Indeed, the results of Zhao *et al.,* (2015) indicate that several nonlinear mathematical models can be adjusted to predict growth and describe the shape of the curve, the fitness exceeded 0.99, but the Gompterz model remains the most suitable because it displays a relatively low bias and a high fitness in all ages.

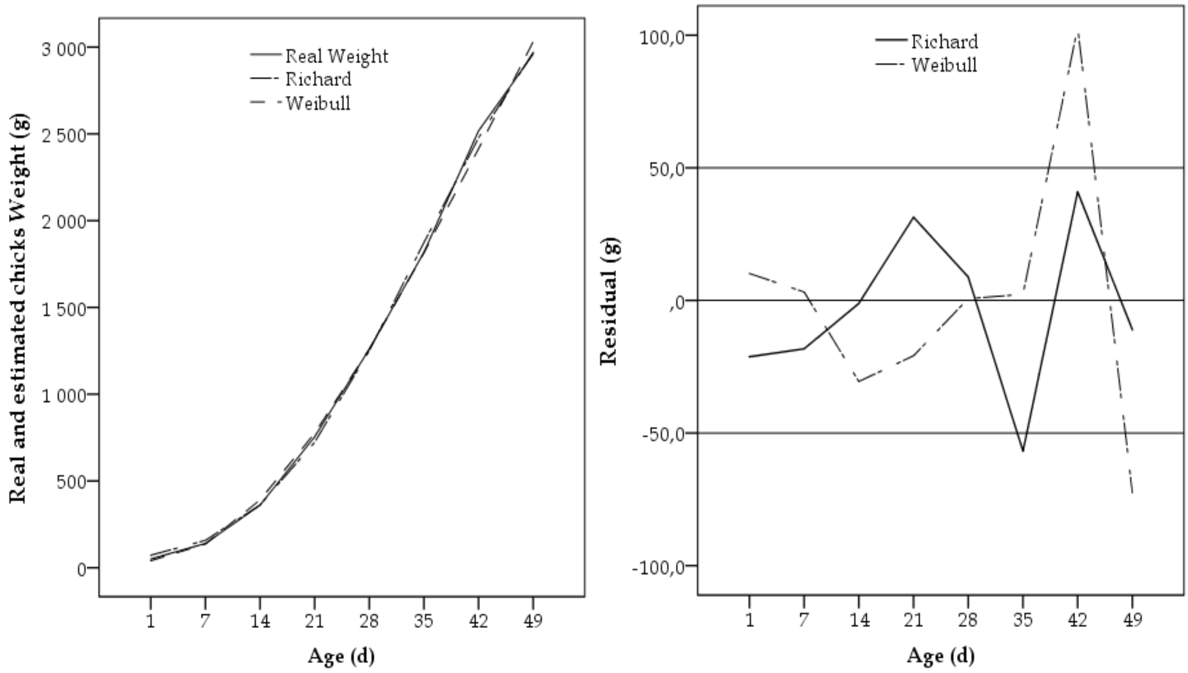

Figure 4. Estimated weight and residual of models with three parameters

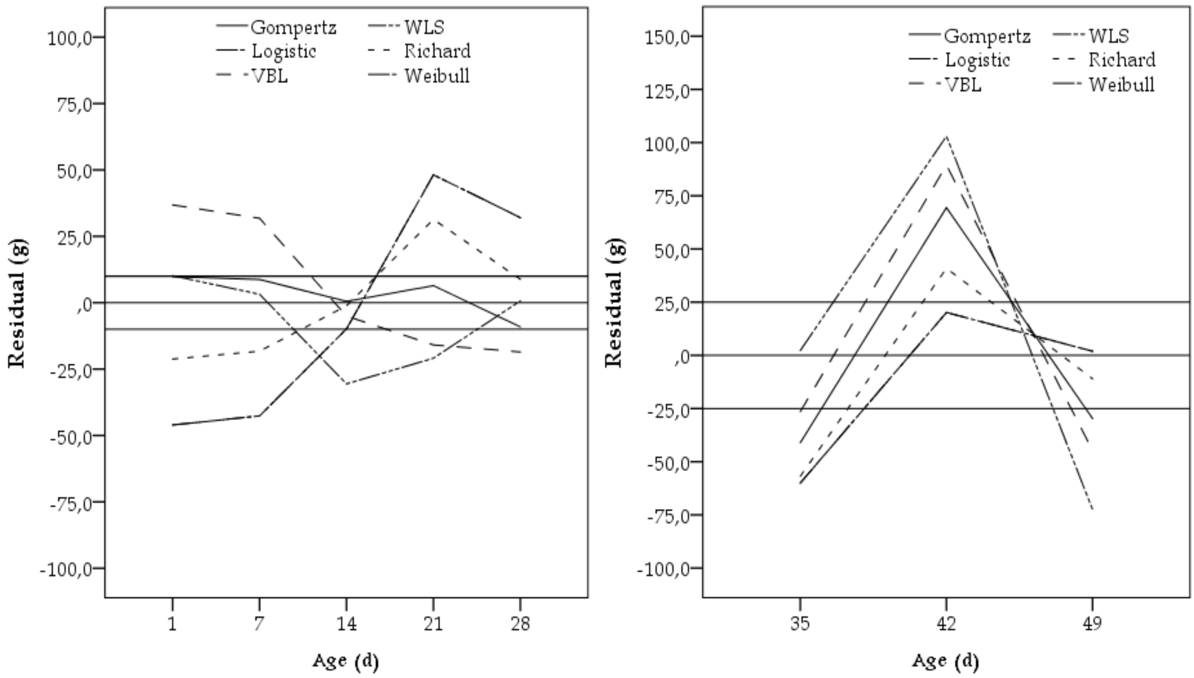

Figure 5. Residual of all models before and after one month of age

However, Raji *et al.* (2014) found that the Gompertz model is not suitable for early age (0 to 6 weeks) in Japanese quail, because differences between the observed weights and those predicted by the model are noted. On the other hand, Atil *et al.*, (2007) showed that Logistic model gave more biologically appropriate results compared with Von Bertalanffy and Gompertz.

The data collected from zootechnical monitoring of the weight and growth of chickens of Cobb500 strain showed relatively moderate performances compared to those reported by the breeding guide (Cobb500 guide, 2012). This shows a low mastery of broiler breeding in our conditions. The differences in weight and growth are clearly evident on the 7th day of breeding (Figure 6).

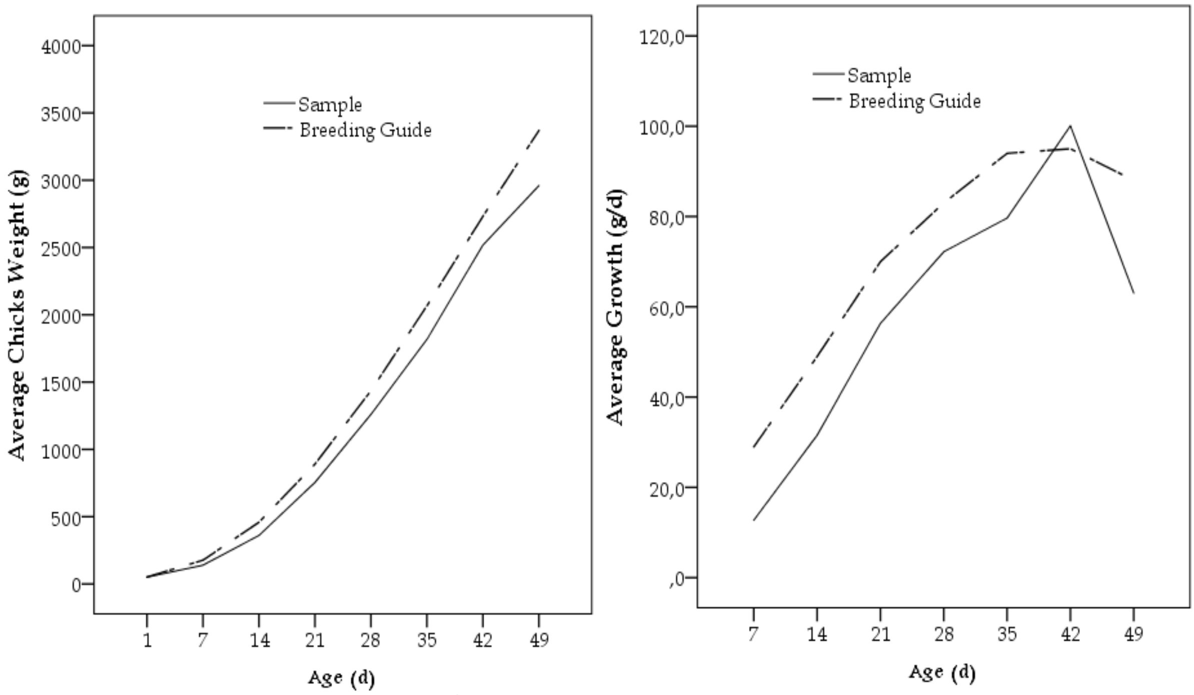

Figure 6. Weight and growth of sample broiler chicks compared with breeding guide curve

In fact, a good start during the first phase of chick breeding was a key element to the success of the whole breeding period. Our results are similar to those reported by other authors under similar conditions (Fatten, 2015). It should also be noted a relatively moderate homogeneity (60-70%) of this lot according to the recommendations of the breeding guide. This problem is observed very early at 14th days which lead to this significant variability of weight and growth. To this purpose, it was advisable to intervene in time and increase the number of feeders to minimize the negative effects of strong competition between individuals. Mathematical modeling established an unquestionable aspect in the search for solutions of the problems of breeding. The results obtained show that several equations can be used to describe the growth curve. The values of the parameters and their estimated errors are more or less different from those of the bibliography (Sekeroğlu *et al.,* 2013; Fatten, 2015; Al-Samarai, 2015). For 3-parameter models, values of 3000 g to 7000 g are reported in the bibliography (Ahmadi and Goliane, 2008; Moula *et al.,* 2009; Rizzi *et al.,* 2013). Eleroglu *et al.,* (2014) report difference on asymptotic values (3700g to 6400g) between sex and strains. Range of 2% to 10% for estimated parameter errors was also comparable to several study results (Rizzi *et al.,* 2013; Eleroglu *et al.,* 2014). For 4 parameters models, errors of estimated parameters were very high for at least one of the parameters. However, other investigators (Sengül and Küraz, 2005) report low errors in estimating the parameters of the Richard model. For Italian local chicken populations, Rizzi *et al.,* (2013) report that to obtain a good fit of the asymptotic weight for the Richards model, it is necessary to carry out a measurement of body weight at 90 days of age or more. However, the advantage of Gompertz model that his presented with one less parameter than the Richard model. Our results showed that the logistic equation showed an overestimation of initial BW for all the groups and sex. The analysis of the evaluation criteria shows a very high efficiency (> 95%), indicating the relative mastery of industrial chicken farming compared to that of ruminants where the recorded efficiency is always less than 85% (Nešetřilová, 2005; Roush *et al.,* 2006; Marinho *et al.,* 2013). It is also noted that this evaluation criterion depends on the category of chicken. Thus, for the model to be clearly effective, it is necessary that it is applied to all categories.

Conclusion

In the present study, several functions have been fitted by adjusting the different parameters. Each of the equations has advantages and disadvantages with respect to the efficiency results and other goodness of fit criteria. The growth functions selected were logistics (WLS), Gompertz and Von Bertalonffy. Based on criteria to measure the quality of the fit, the results of this study showed that Gompertz function was appropriate for estimating broiler weight early before four weeks of age and that the WLS model was effective later after a month of age. However, the Gompertz model is adapted to predict the body weight of chickens at early age in any category. Then, after one month of age, the Von Bertalonffy model is the best predictor of the weights of light chickens while the WLS model is better suited for moderate and heavy chickens. Finally, we can conclude also that some models with good efficiency can be hindered by high estimation errors (Richard and Weibull's case). The multiplication of criteria allowed us to make a reasoned choice of the standard model of growth for a species, strain or others.

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