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RESEARCH PAPER

Analysis of growth curves of Guinea fowl (*Numida meleagris*) fed diets containing dry oregano (*Origanum vulgare* L.) in an organic system

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Abstract

H. Eleroğlu, A. Yıldırım, A. Canikli, M. Duman, and H. Bircan. 2018. Analysis of growth curves of Guinea fowl (*Numidea meleagris*) fed diets containing dry oregano (*Origanum vulgare* L.) in an organic system. Cien. Inv. Agr. 45(2): 99-108. In this study, 240 day-old guinea fowl (*Numida meleagris*) keets were utilized. They were divided into four treatment groups each containing 20 chicks and were randomly distributed into 12 mobile coops placed in a 100-m^2 grazing area. Guinea fowl chicks were randomly allocated to 4 treatment diets containing 0%, 5%, 10%, and 15% dry oregano leaf (DOL) supplements. Nonlinear Gompertz and logistic growth models were used to estimate the mean age-body weight. The growth curve parameters for these models and the following characteristics for fowl were estimated: β_0, the asymptotic weight parameter; β_1, the scaling parameter; β_2, the instantaneous per week growth rate; weight at age of inflection point (WIP); maximum weight gain at inflection point (MWG); and age at the inflection point (AIP). The goodness of fit (GF) for the models was assessed using the following variables: coefficients of determination (r^2), mean square error (MSE), adjusted determination coefficient (ADR^2), Akaike's information criteria (AIC), chi-square test ($Chi.Sq^2$) and residual standard deviation (RSD). The different nonlinear function results of the individual data indicated that supplementation of diets with DOL had no significant effects on growth curve parameters when compared with the control diet. Greater correlation values were estimated among β_0, β_1, β_2, WIP, MWG and AIP in the Gompertz equation, and similar results were estimated in the logistic equation, but there was no significant correlation between β_2-β_1 and β_2-MWG. According to the results obtained from the GF, high r^2 and ADR^2 were estimated in Gompertz and logistic equations (above 0.96).

Key words: Growth models, growth parameters, Guinea fowl, oregano levels, organic production

Introduction

Genetic and environmental conditions affect growth, which is known as the process of a bird gaining body weight with age until it reaches maturity (Porter *et al.*, 2010).Growth measurements for birds and control of the environmental conditions that affect their body weight gain are common practices in the poultry industry because of their economic importance (Aggrey, 2009). In recent years, growth functions have become

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more prevalent for monitoring and characterizing growth and to estimate the different periods of growth such as the WIP, MWG, AIP and age of sexual maturity (Eleroğlu *et al.*, 2014). These characteristic values are used to explain body weight gains and estimate the expected body weight at a particular age. Moreover, mathematical model results for heritability are high and widely used in research focused on selection, environmental changes (Goto *et al.*, 2010) and prediction of daily feed requirements for several ages (Pomar *et al.*, 2009). Additionally, it is feasible to use mathematical models to determine better management practices to increase animal production (Selvaggi *et al.*, 2015). Growth models will allow the determination of optimal management application and productivity of guinea fowl farms (Nahashon *et al.*, 2006a). The growth curves were applied because of their relevance when diets contain various types of additives (Abbas *et al.*, 2014). Additives may not limit the final weight, but they may influence the shape of growth (Fatten, 2015).

There are many growth functions used to describe changes in body weight. Because these growth functions have several characteristics and different mathematical limitations, it is important to be careful when choosing the mathematical model that best describes the growth type (Norris *et al.*, 2007).

Gompertz, Logistic, Von Bertalanffy, Richards and Brody mathematical models are widely used to describe poultry growth curves (Liu *et al.*, 2011; Eleroğlu *et al.*, 2014) and have been modeled for turkeys (*Meleagris gallopavo*), ostriches (*Struthio camelus*) (Brand *et al.*, 2012), quails (*Coturnix coturnix japonica*) (Raji *et al.*, 2014), guinea fowl (*Numida meleagris*) (Nahashon *et al.*, 2006a, 2006b, 2010) and chickens (*Gallus gallus domesticus*) (Marcato *et al.*, 2008; Şekeroğlu *et al.*, 2013; Al-Samarai, 2015).

There are different statistical equations used to define the GF. r^2, MSE, ADR^2, AIC, $Chi.Sq^2$ and RSD are used to compare the compatibility of the growth functions (Akaike, 1974; Yang *et al.*, 2006; Narinc *et al.*, 2010; Miguel *et al.*, 2012; Beiki *et al.*, 2013; Eleroğlu *et al.*, 2014).

The objective of this study was to evaluate the growth response of guinea fowl (*Numida meleagris*) that were fed diets containing three different levels of dry oregano (*Origanum vulgare* L.) raised in an organic system. For this aim, the Gompertz and Logistic growth curves were assessed to measure which model best fit the growth curves for Guinea fowl and the different statistics used to determine the GF.

Materials and Methods

This research study feeding Guinea fowl in organic systems was independently conducted in accordance with the principles and regulations of organic farming practices (OFL, 2010) and was approved by the Ethics Committee of the Cumhuriyet University in Sivas (Ethics No., 04.04.2013/39), Turkey.

In this research, a total of 240-day-old (mixed-sex) Guinea fowl (*Numida meleagris*) keets were utilized after they were weighed and identified with a wing number. They were divided into four treatment groups each containing 20 chicks and were randomly distributed into 12 mobile coops (1.5 × 1.5 m) placed in the 100 m^2 grazing area.

As reported by Eleroğlu *et al.* (2016), Guinea fowl (*Numida meleagris*) chicks were randomly allocated to 4 treatment diets containing a 0%, 5%, 10%, or 15% dry oregano (*Origanum vulgare* L.) supplement. During this experiment, all basal feed and water were provided *ad libitum* for all keets. Nonlinear Gompertz and logistic growth models are widely used to estimate the relationship between mean age and body weight (Eleroğlu *et al.*, 2014). The mathematical equations for these models and the characteristics of growth curves for poultry WIP, MWG and AIP are presented in Table 1 (Narinc *et al.*, 2010; Eleroğlu *et al.*, 2014).

Table 1. The mathematical equations for the models and characteristics of growth curves for poultry

	Gompertz	Logistic
Corresponding weight at time (W)	$\beta_0 exp(-\beta_1 exp(-\beta_2 t))$	$\beta_0(1+ \beta_1 \exp-\beta_2 t)^{-1}$
Age at the inflection point (AIP)	$(\ln \beta_1) / \beta_2$	$(\ln \beta_1) / \beta_2$
Weight at age of inflection point (WIP)	β_0 /e	$\beta_0 /2$
Maximum weight gain at inflection point (MWG)	β_2 WIP	β_2 WIP/2

For each model, β_0 was the asymptotic (mature) weight parameter, β_1 was the scaling parameter (scale parameter related to initial weight), and β_2 was the instantaneous per week growth rate (Yang *et al.*, 2006; Raji *et al.*, 2014; Eleroğlu *et al.*, 2014).

The calculation of GF has different methods to compare the performances of the non-linear models. In this study, GF for the models was assessed using r^2, MSE, ADR^2, AIC, Chi.Sq^2 and RSD. The equations for GF are given in Table 2.

Microsoft Excel 10.0 was utilized for the Chi. Sq^2 computation. The other GF criteria were calculated using ANOVA tables, and calculations were carried out with the nonlinear regression option in SPSS 15.0 (Inc. Chicago IL., USA). The Levenberg–Marquart estimation method was used for two models within the statistical software package program (Marquardt, 1963).

Results

Table 3 shows the estimated standard error of the mean and the P value for Gompertz and logistic model growth parameters for Guinea fowl (*Numida meleagris*) genotypes examined in an organic system. The different nonlinear function results of the individual data indicate that supplementation of diets with DOL had no significant effects on growth curve parameters (β_0, β_1, β_2, AIP, WIP, MWG, and r^2) when compared with the control diet ($P>0.05$).

The estimated β_0 parameter was greater for the Gompertz model (1073.37 to 1320.31 g) when compared with the logistic equations (801.77to 923.23 g). The values for the β_1 parameter in the Gompertz model were lower (3.52, 3.24, 3.30 3.21 for the supplementation of diets with DOL at levels 0%, 5%, 10%, and 15%, respectively) when compared with the respective values for the logistic model (17.16, 13.28, 13.83, 13.07, respectively). The β_2 parameter was lower in the Gompertz model (0.13 to 0.14) when compared that in the logistic model (0.27-0.29). The range in terms for AIP obtained from the Gompertz (8.62-9.94) and logistic (8.92-9.74) models were similar.

The WIP parameter from the Gompertz model was greater (394.91-485.76) when compared that in the logistic models (294.98-339.67) and was affected by the high β_0 values. Although there was no difference between MWG values from the application, the values obtained from the logistic model (84.06-96.05) were greater than the values obtained from the Gompertz model (53.17-60.41).

Table 2. The criteria of the GF test in the selection of Gompertz and logistic models

Criteria	Abbrev.	Equation
Chi-square test	$\chi 2$	$\sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$
Coefficient of determination	r^2	$1-(SE/ TS)$
Adjusted determination coefficient	AR^2	$r^2-((k-1/n-k)(1-r^2))$
Mean square error	MSE	$SE/ (n-k)$
Akaike's information criteria	AIC	$n.\ln (SE/n)+2k$
Residual standard deviation	RSD	$(SE)^{1/2}/(n-k)^{1/2}$

O_i=measured value; E_i=estimated value; SE=sum of squared errors; TS=total sum of squares; n=number of observations; k=number of parameters

Table 3. Estimated mean of standard error and P value for Gompertz and logistic model growth parameters in guinea fowl

Parameters	*Origanum vulgare* L. leaf (DOL) in diet (%)				Average	SEM[†]	P value
	0	5	10	15			
Gompertz model							
β_0	1320.31	1073.37	1174.70	1218.59	1196.74	54.911	0.483
β_1	3.52	3.24	3.30	3.21	3.32	0.054	0.214
β_2	0.13	0.14	0.14	0.14	0.14	0.004	0.489
AIP	9.94	8.62	8.74	9.13	9.11	0.330	0.530
WIP	485.76	394.91	432.19	448.34	440.30	20.203	0.483
MWG	60.41	53.17	59.54	55.67	57.20	1.510	0.291
r^2	0.97	0.96	0.96	0.94	0.96	0.004	0.152
Logistic model							
β_0	923.23	801.77	891.40	856.76	868.29	24.134	0.333
β_1	17.16	13.28	13.83	13.07	14.34	0.630	0.105
β_2	0.28	0.29	0.28	0.27	0.28	0.004	0.672
AIP	9.74	8.92	9.05	9.17	9.22	0.182	0.447
WIP	339.67	294.98	327.96	315.22	319.46	8.879	0.333
MWG	96.05	84.06	94.65	86.05	90.20	2.437	0.209
r^2	0.97	0.97	0.97	0.95	0.97	0.003	0.093

[†]SEM: Standard error of the mean

The average observed and estimated growth curves for body weight obtained from the application of mathematical equations for the Gompertz and Logistic models are represented in Figures 1, 2 and 3. Bodyweight increased with age, and the average AIP was between 9.11 and 9.22 wks when the average MWG (57.20 and 90.20 g wk^{-1}) in the Gompertz and logistic models was attained. WIP at this age averaged 440.30–315.22 g for each Gompertz and Logistic equation. After AIP, the growth rate fell and was near zero at maturity. The shapes of the estimated growth curves were distinctive "S" sigmoid.

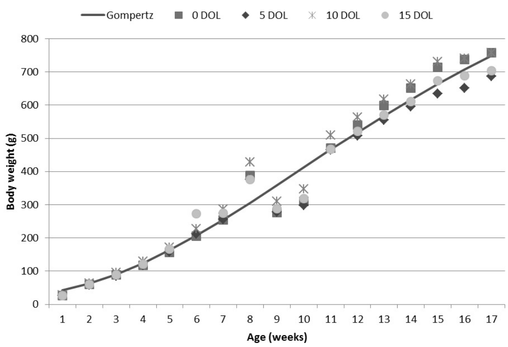

Figure 1. Estimation of growth curves using the Gompertz model for guinea fowl fed diets containing various levels of DOL (0%, 5%, 10%, and 15%) in an organic system

The correlation coefficients for both models were higher and seem similar in structure (Table 4). Higher correlation coefficients were estimated among β_0, β_1, β_2, AIP, WIP and MWG (*P<0.01*) in the Gompertz model. Although comparable results were calculated in the logistic model, there were no significant correlations between β_2-β_1 and β_2-MWG. The correlations were found to be negative among β_2 and β_0, β_1, AIP, WIP and MWG parameters (*P<0.01*) in the Gompertz model. Although comparable negative results were estimated for β_2 (*P<0.01*) in the logistic model, there was no significant correlation between β_2

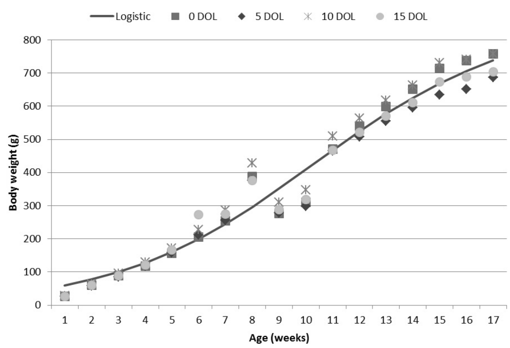

Figure 2. Estimation of growth curves using the logistic model for guinea fowl fed diets containing various levels of DOL (0%, 5%, 10%, and 15%) in an organic system

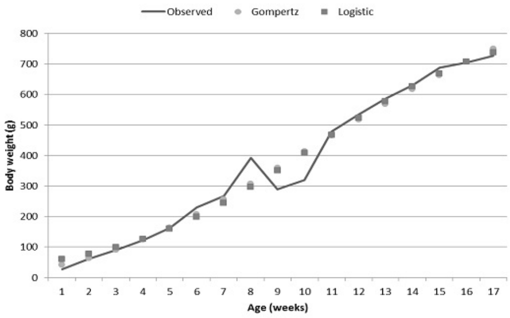

Figure 3. Average observed body weight and estimation of growth curves using the Gompertz and logistic models for guinea fowl in an organic system

and β_1. High positive relationships among β_0 and β_1, AIP, WIP and MWG were found (*P<0.01*) in the two models.

The Gompertz and logistic GF results for DOL levels are presented in Table 5. According to the estimated results, the coefficient of determination (r^2) and adjusted determination coefficient (AR^2) were found to be greater than 0.94 in both growth models for DOL levels. The highest average value of r^2 (0.965) was calculated from the logistic growth curve model. Considering the mean values, fitting the growth functions occurred the lower MSE (2763.51, 2817.46); AIC (152.46, 153.20) and RSD (49.21, 50.02) values occurred in Gompertz and logistic growth curve models, respectively. A chi-square test was applied and estimated individual values for the two models to compare their fitness (Table 5). There were no

Table 4. Estimate correlations of β_0, β_1, β_2 WIP, MWG, AIP from Gompertz and logistic nonlinear growth curve models

	Gompertz Model					
	β_0[1]	β_1[2]	β_2[3]	AIP[4]	WIP[5]	MWG[6]
β_0[1]	1					
β_1[2]	0.739**	1				
β_2[3]	-0.724**	-0.446**	1			
AIP[4]	0.915**	0.698**	-0.863**	1		
WIP[5]	>0.99**	0.739**	-0.724**	0.915**	1	
MWG[6]	0.790**	0.807**	-0.310**	0.540**	0.790**	1
	Logistic Model					
	β_0[1]	β_1[2]	β_2[3]	AIP[4]	WIP[5]	MWG[6]
β_0[1]	1					
β_1[2]	0.678**	1				
β_2[3]	-0.374**	0.074	1			
AIP[4]	0.789**	0.620**	-0.686**	1		
WIP[5]	>0.99**	0.678**	-0.374**	0.789**	1	
MWG[6]	0.868**	0.798**	0.099	0.484**	0.868**	1

**Correlation is significant at the 0.01 level (2-tailed).

Table 5. GF criteria results for β_0, β_1, β_2 WIP, MWG, AIP from Gompertz and logistic nonlinear growth curve models

	Items	*Chi²%					
Model	DOL (%)†	>0.05	r^2	AR^2	MSE	AIC	RSD
Gompertz	0	100	0.97	0.97	2550.51	152.62	48.61
	5	100	0.96	0.97	1976.53	149.00	43.19
	10	100	0.96	0.97	2808.85	154.70	51.57
	15	100	0.94	0.95	3718.14	153.50	53.46
Average		100	0.958	0.965	2763.51	152.46	49.21
Logistic	0	100	0.97	0.97	2491.57	152.82	48.51
	5	100	0.97	0.97	2055.17	149.86	44.19
	10	100	0.97	0.97	2875.85	155.46	52.49
	15	100	0.95	0.95	3847.25	154.64	54.89
Average		100	0.965	0.965	2817.46	153.20	50.02

†DOL: Dry oregano leaf

differences between DOL levels, and the $Chi^2_{0.05}$% parameter values for both models were estimated as higher (100%).

Discussion

No significant differences were detected between the Gompertz and logistic growth curve values for guinea fowl fed diets containing various DOL levels in an organic system (*P>0.05*). For this reason, average or range values were used for discussion.

The shapes of the growth curves obtained from the Gompertz and logistic nonlinear models were typically sigmoid (Figures 1, 2 and 3). According to the literature for poultry and other animals, the age-body weight and volume of the body and most organs are measured from conception to senescence; the curves of the collected data show a flattened sigmoid curve called "S" shape or nonlinear S-shaped function (Swatland, 1994; Arseniy, 2006). However, the growth curves for meat animals raised under intensive production, free range and organic systems may vary as relatively flat or steep slopes. When the data were obtained from very young animals, the growth curve may become apparent, and the growth rate was nearly stable during the intensive growing period (Swatland, 1994). Initially in the sigmoid curve, the rate of growth was low but increased with advanced age. The growth attained a maximum, it complied with to AIP, and then, it slowly declined to zero once the animals achieved their β_0 (Michael, 1999; Arseniy, 2006). In this research and similar conditions in other studies, the Gompertz and logistic growth curves for guinea fowl (Nahashon *et al.*, 2006b) or slow-growing broiler-raised guinea fowl in an organic system at 16 wks (Eleroğlu *et al.*, 2014) were relatively flat compared with growth curves for guinea fowl raised in commercial conditions at 8 wks (Nahashon *et al.*, 2006a, 2010).

Table 3 shows that the average β_0 parameter of 868.29 g estimated by the logistic model was lower than the β_0 parameter of 1196.74 g obtained by the Gompertz model. Although the estimated β_0 values of both models were lower than the results from Nahashon *et al.* (2006b), the β_0 parameter obtained from the Gompertz model was greater than that obtained by the logistic model, which is consistent with the literature (Nahashon *et al.*, 2006a, 2006b; Narinc *et al.*, 2010; Miguel *et al.*, 2012; Eleroğlu *et al.*, 2014). Based on the average value of β_0, the growth pattern of the guinea fowl broiler was closer to the Gompertz than the logistic model.

The logistic model showed a greater predicted β_1 (17.16 g) for the guinea fowl when compared with the Gompertz model (3.52 g). Similar observations were reported previously for guinea fowl (Nahashon *et al.*, 2006a) and slow–growing chicken genotypes raised in an organic system (Eleroğlu *et al.*, 2014).

The β_2 was also lower (0.14) for the Gompertz model than the logistic model (0.28); similar results were reported by Yang *et al.* (2006), Nahashon *et al.* (2006a, 2006b), Miguel *et al.* (2012), Beiki *et al.* (2013) and Eleroğlu *et al.* (2014). The higher β_2 value obtained from the logistic model may further explain the lower β_0 predicted by the logistic model (Nahashon *et al.*, 2006a).

The AIP values were similar for the Gompertz and logistic models (from 9.11 to 9.22 wk of age; Table 3, Figures 1, 2 and 3) but were found to be higher for each model in several other studies (Santos *et al.*, 2005; Nahashon *et al.*, 2006a,b, 2010). The range of AIP values for each model was estimated to be 5.72 to 5.94 wk. of age for the meat-type variety of French guinea fowl when conventionally reared for 9 wks of fattening period (Nahashon *et al.*, 2006a, 2010) and were determined to be between 6.5 to 8.2 wk. of age for the pearl gray guinea fowl during the slow-growing 22 wks of fattening period (Nahashon *et al.*, 2006b). The range of AIP was high (6.28 and 7.08 wk. of age) in the slow-growing broilers (Santos *et al.*, 2005), whereas the corresponding range was low (4.58

and 5.78 wk. of age) in conventionally reared fast-growing broilers (Marcato *et al.*, 2008). On the other hand, in this study, the point of inflection for guinea fowl was close to pure-bred chickens of unselected populations, which ranged from 9.1 to 11.64 wk. of age (Knizetova *et al.*, 1985), and over predicted observations (11.54 to 13.99) were reported for the slow-growing chicken genotypes raised in an organic system (Eleroğlu *et al.*, 2014). According to the results, the AIP value is influenced by genotype, rearing system and fattening period.

The WIP, β_1, and β_2 values can vary depending on the ratio of the nutrient content. Nahashon *et al.* (2010) observed that WIP values were significantly lower in French guinea broilers fed the 21% CP diet (738 g) than those fed the 23% (780 g) and 25% CP diets (789 g) during the conventionally reared 9 wks of the fattening period. In contrast, in this study, according to the findings Nahashon *et al.* (2010), low average WIP at this age was estimated to be 440.30 – 319.46 g for the Gompertz and Logistic models in an organic system during 16 wks of fattening period. The observed differences are explained by the different rearing systems, fattening period and genetic origins of the flocks used.

The β_0 slowly increased with age until the AIP averaged 9.11 and 9.22 wks, at which time the MWG average was 57.20 and 90.20 g wk^{-1}. in the Gompertz and logistic models, respectively. Beyond this age, MWG declined rapidly and approached zero at maturity.

The β_0, β_1 and β_2 values for guinea fowl predicted by the Gompertz and logistic models for the supplementation of diets with DOL at levels of 0%, 5%, 10%, and 15% were compatible with observed body weight values (Figures 1, 2 and 3).

The two models fit the growth curves for guinea fowl in an organic system very well, and the fitting degrees r^2 were all above 0.95; however, the logistic model was the best performing model (0.965%). The GF for the Gompertz and logistic growth curve models in this study was found to be concordant with various studies (Norris *et al.*, 2007; Narinc *et al.*, 2010). Under optimum growing conditions, this maturation rate showed up in the logistic equation, which is a sigmoidal growth curve that describes broiler growth with amazing accuracy (Eleroğlu *et al.*, 2014). This result implies that the growth pattern of guinea fowl was closer to the logistic than the Gompertz model. Although these results are consistent with previous results by Eleroğlu *et al.* (2014), the results are not compatible with results of Nahashon *et al.* (2006b) because of the differences in the duration of fattening and breeding systems.

In the current study, the growth function estimates of β_0, β_1, β_2, AIP, IWP, MWG and r^2 for the guinea fowl fed diets containing DOL at levels 0%, 5%, 10%, and 15%, were 1196.74, 3.32, 0.14, 9.11, 440.30, 57.20 and 0.96, respectively, in the Gompertz model and 868.29, 14.34, 0.28, 9.22, 319.46, 90.20 and 0.97, respectively, in the logistic models. These means were not significant in the Gompertz nor the logistic models ($P>0.05$). Based on the Gompertz and logistic growth model estimates, feeding with DOL at a level of 15% can be recommended as safe and as meat flavor or growth for the guinea fowl in an organic system.

The value of AIP varied depending on the rearing systems and genotypes. Fast-growing broiler genotypes are often used in conventional rearing systems, and estimated lower AIP values and growth patterns for birds were closer to the Gompertz than the logistic model.

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Resumen

H. Eleroğlu, A. Yıldırım, A. Canikli, M. Duman, y H. Bircan. 2018. Análisis de curvas de crecimiento de aves de Guinea (*Numidea meleagris*) con dietas que contienen orégano seco (*Origanum vulgare* L.) en un sistema orgánico. Cien. Inv. Agr. 45(2): 99-108. En este estudio, se utilizaron las gallinas de Guinea (Numidea meleagris) de 240 días de vida. Se dividieron en cuatro grupos de tratamiento cada uno con 20 pollitos y fueron distribuidos al azar en 12 gallineros móviles colocadas en todos y cada uno de los 100 m2 de área de pastoreo. Gallinas de Guinea fueron asignadas al azar a 4 tratamientos (dietas) que contengan 0%, 5%, 10% y 15% de suplemento de hojas de orégano seco (DOL). Modelos no lineales de Gompertz y modelos logísticos fueron utilizados para estimar la edad media-peso vivo. El parámetro de curva de crecimiento de estos modelos y sus características para la gallina β0 es el parámetro de peso asintótico, β1 es el parámetro de escala, β2 es la tasa de crecimiento instantáneo por semana, el peso a la edad del punto de inflexión (WIP), el aumento de peso máximo en el punto de inflexión (MWG), la edad en el punto de inflexión (AIP). La bondad de ajuste (GF) de los modelos evaluados usando Coeficientes de Determinación (r2), El error cuadrático medio (MSE), el coeficiente de determinación ajustado (ADR2), los criterios de información de Akaike (AIC), la prueba de Pearson (ChiSq2) y la desviación estándar residual (RSD). Los diferentes resultados de las funciones no lineales de los datos individuales indicaron que la suplementación de dietas con DOL no tuvo efectos significativos en los parámetros de la curva de crecimiento en comparación con la dieta de control. Se estimaron valores de correlación más altos entre β0, β1, β2, WIP, MWG y AIP en la ecuación de Gompertz y un resultado similar estimado en la ecuación logística, pero no hay correlación significativa entre β2-β1 y β2-MWG. De acuerdo con los resultados obtenidos de GF, r2 alta y ADR2 se estimaron en la ecuación de Gompertz y logística por encima de 0,96.

Palabras clave: Gallina de Guinea, modelos de crecimiento, niveles de orégano, parámetros de crecimiento, producción orgánica.

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