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Comparison of nonlinear models describing growth curves of broiler chickens fed on different levels of corn bran

Abstract

This study compared four nonlinear models to describe growth parameters of broiler chicken fed on different levels of corn bran. Two experiments were designed for this purpose. In the first experiment, 80 chickens (308 Ross strain) that had been fed on the same diet and weighed separately were used to determine the best model. Indicators of R^2, ACI and the number of circulation of the model were used to confirm the best model. In the second experiment, 300 one-day-old Ross 308 broiler chickens were used in a completely randomized design with four treatments and five replicates. The treatments included control and diets contained 2.5, 5 and 7.5% corn bran. Results showed that the Gompertz function had the highest R^2 and the lowest AIC and number of iterations. So, the Gompertz model best described the broiler growth curves. R^2, AIC values and number of iterations of the Gompertz model were 0.9970, 648 and 5, respectively. Different levels of corn bran significantly affected mature body weight (W_f) and body weight at the inflection point (W_i) ($P<0.05$), but did not affect the initial body weight (W_0), inflection point (T_i) and coefficient of relative growth (b) ($P>0.05$). Additionally, corn bran significantly decreased the growth rate on days 21, 28, 35 and 42 ($P<0.05$), but had no significant effect on the growth rate on days 7 and 14 ($P>0.05$). Overall, the results showed that the Gompertz model described the biological curves of broiler fed on corn bran better than other models. Also, growth parameters were affected by corn bran.

Keywords: corn bran, gompertz model, growth curve, nonlinear models

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Introduction

The process of growth measured as body weight on a longitudinal time frame has often been summarized using mathematical models fitted to growth curves. One of the objectives of curve fitting is to describe the course of body weight increase over time with mathematical parameters that are biologically interpretable.[1] In models of animal production systems, growth curves are used to provide estimates of daily feed requirements for growth. These estimates are used in providing total feed requirements, which sets an upper limit to feed intake when animals are given ad libitum access to feeds.[2] The mathematical models for describing growth kinetics are important tools to examine biological parameters, such as body weight at specific time, maximum growth response, and body weight at maturity, growth rates, inflection point, and body weight at the inflection point. Numerous growth functions have been developed to describe and fit the nonlinear sigmoid relationship between growth and time or age. Growth characteristics of poultry have been described by some nonlinear mathematical models such as Gompertz, Brody, Bertalanffy, Weibull, negative exponential, Hyperbolastic Models and logistic growth functions in broiler chicken,[3–5] ducks,[6] pearl gray guinea fowl,[7] turkey[8] and Japanese quail.[9]

According to,[10] fiber is a nutritionally, chemically and physically heterogeneous substance. It may be divided into insoluble fibers which are less viscous and fermentable and soluble fibers which are viscous and fermentable. Both insoluble and soluble fibers have different roles in the digestion and absorption processes in the gastrointestinal tract (GIT). Dietary fiber encompasses very various polymers with large differences in physicochemical properties that, when included in the diet, result in differences in ion exchange capacity, fermentation capability, digestive viscosity, and bulking effect in the GIT.[11,12] The beneficial effects of fiber were also shown to be related to the decreased gizzard pH, which was accompanied by improved nutrient utilization to increase growth.[13] In addition, fiber can provide a fermentative substrate for the large intestinal flora, and a healthy microflora could decline the incidence of intestinal problems such as necrotic enteritis.[14] In terms of weight gain (WG),[15] observed that the addition of 3% of either oat hull or sugar beet pulp improved weight gain from day 1 to day 21. Also,[16] found that WG was increased by the inclusion of insoluble fiber in the broilers' diet. But,[17] reported that an inclusion of 4% oat hull in the diet increased feed intake (FI) in broiler chickens without affecting[18] reported that a high rate of fiber inclusion (up to 12-16%) could reduce the body weight due to depressed FI in chickens from day 14 to day 35. Also,[19] observed that inclusions of 5 and 10% of insoluble fiber increased feed conversion ratio (FCR) and FI but reduced WG.

So, the objectives of this study was to compare five nonlinear models including logistic, Gompertz, Lopez, Richards and Von Bertalanfi for describing growth parameters of broiler chicken and to use the best model to describe growth parameters of broiler chicken fed on different levels of corn bran.

Materials and methods

Experiment I

Chickens, diets and experimental design: Eighty male and female chicks (Ross 308) were raised in a deep litter system. Feed and water were provided *ad libitum*. The birds were fed on a starter diet

(2,900kcal of ME/kg and 21.5% CP) from day 1 through day 21, and a grower diet (3,050kcal of ME/kg and 19.5% CP) from day 22 through day 42. Temperature started at 33°C and was reduced by 2.8°C per week until 21°C was attained. The birds were individually weighed at 09:00 AM and body weights were recorded on every other day for 42 days. Six of the 80 birds died before the end of 42d. The dead birds were not included in the study. The average body weights of the remaining 74 birds were used as the data for the growth curve to be modeled.

Nonlinear models: Four growth models including Logistic, Gompertz, Lopez and Richards were fitted to data using NLIN procedure of the SAS (SAS Institute Inc., 2001) for the evaluation of the growth parameters (Table 1). The models and equations are shown in. In all models, W_t refers to live body weight (g) at age t (day), W_0 is the initial body weight (g), b is the coefficient of relative growth or maturing index (smaller b indicates later maturity, while larger b indicates earlier maturity); t is the age of bird (day) and W_f is the mature body weight (g). The derived parameters were, then, used to estimate the inflection point T_i (day); body weight at the inflection point (g; W_i) and growth rate (GR; g/day).

Table 1 Mathematical description of growth models, biological parameters and growth evaluators

	Mathematical Expression	Weight at Inflection (W^*)	Time to Inflection (t^*)	Growth Rate (dw/dt)
Gompertz	$w = w0 * exp\left(\left(1-exp\left(-b*t\right)\right)*\left(log\left(wf/w0\right)\right)\right)$	$0.368W_f$	$\frac{1}{b}\left[\ln\left(ln\left(\frac{W_f}{W_0}\right)\right)\right]$	$bWln\left(\frac{W_f}{W}\right)$
Logistic	$w = w0 * Wf / \left(W0+\left(Wf-W0\right)*exp\left(-b*t\right)\right)$	$0.5W_f$	$\frac{1}{b}ln\left(\frac{W_f-W_0}{W_0}\right)$	$bW\left(1-\frac{W_f}{W}\right)$
Lopez	$w = \left(w0 * k**b + wf * t**b\right) / \left(k**b + t**b\right)$	$\frac{\left[\left(1+\frac{1}{b}\right)W_0+\left(1-\frac{1}{b}\right)W_f\right]}{2}$	$K\left[\frac{b-1}{b+1}\right]^{1/b}$	$b\left(\frac{t^{b-1}}{K^b+t^b}\right)\left(W_f-W\right)$
Richards	$w = \left(w0*Wf\right) / \left(W0**n+\left(Wf**n-W0**n\right)*exp\left(-b*t\right)\right)**\left(1/n\right)$	$\frac{W_f}{(n+1)^{1/n}}$	$\frac{1}{b}ln\left(\frac{W_f^n-W_0^n}{nW_0^n}\right)$	$bW\left(\frac{W_f^n-W^n}{nW_f^n}\right)$

The treatments included control and diets contained 2.5 (T1), 5 (T2) and 7.5 (T3) percentage of corn bran

Four models were fitted to the data by nonlinear regression using the NLIN procedure of SAS (2001). To select the best model, three principal criteria of adjustment, including coefficient of determination (R^2), number of iterations and Akaike information criterion (AIC) were used.[20,21,22] For each of these criteria, the optimum status was the highest level of the determination coefficient (pseudo R^2), the smallest number of the iterations needed, and the lowest value of the Akaike information criterion.[23] The Akaike information criterion was calculated as;

$$\mathrm{AIC} = \mathrm{n} \times \ln\left(\frac{\mathrm{SSE}}{\mathrm{n}}\right) + 2\mathrm{P}$$

Where, p is the number of parameters +1, SSE is the residuals sum of squares and n is the number of observations.

Experiment 2

Chickens, diets and experimental design: Three hundred one-day-old Ross 308 male broiler chickens were used in a completely randomized design with four treatments and five replicates 15 chicks for each replicate), in days 1 to 42 of the growing phase. The chickens received diets containing 0 (control), 2.5 (T1), 5 (T2) and 7.5% (T3) of corn bran. All chickens were fed on starter (1-21 days), and grower (22-42 days) diets according to Nutritional Requirements of Poultry.[24] This diet was iso energitic and isonitogenic. The ingredients and nutrient contents of the diets are shown in (Table 2). Chickens in each pen were weighed together every three days. Prior to trial commencement, corn bran was purchased from a commercial supplier and was ground using hammer mill (2 mm screen) and analyzed for chemical composition (Table 3). Dry matter (DM), crude protein (CP) and Ether extract (EE) of fiber sources were determined as per the methods described by AOAC.[25]

Statistical analyses: Data were analyzed using the general linear models (GLM) procedure of SAS (2001; SAS Inst. Inc., Cary, NC). Tukey-Kramer method was used to compare treatment means at $P<0.05$.

Table 2 Composition of experimental diets in starter and grower phases

	Starter (1-21)				Grower (22-42)			
Ingredient	Control	T1	T2	T3	Control	T1	T2	T3
Corn	54.86	50.70	46.54	42.39	59.32	55.98	52.66	49.32
Soybean Meal-44	38.64	39.29	39.96	40.60	33.75	33.86	33.96	34.07
Corn bran	0	2.5	5	7.5	0	2.5	5	7.5
Oil	1.70	2.76	3.84	4.89	3.12	3.91	4.71	5.50

Table Continued....

	Starter (1-21)				Grower (22-42)			
Ingredient	**Control**	**T1**	**T2**	**T3**	**Control**	**T1**	**T2**	**T3**
Calcium carbonate	1.17	1.15	1.13	1.12	1.00	0.96	0.92	0.89
Dical. Phos.	1.90	1.9	1.88	1.87	1.47	1.46	1.45	1.43
Sodium bicarbonate	0.09	0.09	0.08	0.08	0.18	0.17	0.17	0.17
Vit & Min Premix	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Common salt	0.32	0.32	0.32	0.31	0.27	0.27	0.26	0.26
DL-Methionine	0.33	0.33	0.33	0.33	0.21	0.22	0.22	0.22
L-Lysine	0.32	0.30	0.28	0.28	0.13	0.12	0.11	0.10
Theronin	0.17	0.16	0.14	0.13	0.05	0.05	0.04	0.04
Calculated composition								
ME (Kcal/kg)	2900	2900	2900	2900	3050	3050	3050	3050
Protein (%)	21.50	21.50	21.50	21.50	19.50	19.50	19.50	19.50
Calcium (%)	0.96	0.96	0.96	0.96	0.79	0.79	0.79	0.79
Phos. (%)	0.48	0.48	0.48	0.48	0.63	0.64	0.64	0.65
Lysine (%)	1.28	1.28	1.28	1.28	1.03	1.00	1.03	1.03
Met+Cys(%)	0.95	0.95	0.95	0.95	0.80	0.80	0.80	0.80

Table 3 Chemical composition of corn bran (CB)

Chemical composition of corn bran (CB)	
Dry matter (%)	95.63
Organic mater	98.94
Ash (%)	1.06
Crude protein (%)	10.43
Ether extract (%)	1.02
Acid detergent fiber (%)	39.81
Neutral detergent fiber (%)	67.32
Calcium (%)	0.67

Results and discussion

Experiment 1

Growth models have been widely used to represent changes in size of body with age or time so that the genetic potential of animals for growth can be evaluated and nutrition can be matched to possible growth. Also, growth models are used to provide estimates of daily feed requirements for growth (Lopez et al., 2000). Comparisons of the models by R^2, number of iterations and Akaike information criterion (AIC) are shown in Table 4. Regarding the goodness of fit criteria, all models were suitable for describing the growth of the broiler chicken. Among all nonlinear models used, the smallest AIC and the lowest number of iterations were calculated for the Gompertz function. The Gompertz model best described the growth curves for body weight of broiler chicken, with R^2, AIC values and number of iterations being 0.9970, 648 and 5, respectively. The Gompertz model is one of the most common models to describe broiler growth curve. In this model, the growth curve is asymmetric around the point of maximum growth rate. However, the point of inflection in Gompertz model is fixed[26,27] compared the Logistic, Gompertz, Von Bertalanfi, Morgan-Mercer-Flodin (MMF) and Weibull growth models and suggested that MMF, Weibull and Gompertz models can be useful for explaining broiler chickens growth performance. Compared the Richards, logistic, Gompertz and spline linear regression models for describing chicken growth curves. This researcher reported that the spline model had the poorest fit to the data as compared with the other three nonlinear models.

Table 4 Estimated parameters for each model in the study of the biological growth curve

Models	W_0	B	W_f	K\n	W_i	T_i	Iterations	R^2	AIC
Gompertz	31.73 (1.90)	0.053 (0.001)	3623 (68)	-	1334	29.28	5	0.9970	648
Logestic	77.68 (2.36)	0.122 (0.001)	2561 (25)	-	1281	28.36	9	0.9960	672
Lopez	47.49 (6.50)	2.119 (0.049)	5155 (291)	49.07 (2.34)	1396	30.25	13	0.9969	655
Richards	25.10 (4.53)	0.047 (0.005)	3956 (251)	-0.106 (0.064)	1374	14.9	10	0.9970	655

W_0: the initial body weight (g); W_f: mature body weight (g); W_i: body weight at the infection point (g); b: coefficient of relative growth; T_i: inflection point (day)

The parameters estimated by four models are presented in (Table 4). In this study, the Logestic model and Richards model exhibited the highest (77.68) and lowest (25.09) W_0, respectively. Also, the Richards model had the lowest b parameter but the Lopez model had the highest one. The final weight (W_f) was estimated between 2561g and 5155g and the Lopez and Logestic model had the minimum and maximum W_f, respectively.[28,29] found that Gompertz gave a higher estimate than the Logistic and Richards models for parameter A in male and female turkeys. Body weight at the inflection point (g; W_i) was 1281g for the Logestic model and 1396g for the Lopez model, which were the lowest and highest W_i, respectively. Time of inflection point was measured between 14.9 to 68.54 days. The Richard model had the lowest estimation and Von had the highest one. Approximate correlation matrix of Gompertz parameters is shown in (Table 5) Correlation between W_0 and b parameters was high and negative (-0.9410502), but a high and positive correlation (0.8341997) was observed between W_0 and W_f. However, b and W_f were correlated strongly and negatively (-0.9652989).

Table 5 Approximate correlation matrix of the Gompertz parameters

Parameter	W_0	B	W_f
W_0	1	-0.9410502	0.8341997
B	-0.9410502	1	-0.9652989
W_f	0.8341997	-0.9652989	1

W_0: the initial body weight (g); b: coefficient of relative growth; W_f: mature body weight (g)

Experiment 2

The effect of the different levels of corn bran on weekly body gain is presented in (Table 6) Results indicated the loss of body weight with the increase in corn bran from 0 to 7.5 percent in diet. In the end of period, i.e. day 42, the final body weight was lower when corn bran was included in the diet ($P<0.05$). Birds fed on control diet (0% CB) had the highest final body weight (2324g) while birds fed on diets containing 7.5% corn bran had the lowest final body weight at the end of the period ($P<0.05$).

The effect of different levels of corn bran on growth parameters including W_0: the initial body weight (g), W_f: mature body weight (g), W_i: body weight at the inflection point (g), b: coefficient of relative growth, and T_i: inflection point (day) is shown in (Table 7). W_f and W_i of the treated chickens were significantly different ($P<0.05$). Birds fed on diet 1 (control) had the highest W_f and W_i while birds fed on diet 4 had the lowest W_f and W_i. However, there was no significant difference ($P>0.05$) between birds fed on diet 2 and control. W_f and W_i decreased linearly with the increase in corn bran percent in diet ($P<0.05$). The different levels of corn bran did not affect W_0, b and T_i ($P>0.05$). The estimated growth rates (GR) of the birds fed on different levels of fiber are shown in Table 8. Growth rate on days 21, 28, 35 and 42 was significantly affected by experimental treatments ($P<0.05$), but on days 7 and 14, it was not affected by treatments ($P>0.05$). The birds fed on diet containing 0 and 7.5% corn bran displayed the highest and lowest GR, respectively. GR on days 21, 28, 35 and 42 decreased linearly with the increase in corn bran in diet ($P<0.05$).

Table 6 Effect of different levels of corn bran on weekly body weight (g)

Treatments	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42
Control	138.9	353.7	777.0	1282.1a	1727.4a	2324.7a
T1	133.3	345.4	756.5	1179.4b	1615.0b	2151.6b
T2	132.2	335.4	741.7	1181.7b	1636.4b	2122.9b
T3	127.8	341.3	749.3	1202.7b	1622.8b	2111.7b
SEM	3.38	8.27	14.73	16.75	29.59	36.44
P-Value	0.201	0.448	0.433	0.002	0.037	0.002

The treatments included control (0%) and diets contained 2.5 (T1), 5 (T2) and 7.5 (T3) percentage of corn bran, SEM: standard error of treatment means.

Table 7 The effect of different levels of fiber on growth parameters

Treatments	W_0	B	W_f	W_i	T_i
Control	38.97	0.0493	4195^a	1543^a	31.58
T1	41.09	0.0492	3810^{ab}	1402^{ab}	30.99
T2	32.63	0.0527	3524^b	1296^b	29.3
T3	31.89	0.0542	3426^b	1260^b	28.58
SEM	2.94	0.0016	172	62	0.952
P-Value	0.248	0.191	0.031	0.031	0.154
Linear	0.078	0.069	0.006	0.0061	0.078
Quadratic	0.699	0.678	0.454	0.4545	0.095

W_0: the initial body weight (g); W_f: mature body weight (g); W_i: body weight at the inflection point (g), b: coefficient of relative growth; T_i: inflection point (day); The treatments included control (0%) and diets containing 2.5 (T1); 5 (T2) and 7.5 (T3) percentage of corn bran; SEM: standard error of treatment means.

Table 8 The effect of different levels of corn bran on growth rate (g/day)

Treatments	GR7	GR14	GR21	GR28	GR35	GR42
Control	23.19	42.84	64.06	74.18^a	74.59^a	66.64^a
T1	21.82	40.47	59.68	67.40^b	67.44^b	59.78^{ab}
T2	22.85	41.5	60.67	67.82^b	65.82^b	56.35^b
T3	22.71	42.38	60.97	67.24^b	63.93^b	53.93^b
SEM	0.629	0.855	0.951	1.621	2.198	2.748
P-Value	0.512	0.272	0.012	0.012	0.016	0.033
Linear	0.88	0.93	0.051	0.01	0.004	0.007
Quadratic	0.372	0.089	0.021	0.075	0.272	0.477

Treatments included control (0%) and diets containing 2.5 (T1), 5 (T2) and 7.5 (T3) percentage of corn bran, GR: Growth Rate, SEM: Standard Error of Treatment Means.

Higher fiber concentrations in chick diets can have negative effects on nutrient digestion and absorption[30] and may subsequently affect

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performance as seen in the ADG response of the broiler chicks in the current experiment. Insoluble fiber in monogastric diets has for long been considered as diluent of nutrients.[31] The little or no degradation of insoluble fiber in chickens results in increased bulk of digest in the intestinal tract. This makes its effect on microbial population quite insignificant.[32,33] Since diets high in insoluble fiber contain low energy, birds tend to increase feed consumption as a way to compensate for the reduced nutrient concentration in feed.[34] There are suggestions that fiber decreases nutrient digestion because it encapsulates nutrients into the plant cell causing a reduction in the activity of digestive enzymes. In some cases, some fiber sources may cause pancreatic enlargement, leading to an increase in secretions.[35] In a study on turkeys,[36] indicated that an increase in the fiber content of the diet reduced performance so that an increase in the crude fiber content of the diet from 3 to 9% reduced body weight from 1 to 4 wk of age. Studied the effects of fiber sources by adding 3% oat husks and soybean hulls into a basal diet containing 2.5% crude fiber in comparison with the control diet containing 1.5% crude fiber.

They reported that adding raw fiber sources had no effect on average daily feed intake from day 1 to day 21 of the age, but it improved the average daily weight gain and feed conversion ratio (FCR). Adding fiber to the diet improves bowel function and development of the digestive system, increases the production of hydrochloric acid (HCl), bile acids and secretion of digestive juices,[37] changes the composition and gastrointestinal tract micro flora population of poultry and pig laboratory conditions[38] and breeding conditions.[39–41] So, the positive effects of adding fiber on growth performance of broiler chickens is related to the improvement of the digestibility of nutrients and metabolic pathways changes.[42] All this information is consistent with our hypothesis that the effects of dietary fiber on broiler performance depend on the source and level of fiber used.

Conclusion

In conclusion, different models were used to monitor the growth of birds in the poultry industry. This study used the logistic, Gompertz, Lopez and Richards models. The Gompertz growth model was the best describing the growth curves for body weight of broiler chickens. The estimated values of growth parameters in the experimental diets containing different levels of fiber were lower than the control group.

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Conflict of interest

The author declares no conflict of interest.

References

1. Aggrey SE. Comparison of Three Nonlinear and Spline Regression Models for Describing Chicken Growth Curves. *Poult Sci*. 2002;81(12):1782–1788.
2. Lopez S, France J, Dhanoa MS, et al. A generalized Michaelis–Menten equation for the analysis of growth. *J Anim Sci*. 2000;78(7):1816–1828.
3. Darmani Kuhi H, Kebreab E, Lopez S, et al. An evaluation of different growth functions for describing the profile of live weight with time (Age) in meat and egg strains of chicken. *Poult Sci*. 2003;82(10):1536–1543.
4. Roush WB, Dozier WA, Branton SL. Comparison of Gompertz and neutral network models of broiler growth. *Poult Sci*. 2006;85(4):794–797.
5. Ahmadi H, Mottaghitalab M. Hyperbolastic models as a new powerful tool to describe broiler growth kinetics. *Poult Sci*. 2007;86(11):2461–2465.
6. Vitezica ZG, Marie–Etancelin C, Bernadet MD, et al. Comparison of nonlinear and spline regression models for describing mule duck growth curves. *Poult Sci*. 2010;89(8):1778–1784
7. Nahashon SN, Aggrey SE, Adefope NA, et al. Growth Characteristics of Pearl Gray Guinea Fowl as Predicted by the Richards, Gompertz, and Logistic Models. *Poult Sci*. 2006;85(2):359–363.
8. Porter T, Kebreab E, Darmani Kuhi H, et al. Flexible alternatives to the Gompertz equation for describing growth with age in turkey hens. *Poult Sci*. 2010;89(2):371–378
9. Narinc D, karaman E, Ziya Firat M, et al. Comparison of Nonlinear Growth models to describe the growth in Japanese Quail. *Journal of animal and veterinary advances*. 2010;9(14):1961–1966.
10. Sarikhan M, Shahryar HA, Nazer–Adl K, et al. Effects of insoluble fiber on serum biochemical characteristics. *International Journal of Agriculture Boilogy*. 2009;11(1):73–75.
11. Asp NG. Definition and analysis of dietary fibre in the context of food carbohydrates In: van JM, der Kamp, Asp NG, Miller J, Schaafsma G, editors. *Dietary fibre: Bioactive carbohydrates for food and feed*. The Netherlands: Wageningen Academic Publishers; 2004. p 21–26.
12. Masoudi A, Chaji M, Bojarpour M, et al. Effects of different levels of date pitson performance, carcass characteristics and blood parameters of broiler chickens. *Journal of Applied Animal Research*. 2011;39:399–405.
13. González–Alvarado JM, Jiménez–Moreno E, Lázaro R, et al. Effects of type of cereal, heat processing of the cereal, and inclusion of fiber in the diet on productive performance and digestive traits of broiler. *Poult Sci*. 2007;86(8):1705–1715.
14. Mateos GG, Lázaro R, Gracia MI. The Feasibility of Using Nutritional Modifications to Replace Drugs in Poultry Feeds. *Journal applied Poultry Research*. 2002;11(4):437–452.
15. Jiménez–Moreno E1, González–Alvarado JM, Lázaro R, et al. Effects of type of cereal, heat processing of the cereal, and fiber inclusion in the diet on gizzard pH and nutrient utilization in broilers at different ages. *Poult Sci*. 2009;88(9):1925–1933.
16. Sarikhan M, Shahryar HA, Gholizadeh B, et al. Effects of insoluble fiber on growth performance, carcass traits and ileum morphological parameters on broiler chick males. *International Journal of Agriculture Boilogy*. 2010;12(4):531–536.
17. Hetland H, Svihus B. Effect of oat hulls on performance, gut capacity and feed passage time in broiler chickens. *Br Poult Sci*. 2001;42(3):354–361.
18. Khempaka S, Molee W, Guillaume M. Dried cassava pulp as an alternative feedstuff for broilers: effect on growth performance, carcass traits, digestive organs, and nutrient digestibility. *Journal Applied Poultry Research*. 2009;18(3):487–493.
19. Mourao JL, Pinheiro VM, Prates JAM, et al. Effect of dietary dehydrated pasture and citrus pulp on the performance and meat quality of broiler chickens. *Poult Sci*. 2008;87(4):733–743.
20. Echeverri AML, Bergmann JAG, Toral FLB, et al. Use of nonlinear models for describing scrotal circumference growth in Guzerat bulls raised under grazing conditions. *Theriogenology*. 2013;79(5):751–759.
21. Tariq MM, Iqbal F, Eyduran E, et al. Comparison of non–linear functions to describe the growth in Mengali sheep breed of Balochistan. *Pakistan Journal of Zoology*. 2013;45:661–665.
22. Lupi TM, Nogales S, Leń JM, et al. Characterization of commercial and biological growth curves in the Segureǎ sheep breed. *Animal*. 2015;9(8):1–8.

23. Thomas MSC, Annaz D, Ansari D, et al. Using developmental trajectories to understand developmental disorders. *Journal of Speech, Language, and Hearing Research*. 2009;52(2):336–358.
24. Posada SL, Noguera RR. Comparacin̈ de modelos matemưticos:una aplicacin̈ en la evaluacin̈ de alimentos para animals. *Rev Col Cienc Pec*. 2007;20:141–148.
25. National Research Council. *Nutrient requirements of poultry*. 8th ed. USA: Rev Ed National Academy Press; 1994.
26. AOAC. *International Official Methods of Analysis of AOAC International*. 17th ed. USA: AOAC Int; 2000.
27. Topal M, Bolukbasi SC. Comparison of Nonlinear Growth Curve Models in Broiler Chickens. *Journal of Applied Animal Research*. 2008;34(2):149–152.
28. Tabatabai M, Williams DK, Bursac Z. Hyperbolastic growth models: Theory and application. *Theor Biol Med Model*. 2005;2:14.
29. Sengul T, Kuraz S. Non–Linear Models for Growth Curves in Large White Turkeys. *Turk Journal of Veterinary Animal Science*. 2005;29:331–337.
30. Krogdahl Å. *Antinutrients affecting digestive functions and performance in poultry Proceedings of the 7th ed*. European Poultry Conference, Paris; 1986. p. 239–248.
31. Sengul T, Kuraz S. Non–Linear Models for Growth Curves in Large White Turkeys. *Turk Journal of Veterinary Animal Science*. 2005;29:331–337.
32. Edward CA. *The physiological effect of dietary fibre*. In: Kritchewsky D, Bonfield C, editors. USA: Dietary fibre in health and disease Eagan Press; 1995. p. 58–71.
33. Choct M, Hughes RJ, Wang J, et al. Increased small intestinal fermentation is partly responsible for the anti–nutritive activity of non–starch polysaccharides in chickens. *Br Poult Sci*. 1996;37(3):609–621.
34. Langhout DJ. *The role of intestinal flora as affected by non–starch polysaccharides in broiler chicks*. Netherlands: PhD Thesis, Wageningen Agricultural University; 1998. 162 p.
35. Hill FW, Dansky LM. Studies of the energy requirements of chickens. *Poult Sci*. 1954;33:112–119.
36. Kratzer FH, Rajaguru RW, Vohra P. The effect of polysaccharides on energy utilization, nitrogen retention and fat absorption in chickens. *Poult Sci*. 1967;46(6):1489–1493.
37. Svihus B. The gizzard: Function, influence of diet structure and effects on nutrient availability. *World's Poultry Science Journal*. 2011;67:207–224.
38. Dunkley KD, Dunkley CS, Njongmeta NL, et al. Comparison of in vitro fermentation and molecular microbial profiles of high–fiber feed substrates incubated with chicken cecal inocula. *Poult Sci*. 2007;86(5):801–810.
39. Shakouri MD, Kermanshahi H, Mohsenzadeh M. Effect of different nonstarch polysaccharides in semi purified diets on performance and intestinal microflora of young broiler chickens. *International Journal of Poultry Science*. 2006;5(6):557–561.
40. Jiménez–Moreno E, Chamorro S, Frikha M, et al. Effects of increasing levels of pea hulls in the diet on productive performance and digestive traits of broilers from one to eighteen days of age. *Journal of Animal Feed science Technology*. 2011;168(1):100–112.
41. Van der Meulen J, Panneman H, Jansman AJM. Effect of pea, pea hulls, faba beans and faba bean hulls on the ileal microbial composition in weaned piglets. *Journal of Livestock Science*. 2010;133(1–3):135–137.
42. Mateos GG, Jiménez–Moreno E, Serrano MP, et al. Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. *Journal applied Poultry Research*. 2012;21(1):156–174.

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