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Modeling of growth curve in farm bred broiler rabbits in organized rabbitry

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ABSTRACT

Rabbit rearing across the Indian subcontinent is growing rapidly. Growth traits are important parameters on which rabbits are being evaluated. Mathematical models have been tried to establish a relationship between body weight and time. Data spread over six years on the weekly body weight of Soviet Chinchilla and White Giant rabbits were collected and subjected to analysis for assessment of genetic parameters and factors which influence the weekly body weight. Three nonlinear growth models; Gompertz, Logistic, and Von Bertalanffy were fitted for both the breeds separately as well as collectively. The least squares mean for weekly body weights in rabbits from weaning to maturity showed an increasing trend. White Giant rabbits weigh higher than Soviet Chinchilla. The period and season of kindling had a significant influence on the weekly body weight of rabbits. The value of growth curve parameter k (an indicator of growth performance) was estimated to be higher for White Giant by all three models. All three models performed well with a high coefficient of determination values. However, Von Bertalanffy model fitted well for Soviet Chinchilla and Gompertz model for the White Giant as well as when both the breeds were fitted collectively.

Keywords: Gompertz, Growth curve, Logistic, Soviet Chinchilla, Von Bertalanffy, White Giant

Rabbitry is gaining momentum in India where the majority of the livestock keepers are marginal and landless who cannot afford a high initial investment for farming. High prolificacy and fast growth makes these animals ideal for meat production in developing countries like India (Marykutty and Nandakumar 2000). Rabbits are known for their high fecundity with short generation interval and can be well utilized for mitigating the growing meat demand. However, acclimatization of temperate breed rabbits in arid and semiarid climatic condition of Gujarat pose serious threat to rabbit husbandry. Growth plays an important role in the production of meat. There are very limited studies on the growth rate of rabbits to find the effect of genetic and non-genetic influences (Kumar *et al.* 2001*,* Das and Sikka 2007*,* Assan 2018*,* Sivakmar *et al.* 2012, Rojan *et al.* 2015, Chandra *et al.* 2017, Bhatt *et al.* 2020).

Relationship between body weight and time (age) in animals has been commonly described with mathematical models. The shape of the growth curve of rabbits is supposed to be non-linear (Jacob *et al.* 2015). These models are well suited to describe the weight gain and evaluate few other biological parameters, as mature weight, the rate of maturing, and the rate of gain. The non-linear models have the advantage of presenting fewer parameters, that is, they are more parsimonious, and have practical and biological interpretation (Fernandes *et al.* 2020). Growth models are also used to predict the optimum slaughter age. It is therefore interesting to assess the various mathematical models applied for rabbit growth to adapt them as important control and optimization instruments for the rabbit production. Some commonly used mathematical functions to study rabbit growth include the Gompertz, Logistic and von Bertalanffy growth models (France *et al.* 1996, Jacob *et al.* 2015, Fernandes *et al.* 2020). Keeping these things in consideration, this study was undertaken to evaluate the suitability of three non-linear growth models namely Gompertz, Logistic and Von Bertalanffy to describe average body weight gain at various stages of growth in Soviet Chinchilla and White Giant breed of rabbits. The various genetic and non-genetic factors influencing the growth traits were also assessed. The performance of the different models was compared using different goodness of fit statistics.

MATERIALS AND METHODS

Data collection and standardization: The data were collected on 66 Soviet Chinchilla (SC) and 70 White Giant (WG) maintained at Department of Livestock Production and Management, College of Veterinary Science and Animal Husbandry, SDAU (now Kamdhenu University), Sardarkrushinagar, over a period of 6 years from 2014 to 2019. The Rabbits with morbidity and those failed to reach the age of 4 weeks were excluded from the study. Data were

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collected on body weight of the rabbits at weekly interval starting from 4th week to 12th week.

The data on the traits collected as well generated, were classified as per the breed and sex of the rabbits. Pedigree data was subjected to *Pedigree Viewer 6.5* which reflects that total six generations of animals were used in the study. On the basis of year and season of birth, the data were further classified in two periods and three seasons. Thus the entire data were classified into two Breeds, SC and WG; two sex; Male and female; two periods viz. P_1: 2014-2016 and P_2: 2017-2019 and 3 seasons viz. S_1 (February to May), S_2 (June to September) and S_3 (October to January). The weight of the dams at kindling was taken as covariate for other body weight measures. The least squares analysis of variance technique using Mixed Model Maximum Likelihood Computer Programme PC-2 developed by Harvey (1960) was applied to study the effect of various factors on different body weights at weekly interval as per the model given below,

$$Y_{ijklm} = \mu + B_i + Se_j + Y_k + S_l + b_{zx}(Z_{ijkl} - Z) + e_{ijklm}$$

Where, Y_{ijklm}, observation of different body weight traits; μ, Population mean; B_i, Fixed effect of i^{th} breed of rabbit; Se_j, Fixed effect of j^{th} sex of rabbit; Y_k, Fixed effect of k^{th} period of birth; S_l, Fixed effect of l^{th} season of birth; b_{zx} is regression of dam's weight at kindling on various body weight traits; Z_{ijkl}, is the weight of dam at kindling to be taken as a co-variable with other body weight measures used in the model; Z, Average dam's weight at kindling of the herd and e_{ijklm}, Random error, assumed to be normally and independently distributed with zero mean and constant variance i. e. (NID, 0, σ^2).

The variance components were estimated by REML method using WOMBAT software (Meyer 2007). Best linear unbiased prediction- Sire model (BLUP-SM) was used for estimation of heritability. Pedigree data were checked for any duplicity of the genealogy using Pedigree Viewer 6.5 software. The model used was:

$$y_{ijk} = Xb_i + Zs_i + e_{ijk}$$

where, y_{ijk} is vector of observations, X is incidence matrix for fixed effects with dimension (nxp), Z is incidence matrix for random sire effect with dimension (nxq), b_i is the vector of fixed effects with dimension (px1), s_i is the vector of sire effect with dimension (qx1) and e_{ijk} is the vector of random residual effects with dimension (nx1). It was further assumed that expectations (E) of the variables are, E(y) = Xb; E(a)/E(s) = E(e) = 0 also Var (s/a) = G, Var (h) = R and Cov (s, e') = 0 and therefore, V (y) = ZGZ' + R.

Non-linear growth modeling: As the relationship between average body weight and age is non-linear in nature, it is reasonable to explore the use of non-linear models to fit the average body weight. A non-linear regression model is one in which at least one of the parameters appear non-linearly and even after transformation, remains non-linear. Three non-linear growth models as given below were considered for fitting the average body weight data of rabbits.

Gompertz $y_t = a\ \exp[-b \exp(-kt)] + \varepsilon_t$

Logistic $y_t = a\,/\,[1+b \exp(-kt)] + \varepsilon_t$

Von Bertalanffy $y_t = a\ [1- b \exp(-kt)]^3 + \varepsilon_t$

Where, y_t is the body weight in grams at the age of *t* weeks, *a* is the asymptotic limit of the weight when age (*t*) approaches infinity or the average weight of the mature rabbit. The parameter *b* is the proportion of asymptotic mature weight to be attained after birth and *k* is growth rate constant, which is a logarithmic function of degree of maturity in body weight changes linearly with time unit, normally referred to as maturing rate and provides a measure of growth rate. Large values of *k* indicate that the animal would mature early. ε_t is the error associated with y_t.

The three non-linear growth models mentioned above were also fitted separately for the growth data of SC and WG breeds of rabbit. Non-linear model parameters were estimated by Levenberg-Marquardt iterative algorithm (Bates and Watts 1988) with a convergence criterion $[(SSE_{(m-1)} - SSE_m)/(SSE_m + 10^{-6})] < 10^{-8}$, where SSE_m is the residual sum of squares resulting from the m^{th} round of iteration. All starting values of the parameters for the iterative algorithm were carefully chosen.

Goodness of fit: To examine the model performance, coefficient of determination, R^2 is generally used. However, Kvalseth and Tarald (1985) has emphasized that, although R^2 is quite appropriate even for non-linear models, uncritical use of and sole reliance on R^2 statistics may fail to reveal important data characteristics and model inadequacies. Hence, in addition to R^2, adjusted R^2, Root Mean Square Error (RMSE), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) as given below were used as the goodness of fit criterion to assess the suitability of models fitted.

$$R^2 = 1 - \left[\left(\sum (y-\hat{y})^2\right) / \left(\sum (y-\bar{y})^2\right)\right]$$

$$\text{RMSE} = \frac{\sqrt{\sum_{i=1}^{n}(Y_i - \hat{Y})^2}}{n}$$

$$\text{AIC} = n \ln(\text{RSS}) + 2p$$

$$\text{BIC} = n \ln(\text{RSS}/n) + p \ln(n)$$

where, y and ŷ are the observed and estimated average weekly body weight values; *n* and *p* are the number of time points and number of parameters in a model, respectively. A good model will have a very high value of R^2, adjusted R^2 and very low values of RMSE, AIC and BIC.

RESULTS AND DISCUSSION

Least squares mean of weekly body weights: The least squares mean for weekly body weights in rabbits from weaning to maturity showed increasing trend; it ranged from approximately half kg at weaning to more than 2 kg at the age of three months (Table 1). In general, WG rabbits weigh higher than SC however, the difference in weight is significant only around weeks immediate to weaning (Weeks 5, 6 and 7). The similar observations were made by

Table 1. Least squares means of weekly body weight (gm) of Rabbits

Traits	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12
µ	497.88±13.58	685.94±15.94	935.84±17.82	1139.49±18.56	1339.53±20.82	1538.61±19.79	1730.13±20.77	1901.93±20.52	2105.42±20.71
Breed	-	**	*	*	-	-	-	-	-
Soviet Chinchilla	478.33±20.32	640.91±23.84	901.28±26.65	1100.56±27.76	1306.3±31.14	1522.27±29.61	1729.13±31.07	1878.87±30.69	2126.29±30.98
White Giant	517.43±18.58	730.97±21.79	970.39±24.37	1178.43±25.38	1372.77±28.47	1554.94±27.07	1731.13±28.4	1924.99±28.06	2084.54±28.32
Sex	**	**	**	**	*	**	**	*	-
Female	471.33±17.99	652.28±21.11	897.43±23.6	1096.76±24.59	1290.53±27.58	1488.89±26.22	1679.14±27.51	1861.81±27.18	2079.84±27.44
Male	524.43±19.23	719.59±22.56	974.24±25.23	1182.23±26.28	1388.54±29.47	1588.32±28.02	1781.11±29.41	1942.04±29.05	2131±29.32
Period				**	**	**	**	**	**
P_1	511.55±16.66	698.37±19.55	915.5±21.86	1082.74±22.77	1280.13±25.54	1439.32±24.28	1619.23±25.48	1801.07±25.17	2003.92±25.41
P_2	484.22±22.64	673.5±26.57	956.17±29.7	1196.25±30.94	1398.94±34.7	1637.89±33.01	1841.03±34.62	2002.79±34.2	2206.91±34.53
Season	**	**	**	*	-	-	-	-	**
S_1	564.94±26.17^a	762.5±30.7^a	999.51±34.33^a	1207.28±35.75^a	1390.35±40.11	1554.09±38.13	1692.4±40.01	1859.14±39.53	2048.5±39.90^a
S_2	444.36±24.44^b	600.39±28.68^b	856.08±32.06^b	1084.91±33.4^b	1283.02±37.46	1506.32±35.62	1720.1±37.38	1888.34±36.92	2069.2±37.27^a
S_3	484.35±20.32^b	694.93±23.84^a	951.92±26.66^a	1126.29±27.77^{ab}	1345.23±31.15	1555.40±29.62	1777.88±31.07	1958.31±30.7	2198.55±30.99^b
b_{zx}	0.125	0.344	0.561	0.694	0.757	0.140**	0.125**	0.122**	0.774

Sivakumar *et al.* (2013) in terms of average weight of kits at weaning in these two breeds. The present study reports higher body weight of Soviet Chinchilla breed of rabbits at 12th week in comparison of the estimates obtained by Kumaresan *et al.* (2011) at 90 days under agro climatic conditions of Mizoram, India. Males were significantly ($p<0.01$) heavier than the females. Similar to present finding, Olateju and Chineke (2022) observed significant influence ($P<0.01$) of genotype on the litter weight at birth as well as on the body weight of the kits at 21st and 35th days in five different breeds: Rex, Dutch-belted, New Zealand white, Californian white and local breed. Effect of period of birth was highly significant on body weight at different ages. It was observed that weight recorded was lower in the first period (2014-16) then second period (2017-2019) which indicates that with time rabbits are getting adapted to the management of the farm and reiterates the importance of acclimatization and adaptation in rabbit rearing. The effect of different season of birth on different body weights was highly significant except for the weight at 8th, 9th and 10th week. In general, the kits born in season-1 (February to May) exhibit comparatively higher weight at various ages (Table 1). The significant effect of period and season on various body weights in these two breeds of rabbit was in corroboration with those of Sivakumar *et al.* (2013), Sakthivel *et al*. (2015), Rojan *et al.* (2015) and Kunnath *et al.* (2018).

Genetic parameter estimates for weekly body weights: Genetic parameters estimate of a trait is of prime importance before adopting proper breeding strategy for animal improvement. Estimates of heritability of various body weight traits are presented in Table 2 which indicates that the estimates for body weights at all ages were moderate to high, in the range of 0.325 to 0.774 (the highest estimate was for WK4 and the lowest estimate was for WK12). The heritability estimates for post weaning growth traits tended to be high; this might be a reflection of the fact that as age advanced, the genetic make-up or the additive genetic effects became more pronounced than environmental effects and therefore genetic improvement in these traits is affected through phenotypic selection. These observations were in line to those obtained by Rojan *et al*. (2009) in an organised rabbitary having White Giant (WG), Soviet Chinchilla (SC) and Grey Giant (GG) rabbits. However,

Table 2. Heritability estimates of weekly body weights

Traits	Heritability±Standard Error
Weight at WK4	0.774±0.020
Weight at WK5	0.746±0.025
Weight at WK6	0.653±0.030
Weight at WK7	0.471±0.033
Weight at WK8	0.411±0.032
Weight at WK9	0.447±0.033
Weight at WK10	0.360±0.031
Weight at WK11	0.423±0.033
Weight at WK12	0.325±0.128

Table 3. Estimates of genetic and phenotypic correlations between different body weight traits

Traits	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12
WK4		0.95±0.01**	0.91±0.01**	0.87±0.03**	0.90±0.02**	0.9±0.02**	0.84±0.03**	0.83±0.04**	0.74±0.06**
WK5	0.92±0.04**		0.99±0.02**	0.98±0.03**	NE	NE	0.95±0.01**	0.91±0.02**	0.79±0.05**
WK6	0.86±0.05**	0.94±0.03**		0.93±0.02**	0.97±0.01**	0.97±0.01**	0.91±0.02**	0.87±0.04**	0.78±0.07**
WK7	0.74±0.07**	0.83±0.06**	0.89±0.05**		0.95±0.02**	0.96±0.01**	0.94±0.02**	0.95±0.02**	0.81±0.08**
WK8	0.69±0.07**	0.75±0.07**	0.78±0.06**	0.85±0.05**		0.96±0.02**	0.87±0.05**	0.83±0.07**	0.61±0.15**
WK9	0.74±0.07**	0.79±0.06**	0.83±0.06**	0.88±0.05**	0.82±0.06**		0.97±0.01**	0.94±0.02**	0.84±0.06**
WK10	0.69±0.08**	0.75±0.07**	0.77±0.07**	0.82±0.06**	0.75±0.07**	0.93±0.04**		0.97±0.01**	0.84±0.06**
WK11	0.61±0.08**	0.65±0.08**	0.68±0.08**	0.72±0.07**	0.62±0.08**	0.82±0.06**	0.91±0.04**		0.93±0.03**
WK12	0.49±0.09**	0.52±0.09**	0.56±0.09**	0.61±0.08**	0.54±0.09**	0.62±0.08**	0.66±0.08**	0.72±0.07**	

**, $P \leq 0.01$; above diagonal, genetic correlations; below diagonal, phenotypic correlations; and N.E., Non Estimable.

Sivakumar *et al.* (2012) while working on litter weight at birth and weaning obtained the contrary estimates of heritability in SC and WG rabbits.

Growth curve modelling: Growth curve is a figure of an individual ability to express its genetic potential to maximum size under the existing environmental condition. The shape of the growth curve of rabbits was non-linear. All the fitted growth curves as presented in Fig. 1. reflect that White Giant is well adapted and performing better under the intensive management system. It can be observed that though the initial post weaning growth of both the breeds is almost same but in later growth stages and particularly around the age of marketing, White Giant breed performs better. This is further reiterated by the fact that the value of growth curve parameter *k* (indicator of growth performance) was estimated to be higher for White Giant by all the three models (Table 4). Similar higher estimate of parameter *k* was estimated by Jacob *et al.* (2015) in White Giant rabbits. Growth was fastest during the period of 5th to 6th and 11th to 12th week in Soviet Chinchilla however, the post weaning growth was mostly steady in White Giant rabbits. This also suggests that White Giant rabbits were relatively able to resist the post weaning shock efficiently. Similar observations were noted by Jacob *et al.* (2015) in same breeds of rabbits and Zerrouki *et al.* (2007) in local Algerian population.

Non-linear model parameters and goodness of fit: The estimated non-linear regression model parameters with the standard error together with the goodness of fit statistics namely R^2, Adjusted R^2, RMSE, AIC and BIC values for Soviet Chinchilla and White Giant rabbit breeds are given in Table 4.

The estimated model parameters and goodness of fit criteria indicated that in this study, all the competing models performed well with high coefficient of determination values. However, Gompretz model performed best for both breeds collectively with superior goodness of fit statistic values. Various growth curves were fitted with all three models using body weights of both the breeds. Curve fitted with actual body weights at various ages and predicted body weight using Gompretz model is coinciding, indicating its better fit (Fig. 2). Data on body weights at various ages for both Soviet Chinchila and White Giant were separately fitted with three growth curve models and it was observed that Gompretz model was most accurately (looking into all the model evaluation parameters) fitting to the White Giant breed of rabbit (Fig. 3). On the same line, when various body weights of Soviet Chinchila breed were fitted with all these three models, Von Bertalanffy model was most accurately fitted as per the goodness of fit criteria (Fig 4, Table 3). However, Jacob *et al.* (2015) reported that Von Bertalanffy model was best fitted for both the breeds of

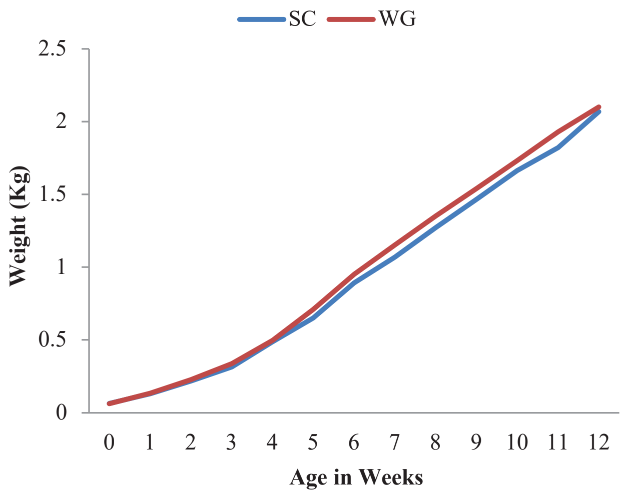

Fig. 1. Comparative growth curve of Soviet Chinchila and White Giant rabbits.

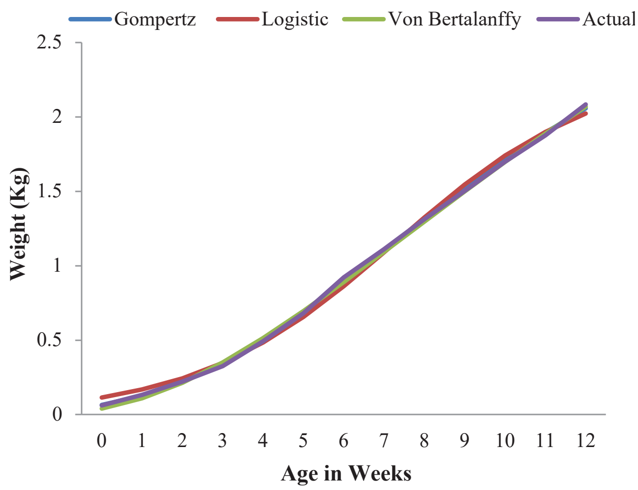

Fig. 2. Different growth curve models fitted for rabbits (both Soviet Chinchilla and White Giant).

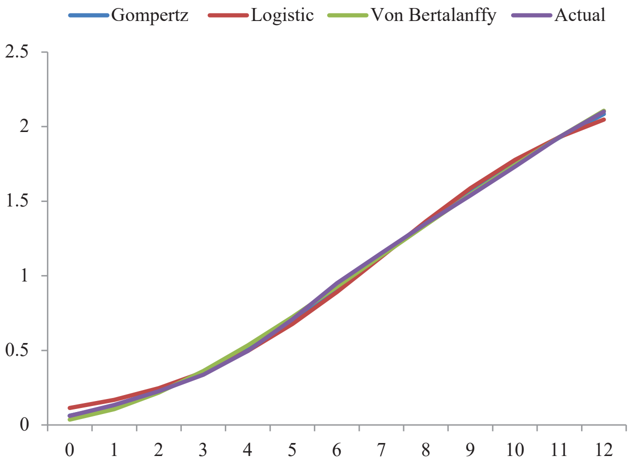

Fig. 3. Different growth curve models fitted for White Giant rabbits.

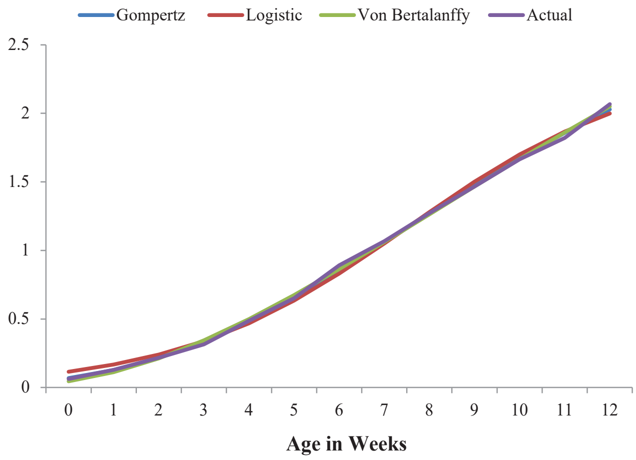

Fig. 4. Different growth curve models fitted for Soviet Chilchilla rabbits.

Table 4. Estimated model parameters ± SE and measures of goodness of fit for average body weights

Models	Parameters			Goodness of fit criterion				
	A	B	K	R^2(%)	Adj R^2(%)	RMSE	AIC	BIC
Rabbits (Both breeds)								
Gompertz	3.067±0.105	4.656±0.113	0.189±0.007	99.94	99.94	0.01723	-64.864	-63.169
Logistic	2.329±0.089	28.772±3.326	0.404±0.022	99.72	99.69	0.03806	-44.264	-42.569
Von Bertalanffy	4.038±0.254	0.879±0.016	0.114±0.007	99.93	99.93	0.01889	-62.479	-60.784
Soviet Chinchilla								
Gompertz	3.179±0.154	4.601±0.132	0.179±.009	99.91	99.9	0.02144	-59.178	-57.483
Logistic	2.343±0.104	28.504±3.409	0.393±0.024	99.67	99.64	0.04022	-42.829	-41.134
Von Bertalanffy	4.351±0.357	0.869±0.016	0.105±.008	99.91	99.9	0.02136	-59.279	-57.584
White Giant								
Gompertz	2.987±0.089	4.718±0.115	0.198±.007	99.95	99.94	0.01667	-65.724	-64.029
Logistic	2.322±0.081	29.121±3.37	0.414±.0022	99.74	99.71	0.03757	-44.597	-42.902
Von Bertalanffy	3.818±0.226	0.890±0.018	0.123±.008	99.74	99.71	0.03757	-44.597	-42.902

rabbits (SC and WG). Similarly, Fernandes *et al.* (2022) proved the Von Bertalanffy model to be more suitable for evaluating the growth of crossbred rabbits using both the longitudinal and crosssectional methods. Obioma *et al.* (2020) compared the non-linear growth curve models in non-descript California and New Zealand rabbits reared in the tropical conditions of Nigeria and found that the Gompertz and Logistic models were both parsimonious and adequate for describing the growth patterns of New Zealand White and California rabbits. However, Chen *et al.* (2021) compared five fitting models of growth curves (Logistic, Gompertz, Brody, Von Bertalanffy, and Richards) in a crossbred population of meat rabbits, and the logistic model was found to be more preferable.

The evaluation of the growth curve in rabbits can be used in the establishment of breeding programs and also in feeding systems for a better feed conversion efficiency and therefore greater animal productivity. Gompretz and Von Bertalanffy growth model described the average weekly body weight growth remarkably well, for WG and SC breeds respectively and hence may be effectively used for regulating feeding regimens and management to improve the overall productivity and profitability of rabbit farming.

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