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Short Communication

Comparison of five mathematical models to describe growth in mixed breeds of growing rabbit bucks

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Abstract
This study was carried out to assess different mathematical models on how they can best describe the body weight of mixed breeds growing rabbit bucks. A total of thirty-two (32) mixed breeds growing rabbit bucks between ages 6 and 7 weeks were raised for 8 weeks and the body weight was measured on weekly basis. The rabbits were kept individually in separate cages. The growth models were fitted to the body weight related to age via a non-linear procedure, using the Marquardt algorithm of J.M.P 13.2 statistical software. The body weights collected were subjected to five mathematical models (Logistic 3, Gompertz 3, Gompertz 4, Logistic 4, and Logistic 5) to predict the growth of 32 mixed breeds of rabbits. All five models performed well with the same coefficient of determination values. However, the Logistic 3 model performed better because lower AIC, BIC, and RMSE (879.49, 887.66, and 164.48, respectively) were obtained in the model. The findings in this study may be exploited in mapping out appropriate management practices geared towards increased productivity of mixed breeds of rabbit bucks in the tropic.

INTRODUCTION

Modeling growth curves in animal populations plays a crucial role in understanding and optimizing livestock production (Pla and Santos, 2006). By analyzing growth patterns, researchers can identify genetic, environmental, and management factors that influence growth rates and determine the optimal strategies for enhancing productivity (Gidenne *et al*., 2012). In the case of rabbits, a widely reared and economically important livestock species, modeling growth curves is particularly valuable for breeders and producers (Bolet *et al*., 2000). The Logistic 3 model is a variation of the logistic growth model. It is characterized by three parameters and is often used to describe population growth when there are limitations on resources or space. It incorporates a carrying capacity, initial population, and a growth rate. The

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Gompertz 3 and 4 models are simplified version of the Gompertz growth model. It includes three parameters and is commonly used to describe the growth of biological organisms, especially in the context of mortality (Thornley and France, 2007). It features an initial population, a maximum growth rate, and a rate of aging. The logistic growth model typically involves three parameters (carrying capacity, initial population, and growth rate. Logistic 4 and 5 models are the extension of the standard logistic growth model with additional parameters, constraints, or features to better fit specific data or scenarios.

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). Non linear models are well suited to describe the weight gain and evaluate a few other biological parameters, such 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 interpretations (Fernandes *et al*., 2020). Growth models are also used to predict the optimum slaughter age.

The modeling of growth curves will involve the application of statistical and mathematical techniques to describe the growth patterns exhibited by the rabbits. Several established growth models, such as the logistic, Gompertz, and von Bertalanffy models, have been widely used in previous studies to describe the growth curves of various animal species (Lukefahr, 1991). These models incorporate key parameters that represent growth rates, asymptotic size, and maturity age, providing a comprehensive representation of growth trajectories. By identifying breed-specific growth patterns and their associated determinants, breeders and producers can make informed decisions regarding selection, breeding strategies, and nutritional interventions to optimize growth and productivity in each breed (Cavani *et al*., 2004).

The findings of this study will have practical implications for rabbit breeders and producers, enabling them to understand the model of best fit and stages of optimal performances. This study therefore aims to compare different models (Logistic 3P, Logistic 4P, Logistic 5P and Gompertz 3P and Gompertz 4P) in order to investigate the growth patterns in mixed breeds of rabbits.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Rabbit Unit of the Teaching and Research Farm, Kaduna State University, Kafanchan Campus, Kaduna State, Nigeria. Kafanchan is located in the Southern part of Kaduna State on latitude 9° 34' 59.99"N and longitude 8° 16' 60.00" E (Ovimaps, 2022).

Ethics approval

According to local regulations, such approval is not required provided the Head of the Department and Research Committee gives consent.

Experimental animals and management

A total of 32 rabbit bucks of mixed breeds between the ages of 6 and 7 weeks old were used for the research, which lasted for 8 weeks. Before the commencement of the experiment, Ivermectin injection (the broad-spectrum anti-parasitic drug was administered to the rabbits to treat endo- and ectoparasites, and embazin was also administered during the experiment. Each rabbit was housed individually per pen and each pen was provided with a feeder and a drinker. Routine management operations such as regular cleaning of pens, feeders, and drinkers were carried out.

Data collection

The animals' body weights were taken before the commencement of the experiment with an initial average body weight of 762.24±52.66 g. The body weights were then taken on a weekly basis for 8 weeks using a sensitive scale (Samurai weighing scale).

Statistical procedures

Repeated measurements of individual body weight at different ages of the rabbits were fitted to 3P, 4P, and 5P models. The growth models (logistic 3P, 4P, and 5P; Gompertz; 3P and 4P) were fitted to the measurements of actual body weight related to age via a non-linear procedure, using the Marquardt algorithm of J.M.P 13.2 statistical software**.** The Goodness of fit was determined using the coefficient of determination (R2), adjusted R^2 mean square error (MSE), and root mean square error (RMSE). The models were employed using the Levenberg-Marquardt estimation option according to Selvaggi *et al.* (2015). The model performance was compared based on the coefficient of determination (R^2), root means square error (RMSE), Akaike information criterion and Bayesian information criterion. RMSE and R^2 of models were considered for the calculated goodness of fit parameters for the comparison among the different models between breeds/strains of improved tropical adapted chickens. Coefficient of determination (R^2)?=?1-(SSE/SST) where SSE is the sum of square of errors, and SST is the total sum of squares. Akaike's information criteria (AIC)?=?n*ln (SSE/n)?+?2k, where n; the number of observations, SSE; sum of square of errors, k; the number of parameters. Bayesian information criterion (BIC)?=?n*ln(SSE/n)?+?k*ln(n), where n; the number of observations, SSE; sum of square of errors, k; the number of parameters.

Table 1: Growth curve models and the age at point of inflection and weight at point of inflection of rabbit bucks.

Model	Functions	Ti	Yi
Logistic 3P	$BW = a \cdot Exp\left(-Exp\left(-b \cdot (Age - c)\right)\right)$	$Ln(1/Age)/a$	$C_{(0.5)}$
Gompertz 3P	$BW = \frac{c}{\left(1 + Exp\left(-a \cdot (Age - b)\right)\right)}$	$Ln(Age)/a$	$0.368(C)$
Logistic 4P and 5P	$BW = a + (b - a) \cdot Exp\left(-Exp\left(-c \cdot (Age - d)\right)\right)$	$\left(-\frac{1}{a}\right) Ln(d/Age)$	$C/\sqrt[n]{n+1}$
Gompertz 4P	$BW = \frac{(d - c)}{\left(1 + Exp\left(-a \cdot (Age - b)\right)\right)}$		

P=parameter; a=growth rate; b=inflexion point; c=lower asymptote; d=upper asymptote; Ti = The age at point of inflection; Yi =Weight at point of inflection; BW=Bodyweight.

RESULTS AND DISCUSSION

Figures 1 and 2 represent the Scatter plot of the linear relationship of body weight and age in the mixed breed rabbit and the fitted curve of body weight and age of the mixed breed rabbit using different models,

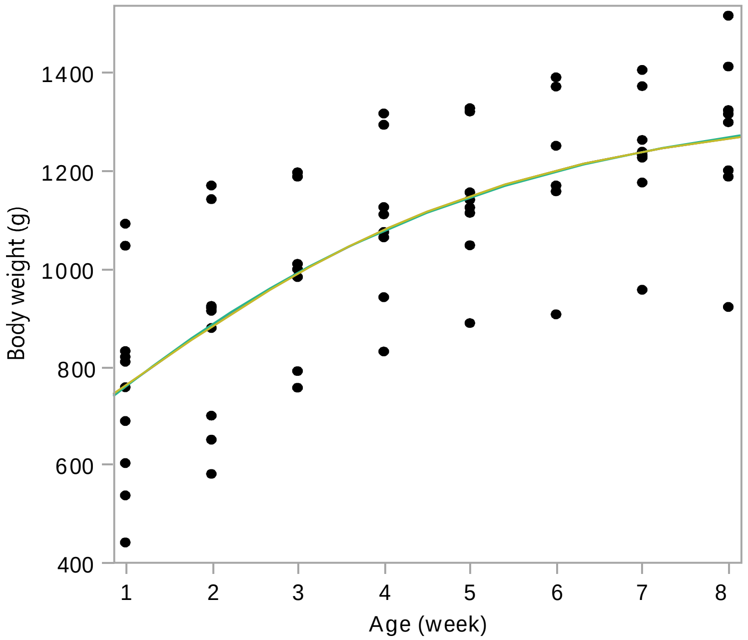

Figure 1. Scatter plot of the linear relationship of body weight and age in the mixed breed of rabbit

respectively. A 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. The fitted growth curve as presented in Figure 2 shows the optimum growth was between 4 and 5 week of age.

Best fit model selection for mixed breed of rabbit using goodness-of-fit tests values arranged in increasing order is presented in Table 2. In the mathematical models used, the Akaike's information criterion (AIC),

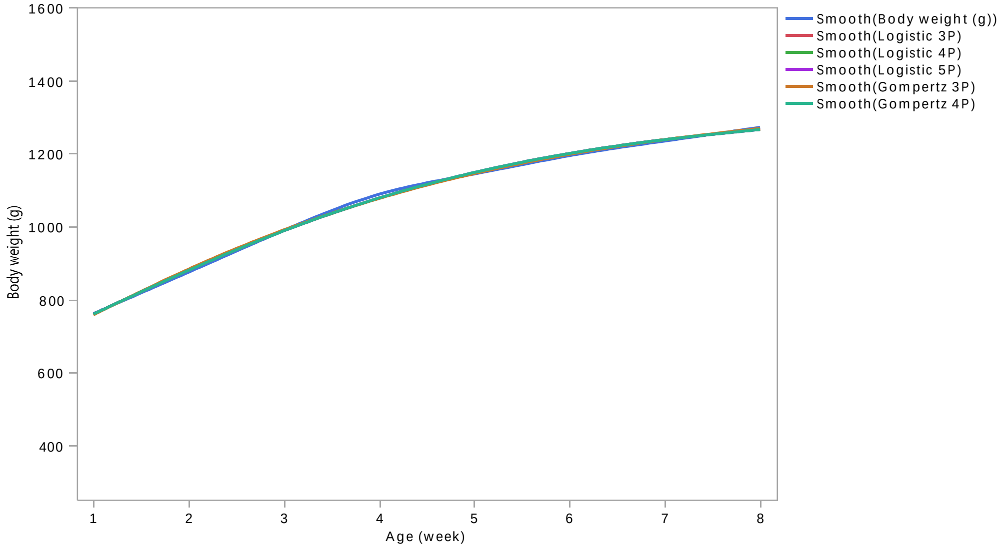

Figure 2. Fit curve of body weight and age of mixed breed of a rabbit using different models.

Bayesian information criterion (BIC), RMSE (879.49, 887.66 and 164.46, respectively) of logistic 3 are lower than Gompertz 3, Gompertz 4, Logistic 4 and Logistic 5. This shows that logistic 3 is the best model for assessing body weights of the rabbits.

The non-linear scatter plot and fit curve obtained in the current study is similar as obtained by Yakubu and Madaki (2017) in dual-purpose Sasso hens in the tropics. Similarly, Gupta *et al*. (2022) reported non-linear curve in modeling of growth curve in farm bred broiler rabbits in organized rabbitry. The reason for non-linear could be that growth reduces or remain static at certain age or when the animal reaches maturity (Gupta *et al*., 2022)

Zerrouki *et al.* (2007) reported that when three growth curve models were used, it was observed that Gompretz model was most accurately looking into all the model evaluation parameters. Jacob *et al.* (2015) reported that when various body weights of the Soviet Chinchilla breed were fitted with all three models, Von Bertalanffy's model was most accurately fitted as per the goodness of fit criteria compared to Gompertz and logistics.

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 preferable. The evaluation of the growth curve in rabbits can be used in the establishment of breeding programs and also in feeding systems for better feed conversion efficiency and therefore greater animal productivity.

Table 2. Best fit model selection for a mixed breed of rabbit using goodness-of-fit tests values arranged in increasing order

	Models				
Parameters	**Logistic 3**	**Gompertz 3**	**Gompertz 4**	**Logistic 4**	**Logistic 5**
AIC	879.49	879.50	881.82	881.83	884.24
BIC	887.66	887.67	891.87	891.87	896.07
WAP (W_i)g	1104.78	1103.25	1105.39	1104.79	1105.38
Age at the inflection point (t_i), wk	4.36	4.36	4.36	4.36	4.36
Growth rate estimate	0.39	0.31	0.38	0.39	0.38
Inflection point	0.25	-0.75	1.12	0.27	-15.85
MSE	27055.12	27058.82	27481.87	27484.57	27925.13
RMSE	164.48	164.50	165.77	165.78	167.11
R^2	0.54(54%)	0.54(54%)	0.54(54%)	0.54(54%)	0.54(54%)

BIC: Bayesian information criterion; RMSE: root mean square error; MSE: mean square error; R^2: coefficient of determination; WAP; Weight at the inflection point (W_i) g, Age at the inflection point (t_i) week.

CONCLUSION AND RECOMMENDATION

Among the mathematical models used, logistic 3p performed better than others because of its lower AIC, BIC, and RMSE.The evaluation of the scatter plot and growth curve in the mixed breed of rabbit bucks can be used in the establishment of breeding programmes for better productivity. The findings in this study may be exploited in mapping out appropriate management practices geared towards increased production in rabbit farming.

Conflicts of interest: The authors declare no conflict of interest.

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