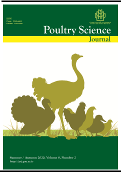

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Describing Growth Pattern Using Gompertz Growth Function – A Case Study of Kuchi Chicken in Kenya

Lihare GO[1,2], Wasike CB[1,2] & Kahi AK[1]

[1]Animal Breeding and Genetics Group, Department of Animal Science, Egerton University, Egerton, Kenya
[2]Livestock Efficiency Enhancement Group (LEEG), Department of Animal Science, Maseno University, Maseno, Kenya

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Corresponding author
George Onyango Lihare
glihare@yahoo.com

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Abstract

This study was conducted to determine the growth patterns of the Kuchi ecotype of chicken in Kenya. Data was obtained from intensively reared Kuchi birds at Indigenous Chicken Improvement Programme (INCIP) facility at Egerton University. Gompertz's nonlinear growth model was fitted to the Kuchi longitudinal growth data to predict the live body weight at various age points and the growth curve parameters. Growth rate and maturity parameters for all ages were calculated using growth curve parameters. The inflection parameter including age at inflection (T_I), body weight at inflection (BW_I), and growth rate at inflection (G_I) was also calculated using the growth curve parameters. Males had significantly ($P < 0.05$) higher body weight from week 14 to week 32, and absolute growth rate from week 12 to week 28 of age. Males were significantly ($P < 0.05$) superior to counterpart females in asymptote (A), body weight at inflection (BW_I), and weight gain at inflection (G_I). Females attained puberty earlier than counterpart males and from week 8 of age, females were more mature than males with significant difference ($P < 0.05$) in both degree of maturity (U) and absolute maturity rate (AMR). From the results of this study, it is recommendable to rear Kuchi males and females separately from the age of inflection (week 12) when they experience significantly different growth rates. Optimum feeding of Kuchi should be done at age of week 8 to week 14 when its growth rate is highest thus high feed conversion efficiency and consequently high-profit margin. Kuchi chickens were found to have slower juvenile growth and may not be the best ecotype of chicken for quick production of tender meat among the indigenous chicken ecotype found in Kenya.

Introduction

Kenya has numerous ecotypes of indigenous chicken (IC) kept mainly by the small-scale farmers for food and income generation (Olwande *et al*., 2010; Okeno *et al*., 2012; Padhi, 2016). These ecotypes are tolerant of harsh tropical environments and diseases making them fit for production in the smallholder poultry farming systems. They vary widely in various aspects of growth and production in the respective climatic and managerial conditions where they are kept. The wide variation in these ecotypes poses the potential for genetic improvement through selection. The ecotype of interest in this study (Kuchi), is mainly found in the coastal region particularly Lamu County (Magothe *et al*., 2012). Growth performance and genetic analyses have been done on the various Kenyan IC ecotypes (Magothe *et al*., 2010; Ngeno, 2010) but studies on the Kuchi are scanty with no information about its growth patterns in Kenyan. A study in Tanzania found Kuchi to be superior in body weight compared to other ecotypes suggesting its genetic potential for improvement in body weight trait (Lwelamira *et al*., 2008). This finding has prompted Kenyan farmers who now focus on utilizing Kuchi for meat and egg production but without full knowledge of its growth and genetic characteristics under the Kenyan environment. It is therefore important to understand the Kuchi growth patterns to allow for the design of its feeding and breeding programs for feed conversion efficiency, age, and weight at maturity for its improved productivity. Description of growth patterns involves

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the use of growth models by fitting the growth data to summarize the information contained in the entire sequence of size-age into a small set of parameters which can be interpreted biologically (Orheruata *et al.,* 2006; Kopuzlu *et al.,* 2013) and be used to derive other relevant growth traits (Fitzhugh, 1976). Graphical expression of these functions also helps in eliminating irregular variations in weight caused by random environmental effects (Nahashon *et al.,* 2006;). Knowledge of the growth patterns can be used on selecting for the desired growth parameters and a better understanding of biological control of the animal's growth. This study aimed to determine the growth patterns of Kuchi chickens reared under an intensive system in Kenya and estimate its growth curve parameters.

Materials and methods

Data source

The age-weight data of 160 kuchi birds kept at Taton Research Unit, Egerton University from June 2012 to November 2016 was used for this study. The data comprised 1741 weight records on 69 males and 91 females from hatch to 32 weeks of age. All birds in the unit were given standard management from hatch to maturity. Chicks were kept in the brooder from hatch the end of week four after which they were transferred to rearing pen at the spacing of 7 birds per square meter. The heat was provided to the chicks in the brooder using infrared bulbs with the initial temperature set at 32°C and was reduced by 2°C every week until room temperature (25°C) was attained at week 4. Birds were then transferred from the brooder to rearing a deep litter pen at the beginning of week 5. Birds were fed ad-libitum on feeds formulated at the farm; starter mash from hatch to week 4 in the brooder, growers mash from week 5 to 17 and layers mash from week 18 onwards. Clean water was provided ad libitum daily and rearing pens cleaned and disinfected routinely. Birds were vaccinated and treated against the Newcastle, Gumboro, Fowl typhoid, and Fowl pox diseases. Eggs were collected and incubated within 10 days of laying upon weighing and cleaning. Chicks were fitted with identification tags at hatch, weighed, and recorded appropriately. Bi-weekly weight data for each bird was taken subsequently from week 2 to week 32 of age using a digital electronic weighing scale. The data included bird ID, sire, dam, egg weight, date of the hatch, sex, weight, and date of weighing. Sex was determined by the phenotypic appearance at week 12.

Data analysis

Model fitting

A preliminary analysis was done to determine the growth model that best fitted the data. Three growth models Richards, Gompertz, and Logistic were fitted to the longitudinal growth data for each bird using the nonlinear regression of Curve Expert professional software 2.2.0 (2014) to describe the growth pattern and derive the growth curve parameters of each bird. Equations for the models fitted according to (Fitzhugh, 1976) are as below:

Richards: $$y_t = A(1 \pm be^{-kt})^M \quad \text{(Equation 1)}$$

Gompertz: $$y_t = Ae^{-be^{-kt}} \quad \text{(Equation 2)}$$

Logistic: $$y_t = A(1 + be^{-kt})^{-1} \quad \text{(Equation 3)}$$

Where y_t is the observed live weight at age t, A is the asymptotic or mature weight, b is a scaling parameter (constant of integration) related with initial values of weight, k is the maturation rate, m is the shape parameter and t is the age in weeks.

Model evaluation

The goodness of fit criteria used was coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}), Akaike Information Criteria (AIC), and Mean Square Prediction Error (MSPE) to find the model that best describes the data. The R^2 and AIC values for the three models were obtained right from the output of the analysis while those of R^2_{adj} and MSPE was derived as below:

$$R^2_{adj} = 1 - \left(1 - R^2\right)\frac{n-1}{n-p-1} \quad \text{(Equation 4)}$$

where R^2 = coefficient of determination (equal to $1-(RSS/TSS)$, RSS = residual sum of squares, TSS = total sum of squares, *n* = number of observations and *p* = number of parameters.

$$MSPE = \frac{\sum_{t=1}^{n} e_t^2}{n} \quad \text{(Equation 5)}$$

Where e_t e is the residual for the body weight at age t of test and n is the number of predicted values obtained.

The model which had the highest value of R^2 and R^2_{adj} and lowest value of AIC and MSPE was considered to best fit the growth data and was used to estimate the live body weight from hatch to week 32 of age. The derived growth curve parameters by the best fitting model were used to calculate growth and maturity rates at particular ages for each bird.

Growth curve parameters by the Gompertz model were used to calculate growth and maturity rates at particular ages for each bird according to the definition of Fitzhugh (1976) as presented in equations (6 to 10):

$$AGR = L \times \exp(-kt)\, y_t \quad \text{(Equation 6)}$$

$$RGR = L \times \exp(-kt) \times 100 \quad \text{(Equation 7)}$$

$$U = \frac{y_t}{A} \quad \text{(Equation 8)}$$

$$AMR = (AGR)A^{-1}$$ (Equation 9)

Where AGR is the absolute growth rate, RGR is the relative growth rate, U is the degree of maturity, AMR absolute average maturity rate, L is initial specific growth rate (k/b), k is the exponential rate of decay of the initial specific growth rate, yt is estimated body weight at age t and A is the mature size (asymptote)

The coordinates of the point of inflection (POI); age (T_I), body weight (BW_I), and weight gain (G_I) were computed as per the definition of (Raji *et al.*, 2014) using the equations (10 to 12):

$$T_I = (b / k)$$ (Equation 10)

$$BW_I = A / e$$ (Equation 11)

$$U_I = Ak / e$$ (Equation 12)

where in addition to the above described A, b, and k, e is the eulerian number or base of the natural logarithm (2.71828)

PROC GLM of SAS (2004) software was used to analyze the effect of the fixed factors of sex and hatch on the estimated growth parameters. The least-square means of the body weight and associated parameters were then tabulated and or plotted by sex against age to obtain curve patterns of kuchi growth.

Results and discussions

Best fit model

R^2 and R^2_{adj} values were high and parallel for all the three models (> 0.99) making it difficult to distinguish the best among them to the data based on the two criteria. The value of AIC was lowest for Gompertz suggesting its best fit compared to Logistics and Richards growth models respectively. Richards model has 4 parameters compared to Gompertz and Logistic which have 3 parameters each making it less parsimonious thus not the best. Mean square prediction error (MSPE) evaluation gave the best distinction among the three growth models that were fitted in the analysis. Gompertz model had the lowest value of MSPE compared to Richards and Logistic respectively (Table 1). Data convergence during the analysis was lowest for Richards (89.70 %) compared to Gompertz (96.36 %) and Logistic (98.18 %) making it far from being the best fit model.

Gompertz model had the most favoring aspects and was therefore considered the best fit model of the three to describe the Kuchi growth data. This finding concurs with the findings on the best-fit growth model to the growth data of various IC ecotypes in Kenya (Magothe *et al.,* 2010); Ngeno *et al.,* 2010). Gompertz has been reported as the most commonly used 3-parameter non-linear growth function for modeling growth in poultry (Narinç *et al.,* 2017). In the modeling of the growth curve of nondescript Italian chicken breed (Selvaggi *et al.*, 2015), Gompertz and Richard's models were found to best describe the growth pattern of female and male birds compared to the Logistic model which slightly overestimated the initial body weight and underestimated the final body weight. Gompertz and Logistic growth models were found to fit the growth curves of slow-growing chicken genotypes in the organic system very well giving R^2 values of 0.998 and 0.999 respectively (Eleroğlu., 2014). Norris *et al.* (2007) reported the Gompertz growth curve to be appropriate for describing the age-live weight relationship in the Venda and Naked Neck indigenous chicken breeds of South Africa. Gompertz was reported better compared to Logistic and Bertalanffy growth models in fitting growth curves of shaobo, Huaixiang, and Youxi indigenous chickens in China (Zhao *et al.*, 2015). Michalczuk *et al.* (2016) reported the Gompertz growth model to best describe the data of medium growing chicken of an experimental line based on the coefficient of determination (R^2) and adjusted coefficient of determination (R^2_{adj}).

Table 1. Presents the various model evaluation criteria that were used and the corresponding values.

Criterion	Gompertz	Logistic	Richards
R^2	0.9950	0.9942	0.9962
R^2_{adj}	0.9943	0.9934	0.9953
AIC	70.8798	72.6957	75.4830
MSPE	10352.94	75600.53	40152.82
No. pars	3	3	4

Body weight

Least square means of estimated live body weight at various ages for Kuchi birds are presented in Table 2. Both sexes had similar juvenile body weight up to week 12 which was the overall point of inflection (POI). The body weights at ages after POI were significantly higher ($P < 0.05$) for males compared to females suggesting post-juvenile sexual dimorphism. Males are known generally to have higher body weight than females but this study has shown a conspicuous sexual dimorphism. The result shows males of Kuchi to be 43.16% higher in mature weight than counterpart females demonstrating sexual dimorphism in growth. Sexual dimorphism has been reported in the growth of various ectypes of chicken around the world with males having significantly superior weight traits compared to counterpart females (Apuno *et al.*, 2011; Alabi *et al.,* 2012; Selvaggi *et al.,* 2015; Tadele *et al.,* 2018; Mata-Estrada, 2019).

Table 2. Least square means (±SE) of Kuchi live body weight (grams) by sex along trajectory

Age	Female	Male	Overall
Week 0	22.11±1.90	26.39± 2.18	24.02±16.60
Week 2	59.22±3.26	65.03± 3.75	64.59±28.51
Week 4	134.42±5.01	140.17± 5.75	145.82±43.82
Week 6	262.58±13.34	265.46±15.33	280.70±116.78
Week 8	403.32±16.40	422.47±18.85	443.07± 143.60
Week 10	562.43±19.18	627.58±22.03	635.21± 167.90
Week 12	720.40±22.92	849.13±26.33	830.59± 200.64
Week 14	864.79±26.98[a]	1063.18± 30.78[b]	1014.94±234.56
Week 16	994.03±30.48[a]	1263.31± 35.02[b]	1182.61±266.80
Week 18	1106.11±33.63[a]	1443.22± 38.63[b]	1329.72±294.36
Week 20	1213.54±36.76[a]	1600.72± 42.23[b]	1462.47±321.79
Week 22	1290.01±39.04[a]	1738.09± 44.85[b]	1566.87±341.76
Week 24	1355.75±43.49[a]	1844.74± 49.96[b]	1649.75±380.70
Week 26	1402.51±46.78[a]	1953.70± 53.75[b]	1725.30±409.52
Week 28	1457.27±48.20[a]	2032.04± 55.37[b]	1792.87±421.91
Week 30	1494.35±51.16[a]	2099.25± 58.78[b]	1843.23±447.87
Week 32	1525.88±53.89[a]	2152.22± 61.91[b]	1883.04±471.75

[ab]Means in a row with different letter subscripts are significantly different ($P < 0.05$).

The live body weights of Kuchi before inflection age were relatively lower than those reported for the other Kenyan IC ecotypes in the literature. This portrays Kuchi as an inferior ecotype in meat production going by the current age of 5-8 weeks at which the commercial breeds (broiler and their crosses) are slaughtered, respectively. The study however found Kuchi to be superior in post inflection body weights to most of the Kenyan IC ecotypes. The inverse difference in pre and post inflection body weights between Kuchi and other Kenyan ecotypes is a potential that can be utilized to develop a hybrid of chicken with both better juvenile and mature weight through crossbreeding.

The live body weights of Kuchi chickens reported in this study were however less than those reported for intensively reared Kuchi in Tanzania (Lwelamira *et al.,* 2008). This is an indicator of existing variation within Kuchi ecotype across their various habitats hence possible improvement through selection. This is however with the consideration that the difference in body weight could as well be largely attributed to the difference in the prevailing climatic conditions. Kuchi is mainly inhabitant of regions with high temperatures and humidity particularly the northern part of Tanzania and the coastal region of Kenya as opposed to the cold and less humid climate of Njoro in Nakuru County where this study was conducted.

Growth curve parameters

The least square means of growth curve parameters for Kuchi chickens are presented in Table 3.

Table 3. The least square means (± SE) of growth curve and inflection parameters of Kuchi chickens by sex

Parameter	Female	Male	Overall
R^2	0.995±0.007	0.994±0.007	0.995±0.006
A (grams)	1703.36± 80.41[a]	2438.88± 92.38[b]	2104.55± 703.94
b	1.57± 0.06	1.58± 0.07	1.57± 0.52
k	0.15± 0.01	0.13± 0.01	0.15± 0.04
T_I (weeks)	11.63± 0.47	12.69± 0.54	11.67± 4.12
BW_I (grams)	626.63±29.58[a]	897.21± 33.99[b]	774.22± 258.96
G_I (grams)	87.67± 2.92[a]	114.35± 3.36[b]	105.48± 25.60
P	0.37	0.37	0.37

R^2 = coefficient of determination, A = asymptotic body weight b = scaling parameter, k = maturation rate, T_I=age at inflection, BW_I= body weight at inflection, G_I = growth rate at inflection and P =proportion of mature weight attained at POI.

[ab]Means in a row with different letter subscripts are significantly different *($P < 0.05$).*

In the derivation of these parameters, R^2 was high for both sexes indicating excellent fit of the Gompertz function to the Kuchi growth data. Overall asymptotic weight (A) of Kuchi in this study (2104 g) was higher than the values earlier reported for other Kenyan IC ecotypes (Ngeno, 2010; Magothe *et al.*, 2010). Maturation rate (k) had the lowest value of standard error showing its excellent goodness of fit of all the estimated parameters. The k value was 0.16 was consistent with those reported for Bondo, Kakamega, Narok, Bomet, and West Pokot IC ecotypes (0.12 – 0.14) in Kenya using the Gompertz model (Ngeno *et al.*, 2010). Magothe *et al.* (2010) however reported much lower values (0.014 – 0.016) of k for other Kenyan IC ecotypes; normal feather, crested-head, fizzle-feather, and naked-neck IC using the Gompertz model. The differences indicate the existence of a wide variation in the rate of maturity among Kenyan IC ecotypes which could be used as a basis of selection.

The POI of the growth curve has three main coordinates namely; age at inflection (T_I), weight at inflection (BW_I), and rate of growth at inflection (G_I). POI is the point of growth at which the growth rate is highest while the acceleration of growth ceases (Segura-Correa *et al.*, 2017) and it provides an estimate of age and weight at puberty. The rate of growth at inflection was significantly different between the sexes. Under the conditions of the present study, males reached puberty significantly ($P < 0.05$) later than counterpart females by one week. Males had higher body weight at the point of inflection compared to counterpart females. The overall body weight and age at inflection for Kuchi in this study were consistent with the estimates reported for some genotypes of Kenyan IC that ranged from 788 to 837 g and 91 to 98 days respectively (Magothe *et al*., 2010). Similar findings have been reported for other IC ecotypes in other parts of the world suggesting an existing relationship among chicken ecotypes across the world. Eleroğlu *et al*. (2014) reported similar age at inflection for female and male slow-growing genotypes of chicken raised by the organic system in Turkey using Gompertz as 11.54 and 12.11 weeks, respectively. Selvaggi *et al*. (2015) reported age at the inflection of non-descript Italian chicken to be 12.0 and 12.1 weeks for females and males respectively but with relatively heavier body weight 4840 g (female) and 5000 g (male), respectively using the Gompertz growth model. The proportion of mature body weight attained at inflection (P) was 0.37 translating to 37% for both sexes. The parameter P is the determinant of the shape of the growth curve and it was similar for the two sexes demonstrating similar growth curve patterns for female and male Kuchi.

Growth rates

The least-square means of Kuchi Absolute growth rate (AGR) at various age points are presented in Table 4. AGR is the measurement and comparison of total growth per unit time while RGR is the growth of a given system per unit time expressed on a common basis. RGR measures the average percentage change in growth over the same time frame. AGR was significantly ($P < 0.05$) different between males and females from week 12 to week 28 of age. Females attained their maximum AGR earlier at week 10 compared to males at week 12. This finding is in concurrence with that of Ngeno (2010) who reported various Kenyan IC ecotypes to attain maximum AGR at 10 - 14 weeks of age.

Table 4. Least square means(±SE) of absolute growth rate (agr_t) of Kuchi at different ages against sex

Age_t	female	male	overall
wk0	2.31±0.26	2.16± 030	2.26± 2.25
wk2	4.60± 0.34	4.24± 0.38	4.68± 2.92
wk4	7.40± (0.35	7.04± 0.40	7.76± 3.03
wk6	9.90± 0.37	10.02± 0.42	10.70± 3.21
wk8	11.21± 0.39	12.13± 0.45	12.51± 3.42
wk10	11.59± 0.40	13.71± 0.46	13.37± 3.47
wk12	11.12± 0.42)^a	14.19± 0.48^b	13.16± 3.67
wk14	10.13± 0.44)^a	13.73± 0.51^b	12.25± 3.89
wk16	8.94± 0.46^a	12.73± 0.53^b	10.99± 4.03
wk18	7.73± 0.46^a	11.44± 0.53^b	9.61± 4.06
wk20	6.62± (0.46^a	1007± 0.53^b	8.27± 4.00
wk22	5.59± 0.44^a	8.72± 0.81^b	7.02± 3.89
wk24	4.70± 0.43^a	7.45± 0.49^b	5.90± 3.72
wk26	3.93± 0.41^a	6.35± 0.46^b	4.950± 3.51
wk28	3.30± 0.38^a	5.37± 0.43^b	4.14± 3.28
wk30	2.76± 0.35	4.52± 0.40	3.46± 3.05
wk32	2.32± 0.32	3.80± 0.37	2.89± 2.81

$agr_{t,}$ = absolute growth rate (g/day) at age t in weeks.
^{ab}Means in a row with different letter subscripts are significantly different ($P < 0.05$).

There was no significant difference in relative growth rate between sexes at all ages but values for males tended to be higher from hatch to week 4 of age (Figure 1). RGR declined drastically for both males and females from hatch to age at inflection and then gradually thereafter approaching maturity.

The changes in these two parameters AGR and RGR give Kuchi ecotype a growth curve that has a characteristic S-shape (Figure 2), typical of mammalian and avian growth curves. Sigmoid growth curves have four characteristics; an accelerating growth phase following hatch, a point of inflection coincident with maximum growth rate, a decelerating growth phase, and a limiting mature weight which is approached asymptotically.

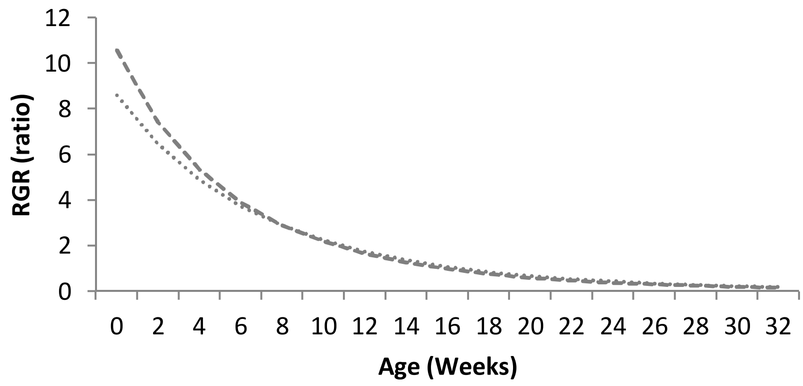

Figure 1. Relative growth rate for male (– – –) and female (……) Kuchi along the trajectory

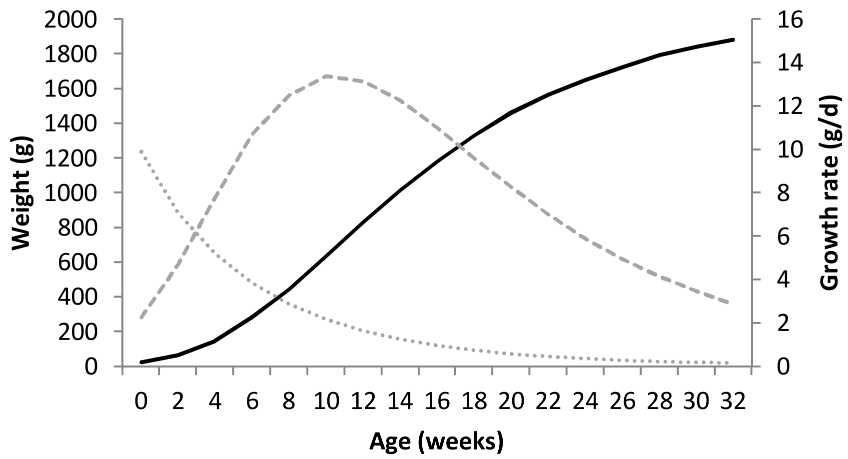

Figure 2. Curves of overall cumulative growth (—), absolute growth rate (– – –) and relative growth rate (…..) of Kuchi by Gompertz model.

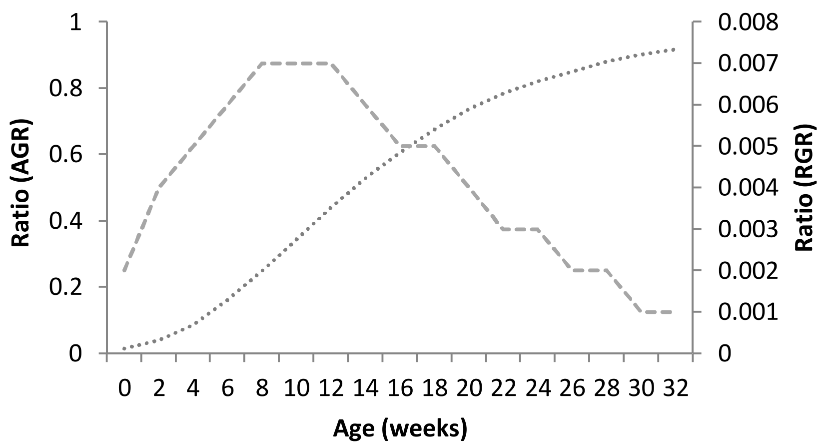

Figure 3. Curves of the degree of maturity (….) and absolute maturity rate (– – –) of Kuchi by Gompertz model.

From the illustration in Figure 2, the overall growth rate of Kuchi increased rapidly until the age at POI (week 10) when maximum growth rate (13.37 g per day) was attained beyond which the growth rate declined approaching zero at maturity. Kuchi growth according to the graphs in this study is determinate with an asymptotic (S-shape) growth curve as described by Karkach (2006).

Maturity rates

Figure 3 shows the overall curves of the degree of maturity (U) and absolute maturity rate (AMR). The degree of maturation as illustrated by the S-curve increased gradually from the hatch, rapidly towards POI and again gradually thereafter. The larger portion of maturation was found to occur before POI as illustrated by the absolute maturity curve. The rate of maturity for Kuchi was highest and constant at weeks 8, 10, and 12 beyond which it declined irregularly towards maturity. The two curves of maturity (Figure 3) intersects at week 16 coinciding with the age at the first egg in chicken known to range between 16-21 weeks depending on breed/ecotype and management. Age at sexual maturity in Cockrell and pullets generally corresponds with the point of inflection of the growth curve. Figures 4 and 5 present the degree of maturity (U) and absolute maturity rate (AMR) by sex, respectively.

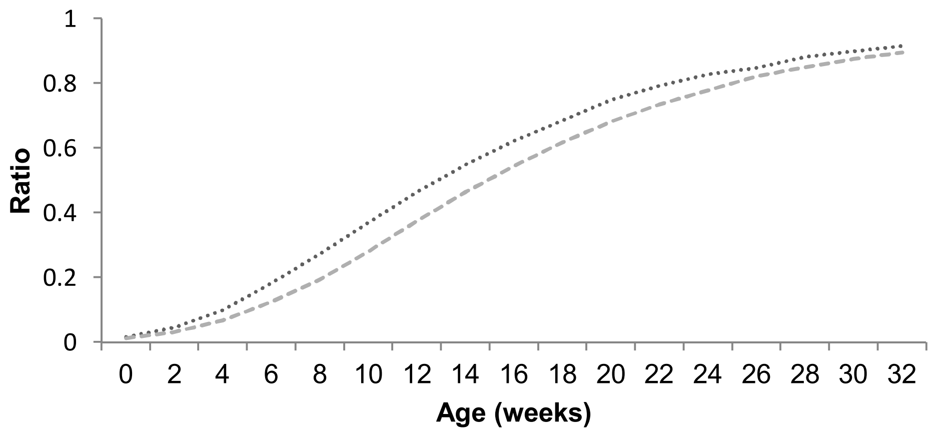

Figure 4. Curves of the degree of maturity (U) for female (……) and male (– – –) Kuchi Chickens.

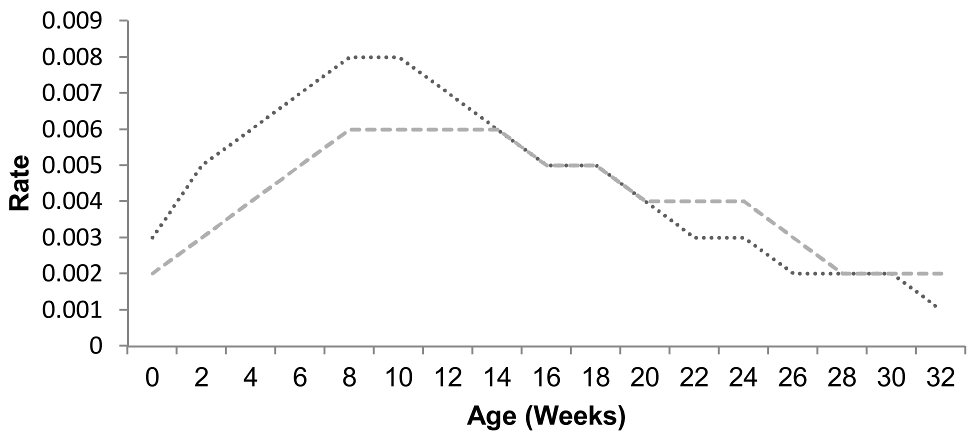

Figure 5. Curves of absolute maturity rate (AMR) for female (……) and male (– – –) Kuchi chickens.

Females had significantly ($P < 0.05$) higher U at 8th, 10th, and 12th weeks of growth (Figure 4) and higher AMR at week 8 (Figure 5) of growth. The findings indicate that female Kuchi matures earlier and attains higher maturity than counterpart males. The study also reveals a high rate of maturation (k) in females than in males as indicated in (Table 2). Males of many chicken breeds have been reported in the literature to take longer to mature and attain higher weight at maturity compared to counterpart females in concurrence with the finding of this study. This could be attributed to the male sex hormone (testosterone) which acts also as a better growth factor. The rate of maturation was however found to decline (decay) faster in females compared to males whose rate of maturity remained relatively higher after the POI.

Conclusion

The Richards, Logistic and Gompertz growth models can be used to model the growth of Kuchi chicken but Gompertz is exceptionally good compared to the other two. Kuchi growth is dimorphic with males having superior body weight, especially from puberty. It is, therefore, recommendable to rear Kuchi males and females separately from week 10 of age which is the age at puberty for females. The highest quality and quantity feeds should be given at weeks 10 and 12 for female and male Kuchi respectively, when growth is maximum for the respective sexes thus high feed conversion efficiency and profit margin. Kuchi has shown slower juvenile growth but superior growth from puberty compared to the other Kenyan IC ecotypes reported in the literature. The inferior pre-inflection body weights of Kuchi give it unfair competition in Kenya where broiler and improved crosses are utilized for commercial chicken meat production within 5 – 8 weeks, respectively. This implies that if the Kuchi ecotype is to be used in Kenya for meat production, selection must be done to improve its early growth. On the other hand, Kuchi is superior in post inflection live body weights and the two extremes can be exploited in developing a hybrid with both better juvenile and mature weight through crossbreeding with the other Kenyan IC. The performance of the Kuchi ecotype in this study is inferior compared to its performance reported in hot and humid provinces of Tanzania. This suggests that this ecotype should be kept and developed in areas where they currently inhabit or under a mimic of similar environmental conditions.

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