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Evaluation of Growth Curves Models in Two Chicken Lines

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Abstract

THIS study investigated growth patterns in two selected lines for rapid growth of native chickens: normal feathering (nana) and naked-neck (NANA/Nana). Body weights (BWs) of 800 chicks (400 per line) were recorded from hatch to 126 days of age at the Poultry Farm, Faculty of Agriculture, Cairo University, Egypt. Body weight data were fitted to three nonlinear regression models (Gompertz, Richards, and Logistic growth curves). Results showed significant line effects ($P<0.001$) on all BWs, with the nana line consistently heavier throughout the growth period. Sex effects were evident only at later ages (70, 112, and 126 days). Among the models, the Gompertz function provided the best fit across all goodness of fit criteria, followed by the Logistic model, while the Richards model ranked last. In the Gompertz model, the NANA/Nana line exhibited higher asymptotic weight and slower maturation compared with the nana line, reaching inflection points at later ages with greater body weights. The earlier maturity of the nana line may be advantageous under heat-stressed conditions, whereas the higher mature weight of the NANA/Nana line suggests potential value in breeding programs aiming at growth improvement.

Keywords: Nonlinear regression, growth models, Gompertz function, native chicken, naked-neck gene.

Introduction

Growth is one of the most important economic traits in poultry, reflecting the increase in body size or weight over time [1,2]. It is influenced by both genetic and environmental factors, which makes single-point measurements inadequate for describing growth variability [3].

Growth curves provide a more comprehensive description of body weight changes with age [4]. Sigmoid-shaped growth curves provide parameters with biological interpretations that describe growth patterns over time [5]. Moreover, these parameters offer valuable insights into maturity-related development and the inflection point, providing more information than analysing body weights at specific ages [6]. Among the available models, the Gompertz, Logistic, and Richards functions are widely applied in poultry because of their strong fit with empirical data and the biological interpretability of their parameters [7–9]

Local chicken breeds are an important genetic resource due to their adaptability and role in sustainable poultry production [10,11]. They are generally more resilient to harsh conditions, which is especially valuable under the increasing impacts of climate change [12]. The naked-neck (Na) gene is a well-known adaptive trait, reducing feather coverage by 20% in heterozygotes (Na/na) and 40% in homozygotes (Na/Na) compared with fully feathered birds (na/na) [13]. This reduction improves heat dissipation and enhances tolerance to high temperatures [14,15]. Evaluating the growth of naked-neck lines is therefore relevant for breeding programs targeting productivity under hot environments. Selective breeding has greatly shaped chicken growth, with much of the improvement in modern chickens attributed to selection for increased body weight [16]. However, selecting at a single age can alter the entire growth curve, influencing parameters across both sexes [17,18]. For this reason, analyzing complete growth trajectories is more informative than relying on isolated body weight records.

Despite the importance of growth curve modeling, few studies have compared the Gompertz, Logistic, and Richards functions in native Egyptian chickens under controlled conditions. This study was therefore designed to evaluate the fit of three nonlinear models in two selected local lines—

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normal-feathered (nana) and naked-neck (NANA/Nana)—and to estimate biologically interpretable parameters that may support the design of sustainable breeding programs.

Material and Methods

Experimental design and dataset

This research was conducted at the Poultry farm, Faculty of Agriculture, Cairo University, Egypt, with approval from the Institutional Animal Care and Use Committee (approval number: CU-H-R-F-1-23). The study aimed to characterize growth patterns in two chicken lines selected for rapid growth as a naturally heat-resistant native chicken breed: normal feathering (nana) and naked-neck (NANA/NAna) [19]. Studied genotypes: naked-neck and normal feathering chickens were presented in Figure (1). Pedigree records of 800 chicks from the eighth generation of selection were analyzed. The dataset included 200 females and 200 males per line, and all chicks originated from the same hatch.

Husbandry and management

After hatching, chicks from both lines were wing-banded for pedigree identification and reared in floor brooding chambers until 6 weeks of age, then transferred to floor pens until 18 weeks, using a conventional housing system. The feeding regimen consisted of ad libitum access to a broiler starter ration (22–23% CP, 2800 kcal ME/kg) from 0–4 weeks, followed by a broiler finisher ration (19–20% CP, 3100 kcal ME/kg) from 5–8 weeks according to NRC 1970. From 9–18 weeks, birds received a growing ration (15% CP, 2700 kcal ME/kg) at 120 g/bird/day. Water was provided ad libitum. Chicks were maintained at a brooding temperature of 32–34 °C during the first week, which was gradually reduced by 2–3 °C per week until reaching 24 °C by week 6, and maintained thereafter. Relative humidity was kept between 55–65%. Birds were subjected to continuous lighting from hatch to 8 weeks of age, then 14–15 h light/day using natural and supplemental light. By week 17, the lighting period was increased to 16–17 h/day. All birds were kept under identical managerial, hygienic, and environmental conditions.

Studied traits

Individual body weights (BW) were recorded to the nearest 0.01g at hatch and at 14-day intervals thereafter, up to 126 days of age. These measurements were designated as BW_0, BW_{14}, BW_{28}, BW_{42}, BW_{56}, BW_{70}, BW_{84}, BW_{98}, BW_{112}, and BW_{126}, respectively.

Statistical analyses

Data of BW's at different ages were analyzed by PROC MIXED [20] to calculate the line and sex specific means by the following model:

$$Y_{ijkl} = \mu + a_i + L_j + S_k + (LS)_{jk} + e_{ijkl}$$

where: Y_{ijkl}: is the observation for a trait, μ: is the overall mean, a: is the random additive genetic effect of the i^{th} animal, L: the effect of j^{th} line, S: the effect of k^{th} sex, $(LS)_{jk}$: the effect of j^{th} line with the k^{th} sex and e_{ijkl}: is the random error term; the random variable was the birds within line.

Growth model analysis

The nonlinear models procedure (PROC NLIN) in SAS software 9.3 [20] was employed to analyze various growth models and estimate their parameters. The specific functions and equations for calculating inflection points are presented in Table 1.

Goodness of fit criteria

To assess and compare the performance of different growth models, that explain the growth of two chicken lines, the following statistical measures were utilized:

1.Coefficient of Determination (R^2) =1 - (SSE / SST)

2.Mean Square Error (MSE) = SSE / (n – k)

3.Akaike's Information Criterion, AIC= n. ln (SSE/n) + 2k

4.Schwarz Bayesian Information Criterion, BIC = n. ln (SSE/n) + k. ln (n)

In these equations: SST represents the total sum of squares, SSE denotes the sum of square errors, n is the number of data points, k indicates the number of parameters in the model.

Results

Body Weight Traits

The body weight (BW) data for males and females in both chicken lines are summarized in Table 2, which presents least square means and their associated standard errors. The analysis revealed a statistically significant line effect (P<0.001) on BW measurements throughout the study period. The nana line demonstrated consistently superior body weight compared to the NANA/Nana line, with differences of approximately 150-200g (8-12% higher) across most measurement periods.

In contrast, sex had no significant effect on most BW measurements studied, with the exception of BW_{70}, BW_{112}, and BW_{126}, where females exhibited higher values, as indicated in Table 2. The interaction between line and sex showed no significant effects on all BW measurements studied, except for BW_{14} and BW_{84}.

Estimated Parameters of Growth Models

The Gompertz model yielded the highest asymptotic weight (alpha) values for both lines. In the nana group, females reached 1970.37g and males 1941.88g, while the NANA/Nana group achieved

2141.36g for females and 2121.39g for males. Across all models tested, the NANA/Nana line consistently demonstrated higher asymptotic weights for both sexes, as shown in Table 3.

Beta values, which define the shape of the growth curves, showed minimal variation between sexes. The gamma parameter, indicating relative maturation rate, ranged from 0.021 to 0.039 for both sexes in the nana line and from 0.018 to 0.0356 for males and 0.018 to 0.0354 for females in the NANA/Nana line. Across all models, no significant difference in gamma values was observed between males and females (Table 3).

Estimated Values for Inflection Point Time (IP_T) and Weight (IP_W) of Growth Models

The values for IP_T and IP_W in the nana and NANA/Nana lines are presented in Table 4. Across all growth models examined in this study, the NANA/Nana line consistently exhibited longer IP_T and higher IP_W than the nana line. Regarding sex effects, females demonstrated higher values for both IP_T and IP_W compared to males.

Goodness of Fit Criteria (GFC)

Table 5 presents a comparison of GFC for the three growth functions investigated. The R^2 values for these models were notably high, ranging from 0.9836 to 0.9974 in the nana line and from 0.9811 to 0.9965 in the NANA/Nana line.

The Gompertz model best described the growth patterns of both female and male chickens in both lines, displaying the lowest AIC, BIC, and MSE values, along with the highest R^2 values. For both lines, the models ranked in the following order of goodness of fit: Gompertz, Logistic, and Richards, as presented in Table 5.

Additionally, Figure 2 illustrates the three growth curves for the nana and NANA/Nana lines. This figure clearly demonstrates that all three growth models closely matched the actual values for both lines. It also shows the differences between the two lines using the three models and confirms the results previously presented in Table 4.

Figs. 3, 4, and 5 illustrate the growth curves for female and male birds in each line using Gompertz, Logistic, and Richards growth models, respectively. These figures demonstrate that all three growth models effectively matched and predicted the observed BWs for both sexes. Regarding sex effect, the three growth curves reflected the convergence between sexes within each line due to the minor effect of sexual dimorphism compared to line effect.

Discussion

The variations in BWs of the tested lines can be attributed to their different genetic backgrounds [21] as all birds from the two lines were kept under the same factors such as diet, managerial hygienic and environmental conditions. Similarly, Magothe et al. [22] and Durosaro et al. [23] found significant BWs differences ($P < 0.05$) favouring normally feathered chickens over their naked neck counterparts.

The superior performance of naked neck birds reported by Njenga [24] and Adomako et al. [25] contrasts sharply with our findings. This discrepancy likely stems from environmental differences rather than genetic inconsistencies. In heat-stress conditions, the reduced plumage of naked neck birds provides thermoregulatory advantages that translate into improved growth performance [27]. However, under our controlled thermal conditions, this advantage disappears, revealing the underlying metabolic efficiency differences between genotypes.

The minor effect of sex on most BW traits indicates limited sexual dimorphism in these lines under the conditions studied. In contrast, the Gompertz model yielded the highest asymptotic weight (alpha) values, particularly with the reported higher asymptotic weights for the NANA/Nana line compared to the nana line [28-30]. Minimal variation in beta values between sexes suggests similarity in the shape of growth curves, which could be attributed to the uniformity in the integration coefficients for males and females within each model. The gamma parameter, indicative of the relative maturation rate, showed comparable values for both sexes, further reinforcing the limited role of sex in growth differentiation. The gamma values observed in this study align with those reported for Kabyle chickens in Algeria [31] and indigenous chickens in Ivory Coast [32].

The inverse relationship between asymptotic weight and maturation rate in the NANA/Nana line suggests a fundamental trade-off in growth strategy. This "grow slow, grow large" phenotype likely reflects differential energy allocation patterns, where resources are channelled toward structural development rather than rapid mass accumulation. These findings show similar inverse associations between alpha and gamma parameters, which are corroborated by studies like Adenaike et al. [33] and Faraji-Arough et al. [34]. This relationship suggests that chickens with higher asymptotic weights tend to mature more slowly. Further research by Masoudi and Azarfar [35] and Faraji-Arough et al. [34] identified a strong negative correlation (exceeding -0.90) between these parameters, indicating that genetic lines with higher alpha values generally exhibit lower gamma values. The inflection point time (IP_T) and weight (IP_W) values observed in the current study highlight the genetic influence on growth patterns, with the NANA/Nana line showing consistently higher IP_T and IP_W estimates across all growth models. Comparing IP_T values of naked neck and normal feathering chickens in this study to those of other native breeds reveals interesting variations.

For instance, native chickens from Italy, Ghana, and China exhibited lower IP_T estimates [36-38], while Kenyan indigenous chickens showed higher values [22]. The inflection point weight values reported by Zhao et al. [39] for Chinese indigenous chicken breeds correspond well with those obtained in the present study, reinforcing the observed genetic diversity in growth patterns among different chicken populations. The observed variations in IP_T and IP_W estimates among different chicken populations confirm the importance of considering genetic diversity and local adaptation when studying growth patterns and developing breeding strategies.

Sexual dimorphism was also evident, as females exhibited higher IP_T and IP_W values than males, suggesting that females reached mature weight at a later stage. This finding is consistent with Tompić et al.'s [40] observations in Ross 308 chickens, where males reached the inflection point earlier than females.

The results of this study are in agreement with previous research, as the findings strongly support the superiority of the Gompertz model in describing the growth patterns of naked neck and normal feathering birds [23,41,42]. Moreover, in previous studies of growth curves, the Gompertz model was the best model to fit and describe the growth patterns for local chicken breeds. This model's consistent performance across different studies, including Nigerian native chickens [33], slow-growing chickens in China [39], and medium-growing chickens in Poland [43], supports its widespread applicability. The figures of growth curves presented in this study demonstrate that the three growth models effectively matched and predicted the observed BWs for both sexes within each line due to the minor effect of sexual dimorphism compared to line effect. This consistency may be due to the high R^2 values in the tested models. This suggests that all three models effectively describe the variations in live weight with respect to age in the two selected lines of chicken, as they exhibit strong fits to the data [44].

Conclusion

These findings have direct applications for breeding strategy development. The nana line's rapid growth characteristics make it ideal for intensive production systems requiring fast turnover and consistent market weights. Conversely, the NANA/Nana line's higher asymptotic weight potential suits premium markets demanding larger carcass sizes, despite extended production periods. In hot regions, the naked neck advantage under heat stress may offset the slower growth patterns observed under controlled conditions, suggesting environment-specific breeding recommendations. Smallholder farmers in hot climates may benefit from NANA/Nana genetics for long-term productivity, while commercial operations in climate-controlled environments should favor nana lines for economic efficiency.

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Declaration of Conflict of Interest
The authors declare that there is no conflict of interest.
Ethical of approval
This research was approved from the Institutional Animal Care and Use Committee of the Faculty of Agriculture, Cairo University, Egypt, (approval number: CU-H-R-F-1-23).

TABLE 1. The growth functions and inflection point equations

Model	Functions and inflection point equations	Reference
Gompertz	$Y_t = \text{alpha} \,.\, exp^{-\text{beta} \,.\, exp^{-gamma \,.\, age}}$	
	$IP_W, \text{g} = \text{alpha/exp}$	
	$IP_t, \text{day} = \ln(\text{beta})/\text{gamma}$	
Richards	$Y_t = \text{alpha}\ (1 + \text{beta} \,.\, exp^{-gamma \,.\, age})^{\ delta}$	
	$IP_W, \text{g} = \text{alpha}/(\text{delta}+1)^{1/\text{delta}}$	[7,9]
	$IP_t, \text{day} = \text{delta}$	
Logistic	$Y_t = \text{alpha}\ (1 + \text{beta} \,.\, exp^{-gamma \,.\, age})^{\ -1}$	
	$IP_W, \text{g} = \text{alpha}/2$	
	$IP_t, \text{day} = \ln(\text{beta})/\text{gamma}$	

Where Yt is body weight (BW, g) of bird at age t, day; alpha: asymptote weight, beta: scale parameter, gamma: relative growth rate, delta: shape parameter in Richards model, IP_T: time at inflection point (days), and IP_W: weight at inflection point (g), exp: is Eulers number (~2.71828….).

TABLE 2. Least square means ± SE for the body weight's traits as affected by line and sex

Item	BW_0	BW_{14}	BW_{28}	BW_{42}	BW_{56}	BW_{70}	BW_{84}	BW_{98}	BW_{112}	BW_{126}
Line effect										
nana	45.93	116.79	317.32	527.37	753.39	925.82	1068.86	1222.62	1456.60	1579.86
NANA/Nana	44.26	100.63	242.39	439.88	696.36	808.44	927.14	1130.32	1339.89	1528.05
SE	0.014	0.176	0.883	1.878	1.842	1.838	1.942	2.646	2.672	3.368
Sex effect										
Male	45.10	108.62	279.07	484.41	722.64	864.03	995.75	1173.88	1392.06	1548.42
Female	45.09	108.81	280.64	482.84	727.11	870.23	1000.24	1179.07	1404.43	1559.49
SE	0.014	0.176	0.883	1.878	1.842	1.838	1.942	2.646	2.672	3.368
P-value										
Line	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Sex	0.7327	0.4448	0.2091	0.5535	0.0866	0.0175	0.1028	0.1662	0.0012	0.0206
Line x sex	0.0985	0.0027	0.4142	0.7166	0.8075	0.1801	0.0177	0.0865	0.1126	0.2450

SE: standard error, BW_0, BW_{14}, BW_{28}, BW_{42}, BW_{56}, BW_{70}, BW_{84}, BW_{98}, BW_{112} and BW_{126}: body weight at hatch, 14, 28, 42, 56, 70, 84, 98, 112 and 126 days of age, respectively and P-value: probability.

TABLE 3. Estimated parameters ± SE of growth models for both sexes in each line

Model	Line	nana selected		NANA/Nana selected	
	Sex	**Male**	**Female**	**Male**	**Female**
Gompertz	**alpha**	1941.88±16.31	1970.37±16.36	2121.39±28.62	2141.367±29.78
	beta	3.326±0.026	3.341±0.025	3.463±0.026	3.464±0.026
	gamma	0.0212±0.0003	0.0211±0.0003	0.018±0.0003	0.018±0.0003
Richards	**alpha**	1914.32±35.82	1914.13±38.06	2063.95±71.86	2087.43±74.69
	beta	0.001±0.0002	0.001±0.0002	0.001±0.0002	0.001±0.0002
	gamma	0.021±0.0011	0.021±0.0012	0.018±0.0014	0.019±0.0014
	delta	58.12±0.49	59.43±0.50	57.79±0.73	58.21±0.91
Logistic	**alpha**	1667.72±11.18	1688.65±11.19	1710.69±16.38	1723.27±16.95
	beta	12.919±0.27	13.067±0.27	14.41±0.30	14.42±0.30
	gamma	0.0389±0.0005	0.0389±0.0005	0.0356±0.0005	0.0354±0.0005

alpha: asymptote weight, beta: scale parameter, gamma: relative growth rate, delta: shape parameter in Richards model.

TABLE 4. Estimated values of IP_T and IP_W for both sexes in each line

Model	Line	nana selected		NANA/Nana selected	
	Sex	**Male**	**Female**	**Male**	**Female**
Gompertz	**IP_T, days**	56.69	57.17	69.00	69.02
	IP_W, g	714.43	724.91	780.47	787.82
Richards	**IP_T, days**	58.12	59.43	57.79	58.21
	IP_W, g	704.52	704.59	759.66	768.31
Logistic	**IP_T, days**	65.78	66.07	74.94	75.38
	IP_W, g	833.86	844.32	855.35	861.64

IP_T: the inflection point time, IP_W: the inflection point weight.

TABLE 5. Statistical analysis of *Staphylococcus aureus* count (log_{10} CFU/g) in the examined samples of thigh and breast of turkey (n=50)

Model	Line	nana selected		NANA/Nana selected	
	Sex	**Male**	**Female**	**Male**	**Female**
Gompertz	**AIC**	21196.24	21162.22	21464.45	21542.33
	BIC	21218.65	21184.62	21486.86	21564.73
	MSE	2339.16	2303.62	2675.44	2781.62
	R^2	0.9973	0.9974	0.9965	0.9963
Richards	**AIC**	22417.07	22399.31	22477.93	22540.04
	BIC	22439.47	22421.71	22500.34	22562.45
	MSE	4307.69	4269.61	4440.80	4580.87
	R^2	0.9836	0.9841	0.9815	0.9811
Logistic	**AIC**	21240.10	21448.07	21579.06	21607.06
	BIC	21268.10	21476.08	10819.07	10841.98
	MSE	2390.30	2652.24	2837.45	2831.76
	R^2	0.9952	0.9953	0.9942	0.9940

alpha: asymptote weight, beta: scale parameter, gamma: relative growth rate, delta: shape parameter in Richards model.

Fig. 1. Studied genotypes: naked-neck and normal feathering chickens

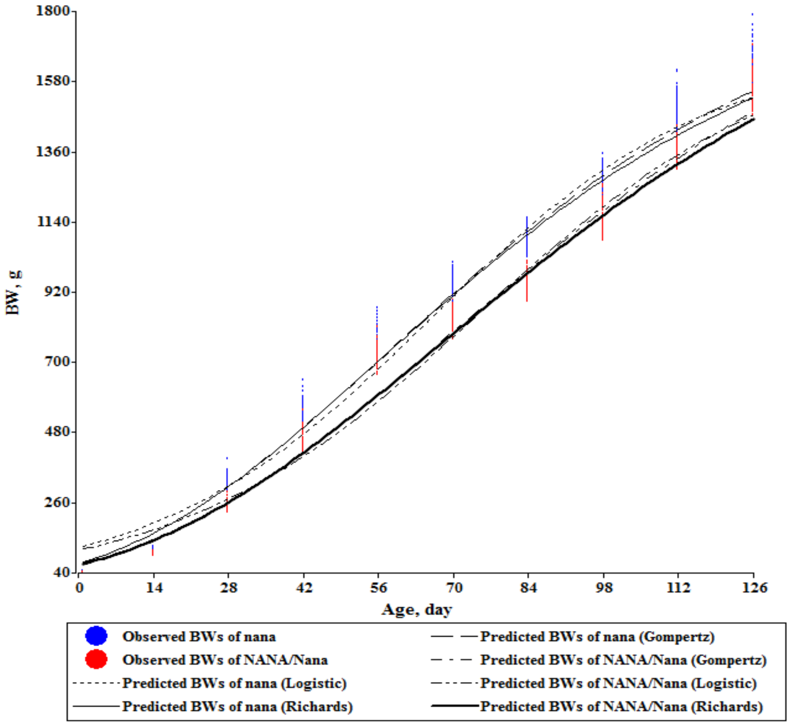

Fig.2: Growth curves of nana and NANA/Nana for different growth functions.

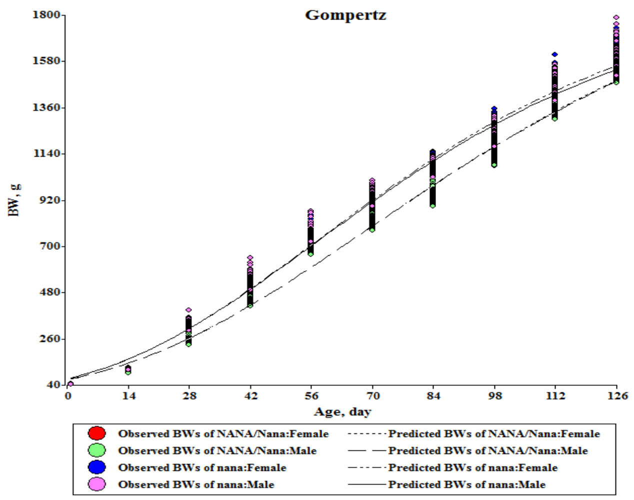

Fig.3: Gompertz growth curves for female and male birds in each line

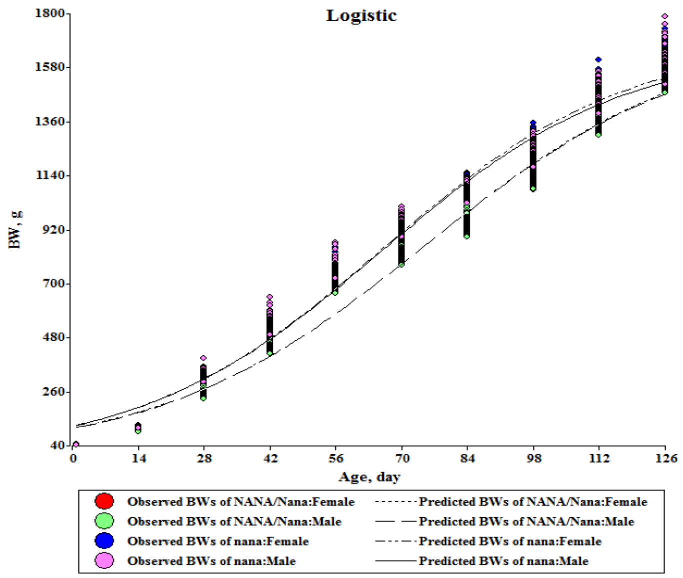

Fig.4: Logistic growth curves for female and male birds in each line

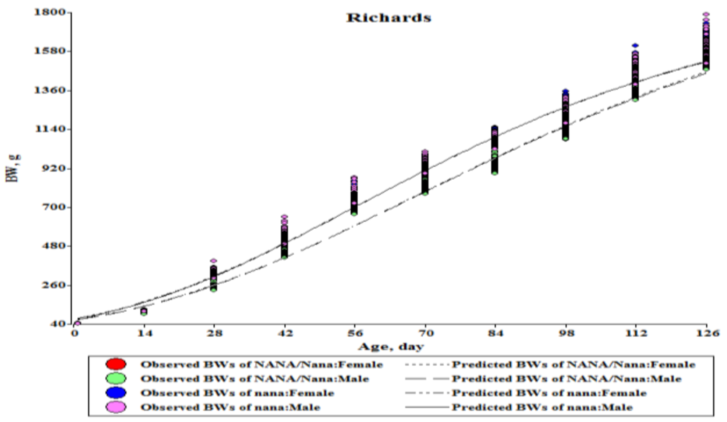

Fig.5: Richards growth curves for female and male birds in each line

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تقييم نماذج منحنيات النمو في خطين من الدجاج

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الملخص

استهدفت هذه الدراسة تقييم أنماط النمو في خطين منتخبين من الدجاج المحلي سريع النمو: الخط العادي الريش (nana) وخط عاري الرقبة (NANA/Nana). تم تسجيل أوزان الجسم لـ 800 كتكوت (400 لكل خط) منذ منذ الفقس وحتى عمر 126 يومًا، وذلك بمزرعة الدواجن، كلية الزراعة، جامعة القاهرة. جرى تحليل بيانات الوزن باستخدام ثلاثة نماذج انحدار غير خطية (جومبرتز، ريتشاردز، ولوجستيك). أظهرت النتائج وجود فروق معنوية عالية بين الخطوط (P<0.001) في جميع الأوزان، حيث تميز خط الـ nana بوزن أعلى بشكل مستمر خلال فترة النمو. كما ظهرت تأثيرات معنوية للجنس في الأعمار المتأخرة (70، 112، 126 يومًا). أظهر نموذج جومبرتز أفضل مطابقة للبيانات وفق جميع معايير الجودة، يليه نموذج اللوجستيك، بينما جاء نموذج ريتشاردز في المرتبة الأخيرة. ووفقًا لنموذج جومبرتز، تميز خط الـ NANA/Nana بوزن نهائي أعلى ومعدل نضج أبطأ مقارنة بخط الـ nana، حيث وصل إلى نقطة الانقلاب في أعمار أكبر وبأوزان أعلى. ويُشير النضج المبكر لخط الـ nana إلى إمكانية تفوقه تحت ظروف الإجهاد الحراري، في حين أن الوزن النهائي المرتفع لخط الـ NANA/Nana يعزز من قيمته في برامج التحسين الوراثي الهادفة إلى تحسين النمو.

الكلمات الدالة: الانحدار غير الخطي، نماذج النمو، دالة جومبرتز، الدجاج المحلي، جين عاري الرقبة.