Research Note: Analysis of Growth Curve Patterns for Muscovy Ducks Using Gompertz and Logistic Models

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Research Note: Analysis of Growth Curve Patterns for Muscovy Ducks Using Gompertz and Logistic Models

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Abstract
This study aimed to estimate the growth parameters of Muscovy ducks. The superiority of the study offers insightful information on the Muscovy duck growth curve, makes quantitative comparisons easier, allows for predictive capacities, and quickly finds problems. A total of 40 Muscovy ducks called "Rambon" were used in the study, consisting of 12 males and 28 females. Body weight was weighed periodically every two days from the day-old ducks (DOD) until 60 days of age. The data was analyzed by using Gompertz and Logistic models. The growth curves were analyzed, and parameters such as adult body weight (A), integral constant (B), and growth rate (K) were determined. Inflection points were also identified. Body weight (Wi) and age at the inflection (Ai) point using Gompertz were 1060.95 g and 46.34 d; 613.41 g and 30.52 d; 712.56 g and 36.81 d, respectively for males, females, and the unsexed. By using Logistic model, the Wi and Ai for males were 934.60 g and 41.46 d, females were 670.52 g and 32.96 d, and unsexed were 739.11 g and 36.56 d. Results showed that the Gompertz model generally outperformed the Logistic model, with lower AIC, BIC, MSE values and slightly higher R^2 for all sex groups, indicating superior fit and predictive accuracy. These findings offer valuable insights into Rambon Muscovy duck growth dynamics, aiding in breeding and production strategies to enhance economic efficiency and sustainability. Farmers can utilize these models to optimize feeding schedules and make informed decisions about slaughtering, ultimately improving Muscovy duck production.

Introduction

Livestock production in general and domestic poultry production in particular plays a vital socio-economic role for people living in low-income countries of Africa and Asia (Moazeni *et al*., 2016a). Domestic poultry are widely distributed avian species around the world due to their short generation interval and adaptability in a wide range of agro-ecologies (Moazeni *et al*., 2016b; Mohammadifar and Mohammadabadi, 2018; Khabiri *et al*., 2022). Domestic poultry provides high-quality protein and income for poor rural households and is the most widely kept livestock species in the world (Mohammadabadi *et al*., 2010; Mohammadifar and Mohammadabadi, 2018). This is due to the presence of the valuable traits of poultry like disease resistance, adaptation to harsh environments and ability to utilize poor-quality feeds (Khabiri *et al*., 2023).

Muscovy ducks are one of the most popular waterfowl species in Indonesia. There is potential for developing Muscovy ducks into livestock that can produce meat. Muscovy ducks' comparatively high body weight concerning other waterfowl makes them famous meat producers (Yakubu, 2013). Rambon ducks are one of the popular Local Muscovy ducks in Indonesia. The characteristic of the Rambon duck is that it has gray feathers and a pink beak, making it a unique type. Adult body weights for male and female ducks were 3.53 kg and 1.97 kg, respectively (Ningsih *et al*., 2022). For farmers, body weight growth is a simpler metric to assess their ducks. One of the fundamental traits of biological systems that

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characterizes genetic potential is growth (Susanti and Purba, 2017). Growth is the change in body size over a given period (Faraji-Arough *et al*., 2019). However, there is currently insufficient analysis of the growth of Muscovy ducks. The appropriate method is needed to make the right decision on when to harvest or slaughter the ducks. Growth is separated into two phases: the acceleration phase and the retardation phase, depending on its rate. The acceleration phase shows rapid growth, stops at an inflection point, and starts to become a retardation phase where growth is slow (Vitezica *et al*., 2010). The growth curve will, therefore, have a sigmoid shape, with the highest maximum growth rate and ideal slaughtering time represented by the inflection point (Setiaji *et al*., 2023).

Success has been achieved in characterizing growth patterns and visualizing the shape of growth over time through mathematical models (Nguyen Hoang *et al*., 2021). Many growth curve models have been developed and used to describe growth curves in various species mathematically. Common growth models applied to animal species are the Gompertz, Bertalanffy, Richard, Logistic, and Asymptotic models (Kurnianto *et al*., 1997). The Gompertz and Logistic models are the most accurate and have a good biological interpretation among these models, particularly when it comes to the inflection point assumption (Moharrery and Mirzaei, 2014). Gompertz and Logistic are nonlinear models commonly used to describe growth curves of poultry: Aggrey (2002) on chicken, Beiki *et al*. (2013) on Japanese quail, and Kaewtapee *et al*. (2018) on ducks.

The equation that states the inflection point is the second derivative of a nonlinear equation is used to determine the estimated value of when the growth curve's inflection point occurs (Goshu and Koya, 2013). The inflection point is the most economical due to the lowest mortality and fastest growth. The inflection point is difficult to determine biologically, so it can be solved with non-linear growth curves (Nahashon *et al*., 2006). Moreover, strategies in poultry breeding programs aim to increase egg volumes, feed efficiency, growth rate, and body weight (BW); decrease abdominal fat; have low production costs and better regulate the biochemical and physiological parameters (Mohammadabadi *et al*., 2010; Mohammadifar and Mohammadabadi, 2017). The growth analysis for the Rambon duck has never been carried out. Hence, the aim of the study was to estimate the growth parameters of Rambon Muscovy ducks. The superiority of the study provides valuable insights into the growth curve of Muscovy ducks, facilitates quantitative comparisons, enables predictive capabilities, identifies optimal growth conditions, and detects abnormalities early. The benefit of the study will support research and breeding programs, and enhance economic efficiency in Muscovy duck production.

Materials and Methods

Research object

The materials used in this study were 40 Rambon Ducks, consisting of 12 males and 28 females. The study material was provided by the farmer community of Rambon ducks from Demak Regency, Central Java Province of Indonesia. Rambon ducks were weighed periodically every two days from hatching until the age of 60 days. A portable weighing scale with a capacity of 5 kg and scale 1 g was used. The descriptive statistics are presented in Table 1.

Table 1. Mean (g) and Standard Deviation of body weight for observed Rambon Ducks

Age	Male		Female		Unsex	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
0	39.94	1.41	38.44	0.57	38.89	1.12
2	60.77	1.65	61.51	0.78	61.29	1.14
4	83.09	1.24	84.59	0.68	84.14	1.11
6	102.42	1.90	107.66	1.16	106.09	2.81
8	139.12	1.31	145.86	2.01	143.84	3.62
10	175.82	2.49	184.05	1.97	181.58	4.37
12	212.52	1.31	222.25	1.68	219.33	4.78
14	251.99	4.11	258.08	2.83	256.26	4.28
16	291.45	0.91	293.90	1.96	293.16	2.05
18	330.92	8.16	329.73	2.22	330.09	4.74
20	376.72	0.95	376.03	1.74	376.23	1.56
22	422.52	1.62	422.32	2.16	422.38	2.00
24	468.32	1.67	468.62	2.47	468.53	2.25
26	517.21	2.89	516.70	2.07	516.85	2.32
28	566.11	1.58	564.79	2.16	565.18	2.08
30	615.00	0.99	612.87	2.13	613.51	2.09
32	661.49	1.71	658.07	2.30	659.10	2.65
34	707.99	1.40	703.26	1.75	704.68	2.74
36	754.48	2.01	748.46	6.42	750.26	6.12

Age	Male		Female		Unsex	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
38	809.71	1.74	788.28	2.34	794.71	10.18
40	864.95	1.93	828.10	6.88	839.16	18.06
42	920.18	2.70	867.92	3.15	883.60	24.44
44	977.71	1.78	912.35	5.80	931.96	30.73
46	1035.23	1.71	956.79	3.14	980.32	36.51
48	1092.76	2.50	1001.22	12.25	1028.68	43.71
50	1161.38	2.61	1038.33	6.74	1075.25	57.40
52	1230.01	2.13	1075.43	10.83	1121.81	72.31
54	1298.63	4.50	1112.54	8.42	1169.79	87.32
56	1361.86	2.90	1156.95	9.54	1218.42	95.44
58	1425.10	2.81	1201.37	11.36	1268.49	104.27
60	1488.33	10.56	1245.78	10.73	1318.55	113.06

Data analysis

The average body weight data of Rambon Ducks were then analyzed using nonlinear growth curves of Gompertz and Logistic models according to (Kurnianto *et al.*, 1997). The NLIN procedure of Statistical Analysis System (SAS) On Demand for Academics (SAS, 2021). were used to fit the Gompertz and Logistics nonlinear growth curve models to the observed body weights of Rambon Ducks. The models for predicting body weight were as follows:

Gompertz model: $Y=Ae(-Be^{-kt})$.

Logistic model: $Y=A/(1+Be^{-kt})$,

Where:

A = Body weight (Asymptote),

B = Integral costantan

e = Basic logarithm (2,71828)

K= Average growth rate until adult age

Y = Body weight at t time

t = Time unit (day)

The weight of inflection and age at the inflection equations, respectively, were according to Nguyen Hoang *et al*. (2021) for Gompertz and Logistic models as follows:

$W_i= A/e$

and

$W_i= A/2$

Where:

Wi = Weight of inflection, B and K, same as described before.

$A_i= \ln (B)/K$

and

$A_i = -\ln(1/B)/K$

Where:

Ai = Age at an inflection point and BA same as described before

ln = natural logarithm

The appropriate model to describe the growth curve of Rambon Ducks was chosen using the goodness of fit criteria listed below.

The adjusted coefficient of determination (R^2) was calculated according to the formula by (Beiki *et al*., 2013) as follows:

$$R^2 = \left(\frac{SSE}{SST}\right)$$

Where SSE represents the sum of squares of errors and SST represents the total sum of squares.

The Akaike Information Criterion (AIC) equation computed according to Narinc *et al*. (2014) as follows:

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

Where n is the number of observations, ln indicates the natural logarithm, and p is the number of model parameters.

The Bayesian Information Criterion (BIC) was computed using the equation Lewis *et al*. (2010) below:

$$BIC = n\ ln\left(\frac{SSE}{n}\right) + p\ ln\ (n)$$

Mean Squared Error Mean squared error (MSE) was calculated as the equation below:

$$MSE = \frac{SSE}{n-p}$$

Result and Discussion

The observed difference in body weight between sexes during specific periods, as described in Table 1 (with males having lower weight from 2-18 days and females having lower weight thereafter). Kaewtapee *et al*. (2018) Reported that female ducks under 14 days of age have a greater average daily gain than males. The phenomena could be attributed to several factors related to growth and development, as well as biological differences between male and female ducks.

Growth parameters

The growth parameters analyzed using the Gompertz and Logistic models are presented in Table 2. The Gompertz model shows the values of A of male, female, and unsex for Rambon ducks were 2883.95 g, 1667.43 g, and 1936.95 g, respectively. The Logistic model shows the asymptote value of adult body weight gain of male, female, and unsex of 1869.20 g, 1341.05 g, and 1478.22 g, respectively. This predicted adult weight gain of Rambon Ducks is relatively low compared to male local ducks at 3243±15.39 g and female local ducks at 1838±220 g

(Susanti, 2021). While Oguntunji and Ayorinde (2014) reported relatively similar results, male ducks showed an adult body weight of 2640±370 g and females 1600±250 g. This is thought to be caused by differences in the observed waterfowl breeds. A value is a trait strongly influenced by genetic factors.

Table 2. Growth parameters (SE in parenthesis) and goodness of fit criteria estimated by Gompertz and Logistic models.

Parameter	Gompertz			Logistic		
	Male	Female	Unsex	Male	Female	Unsex
[1]A	2883.95 (175.01)	1667.43 (35.74)	1936.95 (58.98)	1869.20 (87.14)	1341.05 (34.24)	1478.22 (46.58)
B	3.66 (0.04)	3.289 (0.04)	3.37 (0.04)	16.77 (0.89)	13.08 (0.77)	13.91 (0.81)
K	0.028 (0.001)	0.039 (0.001)	0.033 (0.001)	0.068 (0.003)	0.078 (0.003)	0.072 (0.003)
Wi	1060.95	613.41	712.56	934.60	670.52	739.11
Ai	46.34	30.52	36.81	41.46	32.96	36.56
[2]AIC	185.52	157.30	167.97	219.31	207.43	212.37
BIC	189.82	161.61	172.27	223.61	211.73	216.67
MSE	362.36	145.84	205.74	1077.81	734.65	861.57
R^2	0.9994	0.9997	0.9996	0.9982	0.9985	0.9983

[1]A = Body weight (Asymptote); B = Integral costantan; K= Average growth rate until adult age; Wi = Weight of inflection; Ai = Age at inflection point.

[2]AIC= Akaike's Information Criterion, BIC= Bayesian Information Criterion, MSE=Mean Squared Error; R^2 = coefficient of determination.

The obtained value of K used Gompertz showing the growth rate to reach the adult weight by male, female, and unsex were 0.028, 0.039, and 0.033, respectively. While the K values obtained using Logistic according to males, females, and unsex were 0.068, 0.078, and 0.072, respectively. Relatively low when compared to the K of Local Muscovy ducks reported by Prayogo *et al*. (2017) They reported the values of K were 0.03 for males and 0.05 for females and 0.08 for males and females by using Gompertz and Logistic, respectively. Adult body weight is influenced by how large the K value is, where ducks with a larger K value will reach the adult body quickly (Kurnianto *et al*., 1997). The K value is important in the selection of Rambon Ducks for farming. If the breeding program's goal is to produce animals with lower energy requirements, then early maturity and lower maturity weights might be preferred; however, if the goal is to produce animals with higher maturity weights to satisfy market demand, then later maturity should be taken into consideration (Setiaji *et al*., 2023). A comparison of the Gompertz and Logistic growth curves of Rambon Ducks is presented in Figures 1, 2 and 3, respectively, for male, female and unsex Rambon ducks.

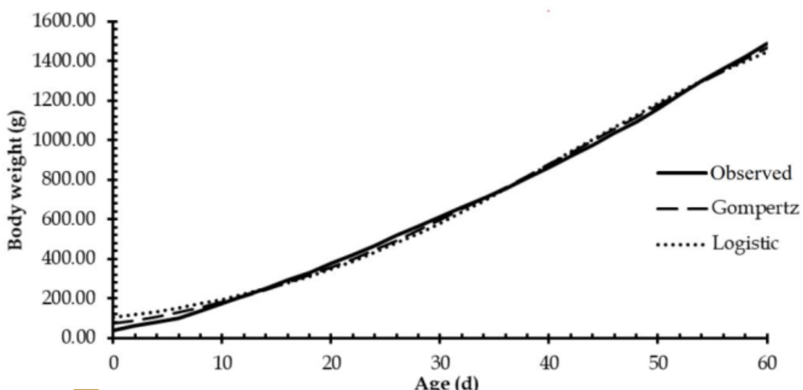

Figure 1. The observed and predicted body weights for male Rambon Ducks

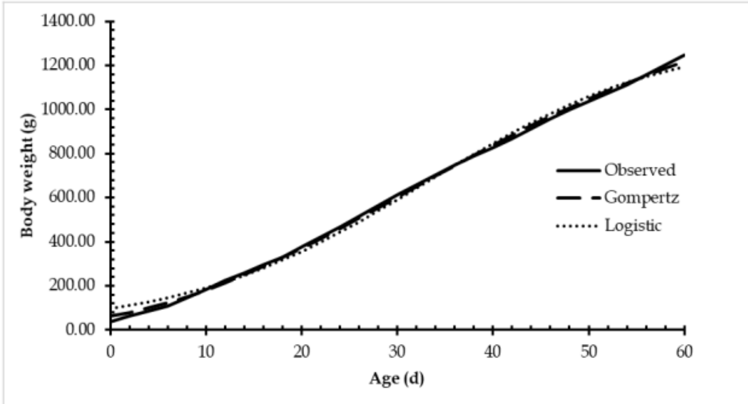

Figure 2. The observed and predicted body weights for female Rambon Ducks

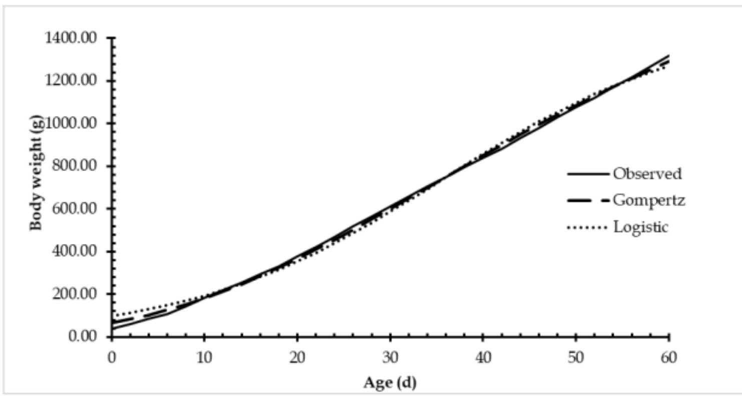

Figure 3. The observed and predicted body weights for unsex Rambon Ducks

Inflection points

The Wi of Rambon Ducks using Gompertz for males, females, and unsex were 1060.95 g, 613.41 g, and 712.56 g, respectively, while the Ai were 46.34 d, 30.52 d, and 36.81 d, respectively. Yusinta *et al.* (2017) reported that the Wi and Ai of male ducks were 932.408 g and 33.177 d, respectively, using the Gompertz model, while 726.014 g and 34.890 d, respectively was estimated using Logistic. In this study, the values of Wi and Ai of Rambon ducks estimated using Logistic in males were 934.60 g and 41.46 d, females were 670.525 g and 32.96 d, and unsexed were 739.11 g and 36.56 d, respectively. Susanti and Purbo (2017) reported that local ducks reached to the inflection point in 50 d with 953.29 g using Gompertz. The age and body weight at the inflection point could be useful in estimating when to slaughter the poultry.

The goodness of fit criterion

The AIC of male, female and usexed? for the Gompertz model were 185.52, 157.30 and 167.97, respectively, compared to that for the Logistic model were 219.31, 207.43 and 212.37. The lowest AIC value explains the most suitable growth analysis model using (Suresh *et al.* 2021). For all groups (male, female, and unsexed), the BIC values for the Gompertz model were lower than those for the logistic model. As a consequence of its superior fit and performance, the Gompertz model was shown to be more advantageous. For all groups (male, female, and unsexed), the MSE values for the Gompertz model are lower than those for the Logistic model, suggesting that the Gompertz model has superior predictive accuracy.

For all groups, the R^2 values for the Gompertz model were slightly higher than those for the Logistic model. Greater R^2 values indicate that, compared to the logistic model, the Gompertz model explains a higher proportion of the variation in the response variable. The model with lower AIC and higher R2 values is more suitable for estimating the growth curve (Setiaji *et al*., 2023).

Conclusion

In conclusion, Gompertz and logistic models may be used to analyze growth curve patterns, providing important new information on the growth dynamics of Rambon Muscovy ducks. These models are helpful tools for improving breeding techniques and production procedures, improving the economic viability and sustainability of Muscovy duck production. By accurately modeling the growth curves of Rambon Muscovy ducks, farmers can optimize feeding schedules, predict growth trajectories, and make informed decisions regarding the timing of harvesting or slaughtering.

Conflict of Interest

The authors declare that they have no conflict of interest

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