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Evaluate Non-Linear Model Logistic, Gompertz, and Weibull: Study Case on Calcium and phosphor Requirements of Laying Hen

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Abstract. This study was to build and evaluate a non-linear model to describe the macro-mineral requirement of the laying hen. Using micro-mineral (Calcium, Total Phosphor, and Available Phosphor) requirements from 8 to 35 weeks, non-linear (Logistic, Gompertz, and Weibull) models were used to estimate patterns of 644 data from 23 laying hen breeds. Data collected from Hendrix Genetics and Lohmann Tierzucht. Data were converted to metabolism body weight (BW^{0.75}) and transformed using min-max transformation. The non-linear model was run in R-base 3.6.0 using the build-in function nls and SS. The RMSE and MAE used to validate the model. The lowest value states that the model has high uniformity and consistency. The lowest RMSE value (0.0629) of the non-linear model of calcium requirement was Logistic, but the lowest MAE value (0.0401) was Weibull. The lowest RMSE and MAE values of the non-linear model of the total phosphor requirement were Weibull models with values of 0.0554 and 0.0424, respectively. The lowest RMSE and MAE values of the non-linear model of the available phosphor requirement were Weibull models with values of 0.0689 and 0.0568, respectively. Therefore, based on the RMSE and MAE, the macro-mineral can accurately be described by the Weibull model.

1. Introduction

Macro-mineral requirements of laying hen become double at 20 weeks. The increment in macro-mineral requirements, due to the egg production. Changes in nutrient requirements exceedingly affect egg production. So that accurate information on nutrient requirements is needed to support the managerial aspects of egg production. [1, 2] The calcium requirement of 20 weeks old laying hens is 14.48 (g/hen/week), the total phosphor is 4.64 (g/hen/week), and the available phosphor is 3.08 (g/hen/week). Or in other words, macro-mineral requirements 2-4.2% and 0.5%, for calcium and phosphor available.[1, 2] macro-mineral requirements data of laying hens follow the non-linear shape. Therefore, it is necessary to choose tools that can fit the data. Tools that can be used in non-linear data such as response surface modeling, artificial neural network, and non-linear regression (non-linear



model).[3] non-linear models that are fitted to estimate patterns of nutrient requirements involve Logistic, Gompertz, and Weibull.[4, 5] These models have the lowest standard error value than other models, but each model built depends on the data. The objective of this research was to compared non-linear models build on macro-mineral requirements of laying hen aged 8 to 32 weeks.

2. Material and Mmthods

2.1. Data Collection and Transformation

A total of 644 data were obtained from Lohmann Tierzucht and Hendrix Genetics database. The breeds of laying hen are Babcock, Bovans, Dekalb, Hisex, ISA, Lohmann Brown, Lohmann Silver, and Shaver. Macro-mineral requirements calculated from feed consumption multiplied by the percentage of macro-mineral requirements.

$$MI - i = FI - i \times PM - i,$$

where MI-i = mineral intake-i (g/hen/week); FI-i = feed intake-i (g/hen/week); PM-i = percentage of macro-mineral requirements-i (%); which i in week, i=(8, ..., 35).

macro-mineral requirements data were converted into metabolic body weight ($BW^{0.75}$) and transformed using min-max transformation. The data conversion and transformation formula is as follows.

$$CMI = MI \div BW \times BW^{0.75},$$

where CMI = converted mineral intake; MI = mineral intake; BW = body weight; $BW^{0.7}$ = metabolism body weight.

$$x' = (x - \min(x)) \div (\max(x) + \min(x)),$$

where x = initial value; x' = transformed value; max(x) = maximum value; min(x) = minimum value.

2.2. Build and Evaluate Model

The non-linear model of this research was built using the R-base 3.6.0 programming language with build-in function nls, SS, and "library (Metrics)".[6, 7] non-linear models were built based on the following formula:

$$\begin{aligned} \text{Logistic} & : Y = a \div \left(1 + \exp((b - X) \div c)\right), \\ \text{Gompertz} & : Y = a \times \left(1 + \exp(-b \times c^X)\right), \\ \text{Webull} & : Y = a - d \times (-\exp(b) \times X^c), \end{aligned}$$

To any model, Y is the body weight at a particular age; X is an age in weeks, *a* is maximum growth response; *b* is a scale parameter related to initial weight; *c* is the intrinsic growth rate; *d* is a numeric parameter representing the change from a to the Y-intercept.

Mean absolute error (MAE) gives uniform weighting errors for all data. Root mean square error (RMSE) is used to view the consistency model because it is sensitive to outlier errors.[6]

3. Results and discussion

The macro-mineral requirements of laying hens are double in the laying period. Data on calcium requirements, total phosphor, and available phosphor collected and notice in Figure 2. A non-linear model of macro-mineral requirements of laying hens aged 8 to 35 weeks in Figure 1.

The results of RMSE and MAE for each non-linear model are presented in Table 1. The best non-linear model of calcium-based on RMSE is a Logistic model, but based on MAE is a Weibull model. Because the MAE value is robust against outliers, the estimation of the goodness of the model is more suitable to use MAE, so the best non-linear model of calcium requirements is the Weibull model. The best model for estimating phosphor requirements based on RMSE and MAE is the Weibull model. Available phosphor for 8 to 35 weeks laying hens can be well described using the Weibull model based on the smaller RMSE and MAE values compared to other models. Macro-mineral requirements of 8 to 35 weeks of laying hens follow the Weibull model pattern. This is following the opinion of Raji *et al.* [5], quail laying growth models follow the Weibull model pattern. The increasing macro-mineral requirements are mainly due to changes in body size and egg production, therefore the pattern of their requirements will follow the growth pattern.[8]

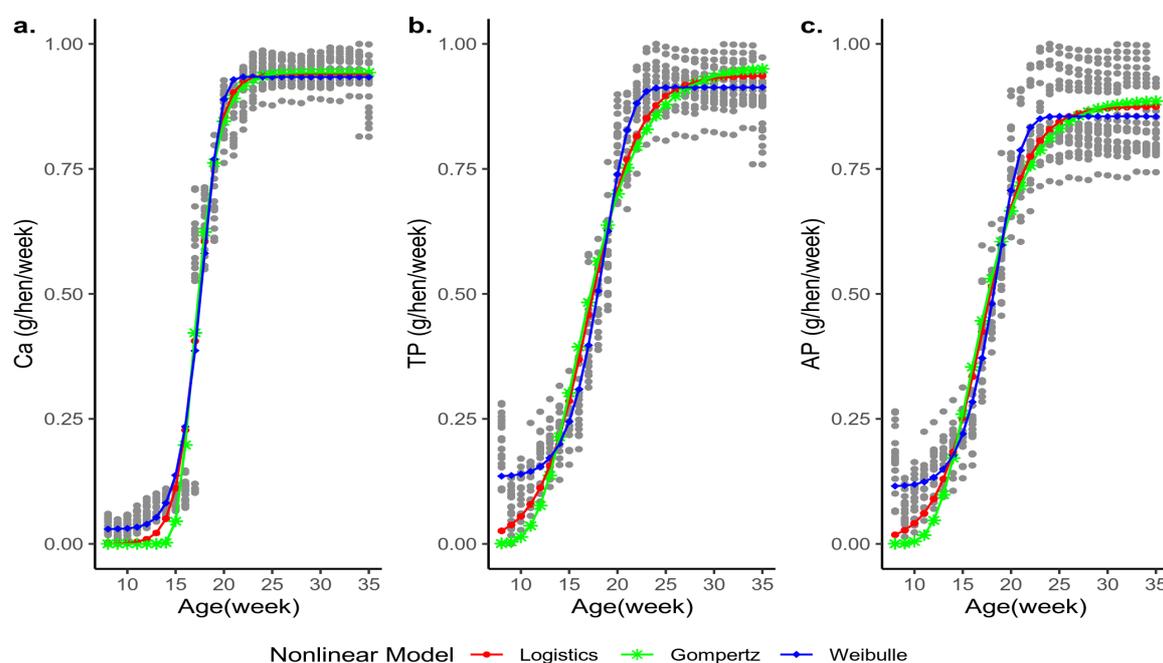


Figure 1. The non-linear model of macro-mineral requirements of laying hen aged 8 to 35 weeks. (a.) calcium, (b.) total phosphor, and (c.) available phosphor. Ca, calcium; TP, total phosphor, AP, available phosphor.

Table 1. Non-linear model validate using residual means standard error and mean square error

Model	Calcium		Total phosphor		Available phosphor	
	RMSE	MAE	RMSE	MAE	RMSE	MAE
Logistic	0.0629	0.0420	0.0726	0.0548	0.0807	0.0665
Gompertz	0.0630	0.0441	0.0861	0.0670	0.0910	0.0763
Weibull	0.0644	0.0401	0.0554	0.0424	0.0689	0.0568

RMSE, residual mean standard error; MAE, mean absolute error.

Actual and predicted values based on non-linear models are presented in Figure 2. Calcium requirements increase at week 20 to more than 16 (g/hen/week), as well as total phosphor 5 (g/hen/week), and phosphor available 3.5 (g/hen/week).

Table 2. Weibull coefficient models of macro-mineral requirements of laying hens aged 8 to 35 weeks

	Calcium	Total phosphor	Available phosphor
a	0.9339	0.9129	0.8549
b	-31.8771	-23.4206	-23.9964
c	11.0077	7.9531	8.1685
d	0.9044	0.7783	0.7401

a is maximum growth response; b is a scale parameter related to initial weight; c is the intrinsic growth rate; d is a numeric parameter representing the change from a to the Y-intercept.

The coefficient of the Weibull model is shown in Table 2, where the coefficient a as the maximum growth, b is the scale between the initial body weight with the coefficients a , c is the body growth rate, and d is the peak body weight intersection. The equations of the coefficients of Table 2, will produce no actual value. So, a reverse transformation is needed to get the actual value.

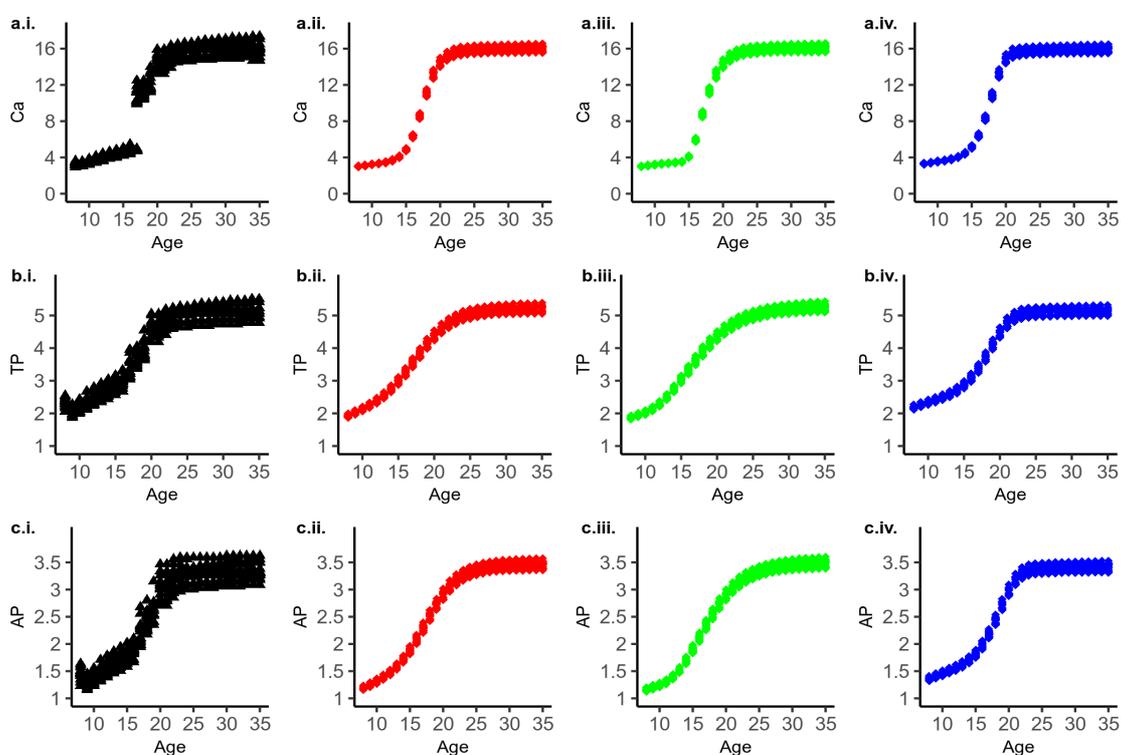


Figure 2. Actual values and predicted values. macro-mineral requirements data of (a.) calcium, (b.) total phosphor, and (c.) available phosphor. macro-mineral requirements data of (i) actual, (ii) Logistic predicted, (iii) Gompertz predicted, and (iv) Weibull predicted. Ca, calcium; TP, total phosphor, AP, available phosphor.

4. Conclusion

It can be concluded, based on the RMSE and MAE, the macro-mineral (calcium, total phosphor, dan available phosphor) can accurately be described by the Weibull model.

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