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Adjustment of egg production curves by the Wood method for four lines of light laying hens

[Ajuste de curvas de produção de ovos pelo método de Wood para quatro linhagens de poedeiras leves]

Karina Milene Maia*[1], Wellington Marques de Souza[2], Maria Vitória Martins de Freitas[2], Mariani Ireni Benitis[2], Robson Marcelo Rossi[2], Simara Marcia Marcato[2]

1 Faculdade UMFG, Cianorte, Paraná, Brazil
2 Universidade Estadual de Maringá (UEM), Maringá, Paraná, Brazil

*corresponding author: Karina.maia@umfg.edu.br

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Abstract: The objective of this study was to adjust the egg production curve of four lines of light laying hens (Nick Chick, Lohmann NA Lite, Bovans White and Lohmann LSL) by Bayesian analysis. A total of 480 birds from one day of age to 80 weeks of age were used, with 120 birds per strain evaluated. The animals were distributed in a completely randomized design, with 20 replicates for each genetic group. All eggs were collected for three days in three periods, every 28 days all eggs were collected. The data were analyzed according to the mathematical model described by Wood, through Bayesian inference with the aid of the R software. Wood's model was efficient to determine the egg production curve of the studied lines (Nick Chick, Lohmann NA, Bovans White and Lohmann LSL) in the period from 18 to 80 weeks of age. The Lohmann LSL Lite strain showed precocity at the beginning of laying (17 weeks), higher yield rate (0.78) and lowest laying decline rate (0.02), when compared to the other lines. The Nick Chik lineage, on the other hand, showed the highest peak laying (114.49 days) with the highest persistence (6.56 weeks).

Keywords: Bovans White; Lohmann LSL; Lohmann NA Lite; Nick Chick; non-linear models.

Resumo: Objetivou-se com este estudo ajustar pelo método de Wood a curva de produção de ovos de quatro linhagens de poedeiras leves (Nick Chick, Lohmann NA Lite, Bovans White e Lohmann LSL) por meio da análise Bayesiana. Foram utilizadas 480 aves de um dia de idade a 80 semanas de idade, sendo 120 aves por linhagem avaliadas. Os animais foram distribuídos em delineamento inteiramente casualizado, com 20 repetições para cada grupo genético. Todos os ovos foram coletados durante três dias, em três períodos; a cada 28 dias, todos os ovos eram coletados. Os dados foram analisados em função do modelo matemático descrito por Wood, por meio da inferência Bayesiana com auxílio do software R. O modelo de Wood foi eficiente para determinar a curva de produção de ovos das linhagens estudas (Nick Chick, Lohmann NA, Bovans White e Lohmann LSL) no período de 18 a 80 semanas de idade. A linhagem Lohmann LSL Lite apresentou precocidade no início de postura (17 semanas), maior taxa de rendimento (0,78 e menor taxa de declínio na postura (0,02), quando comparada com as demais linhagens. Já a linhagem Nick Chik apresentou maior pico de postura (114,49 dias) com maior persistência (6,56 semanas)..

Palavras-chave: Bovans White; Lohmann LSL; Lohmann NA Lite; Nick Chick; modelos não lineares.

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1. Introduction

Modern commercial lines of laying hens are predominantly selected for egg production, disease resistance, feed efficiency, and individual performance [1]. Egg production is influenced by different genes and environmental factors. Likewise, reduction in age at sexual maturity, increased laying rate, and greater persistence and peak of laying directly influence the number of eggs produced [2]. The measurement of the productive efficiency of birds can be done through the number of eggs produced per unit or by the laying rate expressed as a percentage. However, the production curve can be obtained using other more precise methods such as statistical techniques, including nonlinear mathematical models, mixed models, and other tools [2-5].

The nonlinear models described by Gompertz [6], Richards [7], as well as the models by Wood [8], McNally [9], Yang [10], Nelder [11], and Lokhorst [12] are cited in the literature as models capable of fitting and thus predicting the egg production curve [2-5]. This is because the data collected for this analysis exhibit longitudinal behavior, that is, observations of the same individual over time. Furthermore, this characteristic is directly related to genetic heritability, so nonlinear mathematical models that allow biological interpretation of the parameters and accommodate longitudinal data provide better fits.

The model described by Wood [8] was initially used to describe the lactation curve of dairy cattle and, currently, has been employed in the study of determining the egg production curve [3, 5]. In addition to fitting the database and predicting the parameters of the production curve, it is possible with the use of functions to provide other additional parameters of interest: peak production or maximum yield (pp), day or occasion of peak production (dpp), and laying persistence (s). The objectives of this study were to estimate the egg production curves, pp, dpp and s of four strains of light laying hens, Nick Chick, Lohmann NA Lite, Bovans White, and Lohmann Lite, by using the nonlinear equation described by Wood and evaluate the quality of the parameters in the period of 18–80 weeks of age through Bayesian inference.

2. Materials and methods

2.1 Facilities, design, and experimental diet

The experiment was conducted at Granja Figueiredo, located in the municipality of Mandaguari - PR, in accordance with the standards proposed by the Animal Experimentation Ethics Committee of the State University of Maringá (UEM), described under protocol number 6329180919.

A total of 480 laying hens were used, ranging from 18 weeks to approximately 80 weeks of age and sexed, as follows: 120 Nick Chick lineage, 120 Lohman Lite, 120 Bovans White, and 120 Lohman LSL. Management practices included egg collection three times a day and feed provision twice a day. The lighting program used was a combination of artificial and natural light. During laying, the lighting program started with 14 hours at 18 weeks of age and was increased by one hour per week until reaching 16 hours of light per day.

The birds were fed according to the requirements of each life stage following the recommendations described by Rostagno [13], receiving water and feed ad libitum at all stages. During the laying phase, the birds were housed in barns as determined by the company schedule, namely:

Lineage 1 - Nick Chick

The birds were housed in an elevated barn, with a slatted floor aisle, fiber cement roofing, the presence of foggers and lantern vents, galvanized wire cages (35 cm x 30 cm x 30 cm), with four birds per cage, arranged in three stacked rows, with trough-type feeders and nipple-type drinkers, in this barn, egg collection and feeding were carried out manually.

Lineage 2 – Lohmann NA Lite and Lineage 3 - Bovans White

The birds were housed in two elevated sheds (one for each lineage) with a slatted floor corridor, asbestos cement tiles, the presence of misting systems and lanterns, galvanized wire cages (50 cm x 45 cm x 45 cm) with six birds per cage, arranged in three overlapping rows, with an automated trough-type feeder and nipple-type drinker and manual egg collection.

Lineage 4 - Lohmann LSL

The birds were housed in a conventional Californian-type shed, with clay tiles, the presence of cupolas, cages for six birds housed (50 cm x 45 cm x 45 cm) conventional, three overlapping rows, with trough-type feeders and nipple-type drinkers, egg collection and manual feeding.

2.2 Data collection

Egg production was recorded on the last three days of the end of each cycle (28 days) throughout the entire production period (18 to 80 weeks of age) and was recorded as total production to estimate the parameters of the production curve through Bayesian inference.

2.3 Statistical analysis

For the analysis of egg production data, a nonlinear regression was considered to predict the parameters of the curve via the Wood equation [8]:

$$y_{ijk} = a_k t_{ijk}^{b_k} e^{-c_k t_{ijk}} \qquad (1)$$

where i-animal = 1, 2, ... N; j-time = 1, 2, ... J; k-lineage = 1, 2, ... K; y = total (weekly) production; a = initial production; b = rate of increase in yield up to the peak of the curve; c = rate of decline in yield after the peak of the curve (persistence factor); t = weeks;

Through the estimates of the curve parameters, functions of them provide other additional parameters of interest: peak production or maximum yield (pp), day or occasion of peak production (dpp), and lay persistence (s):

$$pp = a\left(-\frac{b}{c}\right)^{b} e^{-b},\ dpp = \frac{b}{c} \text{ e } s = -(b+1)\ln(-c). \qquad (2)$$

To reduce experimental bias due to the low repetitions of the animals and to compare the curve parameters between treatments, Bayesian inference, described by Rossi [14] and Bianchi et al. [15], was used for all parameters of the considered models. For (1), it was assumed that yi ~ N (*f* (ti),τ), where *f* (ti) is the nonlinear function (1) and τ = 1/τ2, the precision according to OpenBUGS parameterization (computational program for Bayesian inference - Spiegelhalter et al. [16]). In addition, non-informative prior distributions were considered for all model parameters, that is, a Gamma distribution for a and for τ (~ Gamma (10-3,10-3)) and uniform for b and c (~ $U_{(0,1)}$).

The multiple comparison procedure was based on the posterior samples of the parameter estimates of the models considered. Significant differences were considered at the 5 % level between treatments, that is, if the value zero was not contained within the 95 % credibility interval of the desired contrast. The posterior marginal distributions for all parameters were obtained using the R program [17] through the BRugs package. For each parameter, 1,100,000 values were generated in an MCMC (Monte Carlo Markov Chain) process, considering a burn-in period

of 100,000 initial values. The final sample was taken in steps of size 50, which means that for every 100 values taken, one was included in the final sample, with 20,000 values generated. The convergence of all chains was verified using the Heidelberger and Welch test [18] from the R coda package.

3. Results and discussion

It was possible, through the equation described by Wood [8], to estimate the egg production curve for the four studied lines. The Bayesian estimates, as well as the mean, standard deviation, median, and credibility interval (P2.5 % and P97.5 %) for the parameters of the Wood model [8], are described in Table 1 and figure 1.

Table 1. Bayesian estimates (mean, standard deviation, median, and credibility interval (P2.5% and P97.5 %)) for the model parameters.

Lineages	Parameters	Bayesian estimates				
		[1]Mean	Standard deviation	Median	$P_{2,5\ \%}$	$P_{97,5\ \%}$
Nick Chick	*a*	20,83[a]	16,35	15,11	8,54	70,70
Lohmann NA Lite		24,67[a]	20,89	17,06	8,43	85,98
Bovans White		34,44[a]	22,81	27,89	8,88	95,41
Lohmann LSL		17,70[b]	13,59	12,98	7,39	57,29
Nick Chick	*b*	0,77[a]	0,20	0,82	0,25	0,99
Lohmann NA Lite		0,73[b]	0,22	0,78	0,18	0,99
Bovans White		0,52[b]	0,25	0,53	0,08	0,94
Lohmann LSL		0,78[a]	0,19	0,84	0,31	0,99
Nick Chick	*c*	0,03[a]	0,005	0,00	0,01	0,03
Lohmann NA Lite		0,03[a]	0,006	0,03	0,01	0,04
Bovans White		0,02[b]	0,006	0,02	0,01	0,03
Lohmann LSL		0,02[b]	0,005	0,02	0,01	0,03

[1] a,b,c Distinct letters in the rows indicate significant differences between the means of the posterior parameters of the lineages considered (NickChick, L2: Lohmann NA; Bovans White and Lohmann LSL), through Bayesian comparisons, at a 95 % credibility level. A: initial production, b: rate of yield increase up to the peak of the curve, c: rate of yield decline after the peak of the curve.

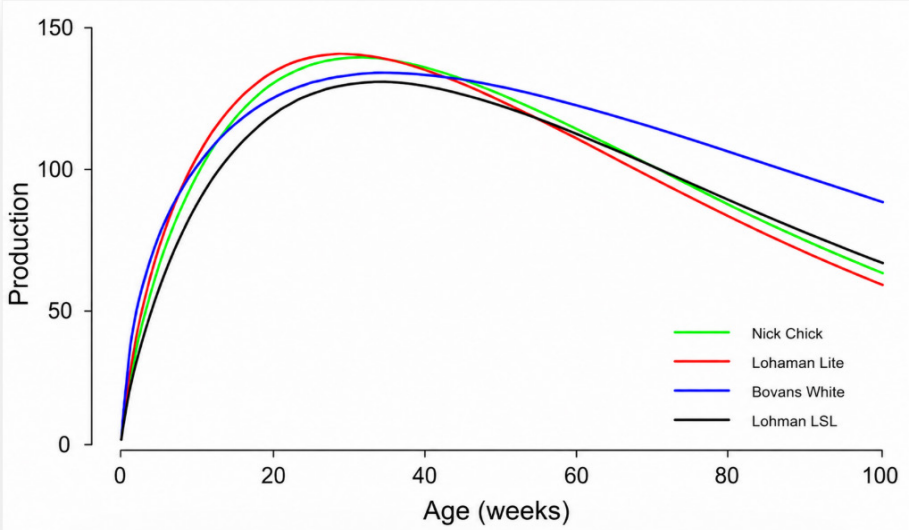

Figure 1 . Comparison between the curves fitted by lineages.

The curve described by Wood [8] and the parameter a correspond to the initial weeks of egg production, showing that the Lohmann LSL line, when compared with the other lines studied—Nick Chick, Lohmann NA, and Bovans White—proved to be earlier, starting production at 17 weeks of age. This line also showed a higher yield rate (0.78) and a lower rate of decline in laying (0.02). In other words, birds of this line reach peak laying later without a loss in production, and after leaving the peak, the concavity of the curve is more moderate, allowing the birds to stay at peak production for a longer period.

In Table 3, we can observe the mean Bayesian estimates, standard deviation, median, and credibility interval (P2.5 % and P97.5 %) for the parameters of interest calculated through the estimates of the Wood curve parameters. These are: peak production or maximum yield (pp), the day or occasion on which the peak production occurred (dpp), and the persistence of production (s), in this case of laying.

Table 2. Bayesian estimates (mean, standard deviation, median, and credibility interval (P2.5 % and P97.5 %)) for the parameters of interest calculated through the estimates of the Wood curve parameters.

Lineages	Parameters	Bayesian estimates				
		[1]Mean	Sandard deviation	Median	$P_{2,5\ \%}$	$P_{97,5\ \%}$
Nick Chick	*pp*	114,48[a]	6,84	114,14	101,95	128,86
Lohmann NA		111,39[b]	9,29	110,60	95,53	131,93
Bovans White		107,72[c]	3,99	107,59	100,24	115,85
Lohmann LSL		108,40[c]	6,94	108,15	11,72	122,96
Nick Chick	*dpp*	30,93[a]	5,03	31,50	18,51	39,12
Lohmann NA		28,81[bc]	7,26	29,35	14,26	39,55
Bovans White		33,95[ac]	51,30	34,62	14,74	44,22
Lohmann LSL		33,83[b]	7,70	34,00	21,82	43,75
Nick Chick	*s*	6,56[a]	0,46	6,65	5,41	7,21
Lohmann NA		6,38[b]	0,53	6,48	5,13	7,17
Bovans White		6,43[b]	0,46	6,42	5,55	7,26
Lohmann LSL		6,72[ab]	0,45	6,81	5,62	7,39

[*]a,b,c Distinct letters in the rows indicate significant differences between the posterior means of the parameters of the lineages considered (6-7-8-9), through Bayesian comparisons, at a 95 % credibility level. pp: peak of production or maximum yield, dpp: day or occasion of peak production, s: production persistence.

Considering the parameters estimated through Bayesian inference for the studied strains, it was possible to estimate, using mathematical functions, the peak production or duration at the peak (pp), the day in weeks when the peak occurred (dpp), and the laying persistence (s). The strain that showed the highest yield, that is, the longest duration at the peak, was Nick Chick, with 114.48 days ≈ 16.5 weeks, followed by Lohmann NA (111.39 ≈ 16 weeks), Lohmann LSL (108.40 ≈ 15.48 weeks), and Bovans White with 107.42 ≈ 15.34 weeks. Comparing the estimated values with those described by the manuals of the studied strains, it is observed that, for all strains, the duration of the laying peak was overestimated. The manuals describe it as 10 weeks for Nick Chick, 12 weeks for Lohmann NA Lite, 13 weeks for Bovans White, and 10 weeks for Lohmann LSL Lite [19-22].

The Lohmann NA lineage reached the peak of laying at 28.81 weeks of age, which was the earliest, followed by the Nick Chick (30.93 weeks of age), Lohmann LSL (33.83 weeks of age), and Bovans White (33.95 weeks of age). For post-peak laying persistence, the Nick Chick

and Lohmann LSL lineages showed a longer period of productivity, followed by Bovans White and Lohmann NA. The age at which the animals reached peak laying was underestimated for the Nick Chick and Lohmann NA LSL lineages (36 weeks and 33.5 weeks of age, respectively) and overestimated for the Bovans White lineage (31 weeks of age) (19-22). However, for the Lohmann LSL Lite lineage, the estimated and recommended values are in agreement, being 33 weeks of age [20].

Similar results were observed by Galeano et al. [23] when evaluating different mathematical models to estimate the egg production curve in commercial laying hens of the Hy-Line Brown, Lohmann LSL, Isa Brown, and Lohmann Brown strains. The authors found that the tested models had good predictive ability, particularly the Delay and Lokhorst models, showing that using nonlinear functions allows for a more accurate description of the productive behavior of the birds throughout the laying cycle. Furthermore, they observed variations among strains in terms of the curve shape and productive persistence, demonstrating the influence of genetic potential on the estimated parameters. Such results corroborate those found in the present study, in which differences between the evaluated strains were also observed for precocity, peak of lay, and persistence, reinforcing the importance of applying mathematical models, such as the Wood model, in production monitoring and in making more accurate decisions in the management of commercial layers.

Studying the relationship between egg production and quality and the age of the birds (100 weeks) of the Nick Brown line raised in cages, Alfonso-Carrillo et al. [24] observed that the birds showed high variation in egg production, ranging from 75 to 55 %, with an average weight of 67g. The authors highlighted that birds with higher production and high shell quality are the heaviest animals and have larger uteri. This fact may be related to the full development of the reproductive system, indicating that maturity weight and egg weight are correlated with the reproductive cycle [24-26].

4. Conclusion

Wood's model was efficient in determining the egg production curve of hens from the studied lineages (Nick Chick, Lohmann NA, Bovans White, and Lohmann LSL) in the period from 18 to 80 weeks of age, with the Nick Chick lineage showing the highest pp (peak of laying) with the highest s (persistence).

Conflict of interest statement

The authors declare no competing interest.

Data availability statement

The complete data set that supports the results of this study was published in the article itself.

Author contributions

Conceptualization: Maia, K. M. and Marcato, S. M., Data curation: Maia, K. M.; Souza, M. and Benitis, M. I., Formal analysis: Rossi, M. R., Investigation: Maia, K. M.; Souza, W. M.; Benitis, M. I. and Freitas, M. V. M., Methodology: Rossi, M. R. and Marcato, S. M., Project management: Maia, K. M., Supervision: Marcato, S. M.

Generative AI use statement

The authors did not use generative artificial intelligence tools or technologies in the creation or editing of any part of this manuscript.

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