Estimate of lysine nutritional requirements for Japanese quail breeders

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Background. Japanese quail breeding is the basis for genetic improvement and multiplication for commercial layers, however, there have been no known studies on the optimal lysine level for these birds. Thus, study the egg output response to the Lys supply using different e-functions and evaluate the that best fit, have allowed the partition the lysine requirements for maintenance, both weight and egg output maximum. **Methods.** The objectives of this study were to identify the responses of birds to various Lysine (Lys) levels, identify the functions related to these responses and determine the ideal Lys intake amount for Japanese quail breeders. A completely randomized design of seven treatments with seven replicated was used. Treatments consisted of diet supplementation by Lys in concentrations of 16.8, 11.8, 8.4, 6.7, 5.0, 3.4, and 1.7 g/kg. Six exponential models were adjusted. **Results.** The level of Lys was found to affect bird responses ($P < 0.001$). The birds responded to the levels provided, allowing for the creation of a lysine response curve. A monomolecular function with four parameters was balanced against the statistics of adjustment and selection of models. It was possible to estimate the level of lysine required for maintenance as 133 ± 2 mg/kg $BW^{0.67}$, and based an average of 41% efficiency, 22 mg Lys produced 1 g of egg output (EO). The daily intake calculated by the monomolecular factorial model was 284 mg Lys for a bird with 0.170 kg body weight and production of 10 g EO/day. The four-parameter monomolecular function proposed in this study is adequate for interpreting the animal response and calculating lysine intake for breeders.

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Abstract

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Results. The level of Lys was found to affect bird responses ($P < 0.001$). The birds responded to the levels provided, allowing for the creation of a lysine response curve. A monomolecular function with four parameters was balanced against the statistics of adjustment and selection of models. It was possible to estimate the level of lysine required for maintenance as 133 ± 2 mg/kg $BW^{0.67}$, and based an average of 41% efficiency, 22 mg Lys produced 1 g of egg output (EO). The daily intake calculated by the monomolecular factorial model was 284 mg Lys for a bird with 0.170 kg body weight and production of 10 g EO/day. The four-parameter monomolecular function proposed in this study is adequate for interpreting the animal response and calculating lysine intake for breeders.

Keywords. Dilution technique, efficiency, maintenance, models, requirement.

1. Introduction

Japanese quail breeders is the basis for genetic improvement and multiplication for commercial layers. Through the selection process, in each generation, genetically superior animals are used to form the breeding stock. Approximately 4,444 breeder birds are required to produce one million Japanese quails, and in Brazil, more than 111,000 were necessary to yield the 25 million currently housed (Silva et al., 2020). The breeders used in this study were selected for egg production and belong to the male line of laying quails. There have been no known studies on the optimal amino acid level for Japanese quails breeders. Lysine (Lys) is the reference amino acid for establishing the ideal relationship, and it is the second limiting amino acid in maize and soybean diets of birds. Lys acts on protein and lipid metabolism, and in reproduction, subdoses are related to atrophy of reproductive organs and the liver (Ruan et al., 2019; Tian et al.,2019).

Among the main methods used to establish amino acid intake are dose response and factorial analysis. The factorial method is a reasonable option to establish amino acid intake by using variables such as body weight (BW) and egg output (EO) (Silva et al., 2019). This method is based on using the linear relationships between amino acid intake and these variables (mg per kg BW and mg per g EO) to partition the BW maintenance requirement and EO production (Sakomura et al., 2015; Reis et al., 2018). A reduction in feed conversion (Basaglia et al., 2005) is possible because the input values for BW and EO correspond to the average population potential (Hauschild, Pomar & Lovatto, 2010).

Although feed conversion reduction in the egg production industry can be useful, the effectiveness of this reduction is based on the average production potential of the batch (Basaglia et al., 2005, Silva et al., 2015a), and thus individuals above the average population potential would inevitably receive a subdose (Hauschild, Pomar & Lovatto, 2010; Silva et al., 2019; Silva et al., 2015a). This characteristic of the factorial method may be a limitation for nutritionists in genetic improvement programs and multiplication systems, in terms of how individuals performing above the population average should be adequately identified and nurtured. Therefore, since linear relationships are limited because they are infinite in all directions, empirical constraints should be used to obtain more precise estimates that represent a closer approximation to the actual condition (Silva et al., 2015a; Silva et al., 2019).

Nonlinear factorial models are alternatives for breeders (Kebreab et al., 2008; Ekmay et al., 2014) especially for birds that prioritize reproduction by mobilizing body reserves to maintain egg laying (Lima et al., 2018; Lima et al., 2020). Exponential functions allow for the consideration of maintenance and production partitioning (Samadi & Liebert, 2008; Dorigam et al., 2017) while catering to the most productive animals of the population, since curvilinear adjustment can change the response rate ($\alpha/\beta\,x$) with the approximation of the maximum genetic potential (Fuller & Garthwaite, 1993; Silva et al, 2019). Factorial models based on e-functions are available that have parameters with biological significance that can be improved, such as the requirement to maintain unity on the axis of the ordinate (Samadi & Liebert, 2008; Dorigam et al., 2014; Dorigam et al., 2017) when the ideal would be on the axis of the abscissa (Kebreab et

80 al., 2008; Sarcinelli et al., 2020; Silva et al., 2020), thereby avoiding confusion between the
81 minimal response on the ordinate axis (Lima et al., 2013; Dorigam et al., 2017) and the
82 requirement of nutrient maintenance on the abscissa axis. Therefore, this study aimed to (1)
83 study the EO response to the Lys supply using different e-functions, (2) evaluate the e-functions
84 that best fit the EO responses, (3) partition the Lys requirements for BW maintenance and EO
85 production, and (4) the Lys intake level that maximizes EO.

2. Materials & Methods

87 The study was conducted in the Laboratory of Poultry Sciences of the Departament of
88 Zootecnia da Faculdade de Ciências Agrárias e Veterinárias of the Universidade Estadual
89 Paulista, Campus of Jaboticabal, São Paulo, Brazil. The procedures used in this study were
90 approved by the Committee on Animal Use Ethics, under protocol 012203/17.

2.1 Birds, housing, and experimental design

92 Forty-nine VICAMI® Japanese quails breeders were used at 14 weeks of age, when they are at
93 their peak performance. The experiment was conducted in a temperature-controlled climate
94 chamber containing galvanized wire cages measuring 0.26 m × 0.37 m × 0.36 m, with channel
95 feeders and nipple drinkers. The temperature during the experimental period was maintained at
96 24 °C, with a 16:8 h (L:D) photoperiod. Water was provided ad libitum. A completely
97 randomized design was used, with seven treatments and seven repetitions. Each experimental
98 unit consisted of one bird per cage. All cages were identified with different colored labels,
99 according to the treatments. The treatments consisted of seven levels of Lys in the diet as
100 follows: D7 – 16.8 g/kg; D6 – 11.8 g/kg; D5 – 8.4 g/kg; D4 – 6.7 g/kg; D3 – 5.0 g/kg; D2 – 3.4
101 g/kg, and D1 – 1.7 g/kg. After the trial the animals remained in the university's herd for egg
102 production.

2.2 Experimental treatments and diets

104 The level of Lys in the dietary protein profile and experimental diets were formulated as
105 described by Fisher and Morris (1970). A formulation with a high crude protein content (HPD)
106 and a relative deficiency in Lys compared to the other amino acids, and a second formulation
107 that was free of protein and amino acids (NFD) were prepared (Table 1). The nutritional levels of
108 the essential amino acids in the HPD were based on the recommendations described previously
109 by Rostagno et al. (2011) (Table 2). The Lys level was established by multiplying the
110 recommended amount by 1.5, and that of the other amino acids by 2.0 to maintain a minimum
111 Lys deficiency of 50% compared to the other amino acids. For energy and other nutrients
112 (vitamins and minerals), the minimum recommendations were followed by Rostagno et al.
113 (2011). NFD was formulated to provide energy and the other nutrients with no amino acids. The
114 intermediate experimental levels of Lys were obtained by diluting the HPD with NFD in the
115 following proportions (HPD:NFD): 100:0; 70:30; 50.1:49.9; 40:60; 30:70; 20.1:79.9; and 10:90;
116 thus obtaining Lys concentrations of 16.8, 11.8, 8.4, 6.7, 5.0, 3.4, and 1.7 g/kg respectively.

2.3 Measurements and variables analysed

118 The experiment occurred for 22 days, with the first 7 days of adaptation. The feed supply was
119 according to the body weight (measured weekly) of the birds in Kg of $BW^{0.67}$, thus determining

120   the maximum consumption. The variables evaluated were: daily feed intake (FI, g/bird), daily
121   Lys intake (LysIntake, mg/bird), body weight (BW, kg), body weight change (BW, g/bird), daily
122   egg production (EP, %/bird), egg weight, and daily deposition of Lys in egg mass (dLys,
123   mg/bird), which was achieved by considering the concentration of 13% protein (Ali, 2019) and
124   the 6.89% level of Lys in egg protein (Ali, 2019). Lys mobilization was calculated from the
125   change in BW, considering the mobilized protein fraction and, consequently, the proportion of
126   Lys in the mobilized protein. Protein and Lys concentrations in the body were obtained from the
127   method of a previous study (Siqueira et al., 2021).

128   **2.4 Description of responses by different mathematical functions**

129   The variables dLys and LysIntake were related to the metabolic weight of the bird ($BW^{0.67}$).
130   Two linear functions were used: linear regression and broken-line regression (Table 3).

131   To interpret the relationship between dLys and LysIntake, six e-functions were used, one of
132   which was proposed in this research and the other five were obtained from the literature,
133   considering the interpretation and biological meaning of the parameterization of the model
134   (Table 3). The adjusted functions consisted of a monomolecular parameterized model with three
135   (Kebreab et al., 2008; Samadi & Liebert, 2008) and four parameters (Kops & Lamberson, 2006;
136   Strathe et al., 2011).

137   **2.5 Model Adjustment and Selection Statistics**

138   The adjustment and selection statistics used were the determination coefficient (R^2),
139   determination coefficient adjusted for the number of parameters (R^2 Adjust), Akaike information
140   criterion (AIC), corrected Akaike information criterion (AICC) and the Bayesian information
141   criterion (BIC), model quality was based on the lowest score for AIC, AICC and, BIC.

142

143   **2.6 Structure and assessment of linear and non-linear factorial models to estimate Lys**
144   **intake based on BW and EO values**

145   The factorial model calculated the nutrient Lys according to its partition, maintenance, and
146   production. The nonlinear factorial model was based on the logarithmic transformation of
147   Samadi and Liebert (2008), according to Equation 9 (M9). In this model, the maintenance
148   parameter was added after calculating the requirements for egg mass production.

149

150     $$\text{LysIntake} = BW^{0.67} \times [\text{Lysm} + (\ln R_{max} - \ln(R_{max} - 8.853 \times (EO/BW^{0.67})))/k] \qquad (9)$$

151

152   The parameters necessary to calculate LysIntake were the R_{max}, Lysm, and k that were
153   obtained from M3, M5, and M8, generating the predicted values and the respective prediction
154   errors for each monomolecular function.

155   To compare the LysIntake estimates by the nonlinear factorial model M9, the traditional
156   factorial model (Sakomura et al., 2015; Silva et al., 2019) was used to estimate LysIntake
157   according to Equation 10 (M10).

158

159     $$\text{LysIntake} = BW^{0.67} \times [\text{Lysm} + a \times (8.853 \times EO)] \qquad (10)$$

160

161  The parameters required to calculate LysIntake were Lysm and a, which were obtained from

162 linear models M1 and M2.

163  The input variables in Equations 9 and 10 were BW and EO expressed in $kg^{0.67}$ and g/kg

164 $BW^{0.67}$, respectively, and the value of 8.853 is the relationship between dLys and EO. LysIntake

165 in Equations 9 and 10 is the model output of daily intake in mg/bird.

166  Assessment of dLys response prediction error as a function of LysIntake estimated by non-

167 linear and linear factorial models. The prediction error was determined as the difference between

168 the observed and predicted values of dLys. The errors were subjected to linear regression

169 analysis according to the predicted value of a previous study (St-Pierre, 2003), according to

170 Equation. 11 (M11).

171

172 $ep = b0 + b1\,(Yp - \bar{Y}p) + \hat{e}$           (11),

173

174  where ep was the residual value for all observation; b0 and b1 were the estimates of the

175 parameters, Yp was the predicted value, $\bar{Y}p$ was the average of the predicted values, and $\hat{e}$ was

176 the regression error of the residues to the predicted values. The decision rule was based on the

177 assumption that the model is impartial when the correlation approaches 1 and R^2 approaches 0.

178 Therefore, the residues are not correlated with the predictions, and consequently, the value of b1

179 is close to zero for the unbiased model. The ratios of the parameters (b0 and b1) to regression

180 error ($\hat{e}$), scalar error (b0/$\hat{e}$), and prediction bias (b1/$\hat{e}$) were obtained for the model.

181 **2.7 Statistical analyses**

182  The assumptions of homoscedasticity and residual normality were tested. Subsequently, the

183 data were subjected to analyses of variance, and when an invalid hypothesis was verified, the

184 data were analyzed for linear and quadratic effects of the Lys levels, considering a significance

185 of 0.05. The parameters of the models were estimated by the maximum probiosimilarity, using

186 the NLMIXED procedure of SAS, considering the maximum random effect of the model

187 (Robbins, Saxton & Southern, 2006). The values were calculated using SAS software (SAS

188 Institute Inc., Cary, NC, USA, 2014, version 9.4).

189 **3. Results**

190  The Lys level in the diet affected the performance of Japanese quails breeders (Table 4),

191 thereby rejecting the null hypothesis, where the variables do not differ with the levels of Lys in

192 the diet (P < 0.05). The contrast analysis was significant for the linear and quadratic effects of

193 Lys levels on bird replenishment, except for BW, which responded linearly to Lys levels in the

194 diet. The homoscedasticity and residual normality were tested by the Shapiro-Wilk test, the data

195 were normal, and the residuals are randomly distributed around zero (p>0.05).

196  The quails that were fed a lower level of Lys (1.7 g/kg) reduced their daily consumption by

197 39%, when compared with 8.4 g Lys per kg consumed the maximum value of 25.1 g/bird. The

198 daily Lys intake at 1.7 g/kg was 13% of that of the highest level of Lys in the diet (16.8 g/kg).

199 Therefore, the egg production and egg weight were reduced in different proportions. In 1.7 g/kg

200 of Lys diet, the egg production decreased by 77% from the maximum value of 94%, while egg
201 weight reduced only 25% of the maximum value of 11.2 g obtained at 16.8 g/kg of Lys diet
202 (Table 4).
203   Egg mass and Lys deposition decreased by 82% in response to the limitation of Lys intake in
204 the diet. Birds exhibited greater weight loss and consequently higher daily Lys mobilization
205 values in diets with a greater degree of limitation in daily Lys intake. Increased intake of Lys
206 linearly decreased its mobilization. Although consumption decreased, Lys limitation was
207 responsible for low feed efficiency and consequently higher feed conversion values (Table 4).
208 The feed conversion presented the largest amplitude (6.04) between the maximum (8.4 g/g at the
209 level of 1.7 g/kg) and minimum (1.7 g/g at 16.8 g/kg) values corresponding to a change of 356%
210 (Table 4). This result shows that the daily consumption of 15.2 g/bird would support a larger egg
211 production, but Lys was limiting for protein synthesis.
212 **3.1 Analysis of adjustment and selection functions and statistics**
213   The selection of Lys intake models is shown in Table 5. M2 presented better adjustment when
214 considering only the values of the adjacent R². Model selection statistics (AIC, AICC, and BIC)
215 indicated that the broken-line model (Table 5: M2) and the double exponential function (Table 5:
216 M7) best adjusted the relationship between dLys and LysIntake.
217   The maintenance requirements of 36 and 139 mg/kg values of $BW^{0.67}$ obtained with M1 and
218 M8, respectively, revealed no information on variability. A value of 52 mg/kg was the $BW^{0.67}$
219 obtained for maintenance using M2 (Table 5) at dLys = 0; therefore, this also showed no
220 variability. However, this model (Table 5: M2) presented a better adjustment and lower AIC,
221 AICC, and BIC values (Table 5). In contrast, the M6 and M7 models (Table 5) estimated
222 retention requirement values between 10 and 7 times greater than the M2-based value,
223 respectively. The M7 (Table 5), along with the M2 presented better adjustments and lower values
224 of AIC, AICC, and BIC (Table 5), while the R_{max} estimates revealed the lowest determined
225 value, which underestimated the genetic potential value, since the maximum response that was
226 estimated as 269 mg/kg $BW^{0.67}$ was lower than the values obtained in the treatments with 6.7 –
227 16.8 g of Lys per kg.
228   For Models 3 and 4, the results of the adjustment and selection statistics support M4 as
229 superior (Table 5). This model presented the highest maximum response value, which was
230 estimated at 444 mg/kg $BW^{0.67}$. The maximum observed response of 297 mg/kg $BW^{0.67}$, was
231 67% of the estimated value for R_{max}. R_{min} showed a variation of 43%, indicating a limited power
232 of inference to interpret the animal response.
233   M3 presented estimates for R_{max}, R_{min}, k, and Lysm with smaller error values, supporting the
234 biological significance in interpreting the bird response (Table 5). The maximum estimated
235 response of 357 mg/kg $BW^{0.67}$ was 17% greater than the maximum observed value. The value of
236 Lysm was 133 mg/kg $BW^{0.67}$, with a range of 128 to 137 mg/kg $BW^{0.67}$. Among the adjusted
237 models with Lysm as a parameter, M5 returned 114 mg/kg $BW^{0.67}$ with a range of 25 to 203
238 mg/kg $BW^{0.67}$. For M8, 139 mg/kg was the estimated $BW^{0.67}$; therefore, the 133 mg/kg $BW^{0.67}$
239 value of the M3 was similar to those estimated in M5 and M8 (Table 5).

3.2 Structure and assessment of linear and non-linear factorial models

The observed averages for LysIntake and dLys, in mg/kg $BW^{0.67}$ for each treatment and the respective estimated values are shown in Table 6. The estimates of the linear factorial models differed, especially in relation to the prediction of animal replenishment. M2 (Table 6) overestimated the response after ingestion of 286 mg/kg $BW^{0.67}$, while M1 presented better response estimates.

The M6 and M7 exponential models (Table 6) showed a discrepancy between the response estimates, where in M6, the estimated between levels did not differ and for M7 it was not possible to estimate for the level 6.7 g/kg of Lys per diet. While M3, M4, M5, and M8 revealed errors of 33.4, 33.4, 33.5, and 32.2 mg/kg $BW^{0.67}$, respectively (Figure 1, Table 7). The prediction of nonlinear factorial models could only be reasonably evaluated with the aid of residue analysis (Figure 1, 2). Residue analysis statistics (Figure 1) show that M5 and M8 presented lower values for scalar error and prediction bias (Figure 2). However, this analysis considers only the lines with observations, and some experimental units had dLys values greater than the R_{max} of these models, resulting in negative values and therefore no solution, which decreased the number of observations for the analysis of the association between the residue and the predicted value, thereby limiting the use of these models in the factorial calculation of LysIntake.

M3 with the values of R_{max}, k and Lysm (LysIntake = 133+(ln(357)–ln(357–Deposition))/0.0021) and M4 (LysIntake = 117+(ln(444)-ln(444–Deposition))/0.0027) presented no limitation when calculating LysIntake, but residue assessment statistics indicated a better predictive capacity for the factorial model with the M4 parameters. This result revealed that the biological interpretation and predictive capacity were not reconciled in the same model. M3 has parameters that assist the biological interpretation, but its application in the factorial model resulted in 10% less predictive capacity compared to M4 (Figure 2, Table 7).

4. Discussion

To our knowledge, this is the first study to investigate the relationship between Lys levels and the response by Japanese quail breeders. The experimental period used here was 21 days, conforming with methodologies by Silva et al. (2019).The experimental period could be reduced if there was greater differences in the diet levels (amplitude) of Lys. Both the present study and that of Silva et al. (2019) show that the definition of the treatments and their amplitude should also be considered, along with the experimental period. The breadth of Lys levels and responses, especially in the egg production, is indispensable to support the findings independent of the statistical tool. Previous studies with Japanese quails obtained an amplitude of 4% (Pinto et al., 2003; Costa et al., 2008) and 8% (Oliveira et al., 1999), whereas this survey returned 77%. The results showed that the levels of Lys in the diet were limiting for Japanese quails breeders. The amplitude Lys deposition in the egg was close to 470%, supporting the findings of this study regarding the dietary limitation of Lys. In addition to experimental period reduced, was followed this study the "reduction", formulated by Willian Russel and Rex Burch, which allowed the reduction in the number of animals used to maintain the precision of results (Hubrecht & Carter).

280   The feed of quails used in a breeding program should provide nutritional levels that support
281   the expression of the maximum genetic potential. Therefore, linear procedures are limited to
282   generating recommendations that approach the population average (Baker, 1986; Basaglia et al.,
283   2005; Hauschild, Pomar & Lovatto, 2010; Silva et al., 2019) as opposed to the maximum.
284   Among the variables analyzed here, the relationship between ingestion and deposition of Lys in
285   the egg was selected to interpret the responses of the birds using exponential models. The results
286   obtained in this study support the hypothesis that the method used can influence the Lys intake
287   calculated and the interpretation of the animal response, especially the genetic potential of the
288   bird, using six different exponential functions.
289   M2 was included in this analysis as a benchmark, especially for the interpretation of its
290   parameters. The R_{max} parameter of the broken-line model is associated with the average
291   population potential (Cosse & Baker, 1996; Hauschild, Pomar & Lovatto, 2010) however, the
292   R_{max} values of the dual-exponential models (M6 and M7) were similar to that of the broken-line
293   model. As both M6 and M7 models approximate the nutritional requirements of the average bird,
294   the R_{max} parameter population is forced to underperform and conform to the average bird
295   population as their requirements are not being fully met. The parameterization of the exponential
296   double was defined to (Strathe et al., 2011) approximate the asymptotic response of the model to
297   the observed values, thereby avoiding the use of an asymptotic response ratio to establish
298   optimal performance and necessary intake (Strathe et al., 2011). In dose-response studies, the use
299   of proportions to establish optimal performance and the respective nutrient intake may vary from
300   50% to 95% of R_{max} (Halle, Jeroch & Gebhardt, 1984; Cosse & Baker, 1996; Samadi & Liebert,
301   2008; Strathe et al., 2011). Therefore, it represents a criterion that confuses the lack of model
302   adjustment and the proportion of optimal performance. In an attempt to approximate the
303   adjustment of the model to the data and the parameterization, the double exponential used could
304   have limited the adjustment of the functions to studies with smaller amplitudes in the responses
305   of nutrient deposition intake. In this study, the treatments vastly modified the responses of the
306   birds by close to 476%, and the double exponential functions presented the poorest performance.
307   Two other objectives investigated in this research were the evaluation of the ability to
308   interpret the response through the parameters of the model, and the predictive capacity when
309   applied in a factorial approach. The results showed that it was not possible to reconcile the two
310   objectives by the same mathematical model. The model that presented consistent estimation of
311   the parameters and that aided in the interpretation of the response was the monomolecular with
312   four parameters (M3). However, this model presented less predictive capacity when compared to
313   the monomolecular with three parameters (M4). In a detailed analysis, the difference in the
314   accuracy of these models (M3: 0.908 vs. M4: 0.999) is related to the scalar error, mainly the
315   error of 26 mg/kg $BW^{0.67}$ in the M3 relative to the observed value at the first level of Lys in the
316   diet, since the prediction bias value could only scarcely justify some differences between the
317   models (Figure 2).
318   The estimated R_{min} parameter of 3.1 was close to zero (2–6 mg/kg $BW^{0.67}$), and this value has
319   biological support. The lower level diet (1.7 g/kg) does not provide sufficient Lys for egg

320   formation. Therefore, a significant body weight reduction was observed, equivalent to
321   approximately 4 mg/kg BW$^{0.67}$ of Lys mobilized daily (Table 4). Subtracting the maintenance of
322   133 mg/kg BW$^{0.67}$, from the intake of 190 mg/kg BW$^{0.67}$ at the lowest level of Lys (1.7 g/kg),
323   only 57 mg/kg BW$^{0.67}$ synthesis and deposition in the egg would be available. The prediction of
324   the M4 of dLys and LysIntake at the lowest level was 61 and 174 mg/kg BW$^{0.67}$, respectively,
325   resulting in 108% utilization efficiency, which indicates body reserve mobilization to sustain the
326   minimal deposition of Lys in the egg. Based on this, the R$_{min}$ parameter estimated by M4 of 117
327   mg/kg BW$^{0.67}$ has no biological support, as it represents close to double the value seen in the diet
328   with a lower level of Lys (63 mg/kg BW$^{0.67}$). Some authors attribute the interpretation of
329   maintenance requirement to the R$_{min}$ of M4 considering that the value of R$_{min}$ represents an
330   inevitable loss and must be provided in equal quantity by diet to avoid the animal undergoing a
331   negative nitrogen balance. This finding reinforces the initial hypothesis that some factorial
332   models use the value of the maintenance requirement extracted on the axis of the ordinate
333   (Strathe et al., 2011; Dorigam et al., 2014; Dorigam et al., 2017), when the ideal is on the axis of
334   the abscissa (Kebreab et al., 2008; Silva et al., 2019), to avoid confusion between minimal
335   response, R$_{min}$, axis of the ordinate (Silva et al., 2013; Dorigam et al., 2017), and requirement of
336   maintenance, Lysm, on the axis of the abscissa.
337   With the four-parameter monomolecular function, it was possible to estimate the maintenance
338   requirement for Lys based on production responses close to zero. The use of curvilinear models
339   for this purpose can be considered as a reasonable option, since for parameter estimation, all
340   observations were used from the lowest to the highest level of Lys in the diet. When compared to
341   the estimate of Silva et al. (2019) of 156.8 mg/kg BW$^{0.75}$, the figures appeared to differ, but in
342   this research the metabolic weight was calculated using the BW$^{0.67}$, and Silva et al. (2019) used
343   BW$^{0.75}$. When standardized the value of Silva et al. (2019) to the same basis used here: in the
344   result is 136 mg/kg BW$^{0.67}$, considering a mean BW of 0.16 kg (Table 4), and this value is in the
345   confidence interval of 128–137 mg/kg BW$^{0.67}$ estimated for Lysm in this survey.
346   The requirement for retention of quail breeders was 2.6 times greater than that of cut breeders
347   (51 mg/kg BW$^{0.67}$) (Silva et al., 2015b) and 2.2 times greater than commercial dusts (61 mg/kg
348   BW$^{0.67}$) (Silva et al., 2015b), demonstrating the difference between genotypes for egg production
349   function, and thereby justifying this research.
350   Based on the factorial calculation of LysIntake and dLys (Table 6), it was possible to obtain
351   the utilization efficiency of each level of Lys in the diet, with an average of 41% obtained with
352   Model 3, and 87% for Model 4. The requirement of Lys per g egg mass calculated on the basis of
353   these models was 23 mg/g for Model 3 and 11 mg/g for Model 4 considering the relationship
354   between Lys deposition and use efficiency: 8.853/0.41 = 23 mg/g for Model 3 and 8.853/0.87 =
355   11 mg/g for Model 4. In previous studies, the efficiency of Lys was 47% (Silva et al., 2019), and
356   Met + Cys, Thr, and Trp, returned values of 59%, 42%, and 26%, respectively (Sarcinelli et al.,
357   2014). The mean of these results is 43%, which is similar to the average efficiency, considering
358   all treatments, obtained with models M3 and M4, verifying the importance in the selection of the
359   function to interpret and predict the animal response. Despite the similarity between the values

360   found in this search (41%) and with the average (43%) obtained from previous studies (Sarcinelli
361   et al., 2014; Silva et al., 2019), it is important to highlight the limitation of information on the
362   concentration of amino acids contained in the quail egg, especially for tryptophan which was
363   found in only one publication (Ali, 2019) and tritonin, whose concentration varied from 5.3 (Ali,
364   2019) to 7.3 mg/egg (Genchev, 2012). Therefore, establishing the amino acid profile of the quail
365   egg will help to consolidate the understanding of the efficiency of amino acid use, since recent
366   studies have reported that this efficiency by quails is half that of other layers (Sakomura et al.,
367   2015; Silva et al., 2015b).

368   The daily Lys intake calculated by the non-linear factorial model was 284 mg/bird for a bird
369   of 0.170 kg BW and daily production of 10 g/bird EO. To use the model, the first step is to
370   change the values of BW ($0.305 = 0.170^{0.67}$) and EO ($32.8 = 10 \times 0.305$) to metabolic body
371   weight (MBW). EO is then transformed to dLys (290 mg/kg $BW^{0.67}$), multiplying 32.8 by 8.853
372   (8.853 is the relationship between dLys and EO). To calculate LysIntake initially, only dLys
373   (290 mg/kg $BW^{0.67}$) was used to obtain LysIntake in mg/kg $BW^{0.67}$: 931 mg/kg $BW^{0.67}$ = (133 +
374   (ln (357) -ln (357-290))/0.0021), then multiplying by MBW (0.30) This model assumes solutions
375   for dLys < 357 mg/kg $BW^{0.67}$, equivalent to 12.3 EO, which is the maximum egg mass
376   production. Another limitation of this model relates to the diet, with a value of 0.0021
377   representing the rate of use of the dietary protein, based on the ingredients maize, soybean, and
378   corn gluten, with 60%, necessitating the use of the proposed model with other ingredients.

379   The factorial model prediction was positioned based on the equation parameters in relation to
380   the values found in the literature, which used studies with Japanese quail eggs, due to the
381   absence of studies with breeders. The value of LysIntake for a bird with 0.170 kg BW and with
382   daily production of 10 g/bird EO was 284 mg/bird. By the linear factorial model of Rostagno et
383   al. (2017), LysIntake was 267 mg/bird daily. The model of Rostagno et al. (2017) has been
384   accepted by technicians and researchers in the area, and the difference shown here of 18 mg/bird
385   may be a limiting factor for animals that are in genetic selection programs, especially
386   considering the cumulative effect of the subdosage. Using the responses of 9.04 EO and 0.154
387   BW from the previous (Pinto et al., 2003) survey, LysIntake was calculated as 247 mg/bird using
388   the non-linear factorial model proposed here, differing by 7 mg/bird from the value of 254
389   mg/bird (Pinto et al., 2003).

390   Therefore, the four-parameter monomolecular function proposed in this study is adequate for
391   interpreting the animal response. The parameters of this function when used for non-linear
392   factorial calculations were suitable for calculating lysine intake for Japanese quail breeders.

393 **5. Conclusions**

394   The methodology used limited the supply of lysine and the birds responded to the degree of
395   limitation, and the lysine response curve could be studied carefully. Considering the ability to
396   interpret to predict the animal response the monomolecular function with four parameters was
397   balanced against the statistics of adjustment and selection of models, being a reasonable option.
398   It was possible to estimate the requirement of lysine for maintenance 133 ± 2 mg/kg $BW^{0.67}$ and
399   based on average 41% efficiency the requirement of 22 mg Lys was obtained to produce 1 g egg

400 output. The daily intake Lys calculated by the non-linear factorial model was 284 mg/bird for a
401 bird with 0.170 kg BW and with daily production of 10 g/bird EO.

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Data availability statement

406   The following information was supplied regarding data availability: The raw measurements
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411

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Figure 1

Mean predicted of percentage lysine deposition errors for models (M).

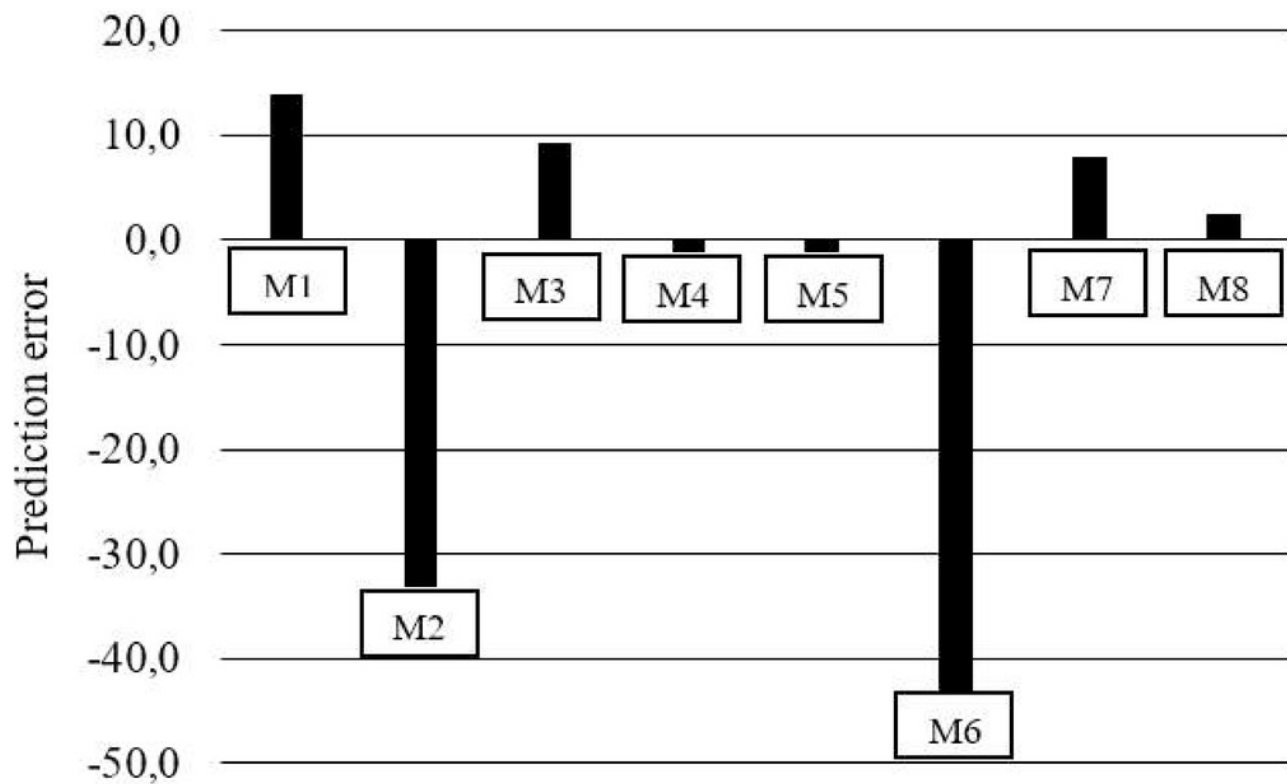
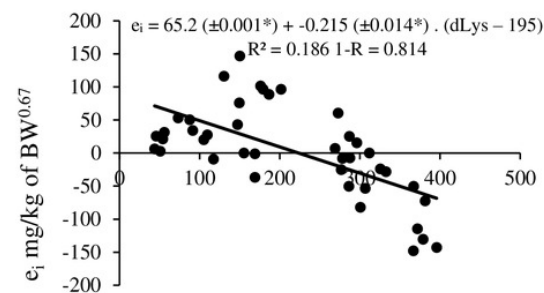
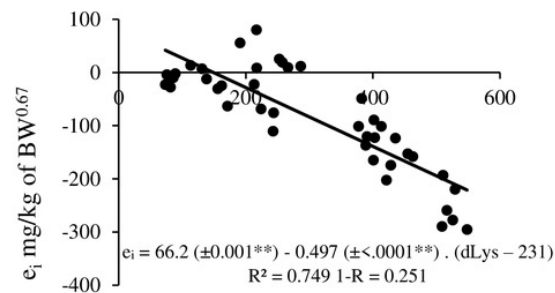
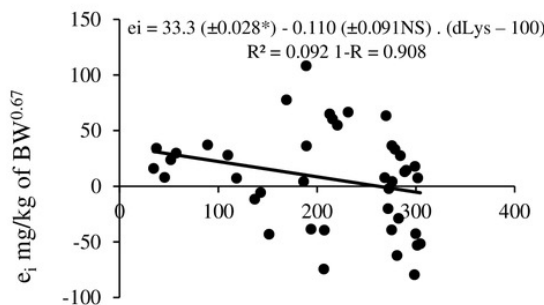



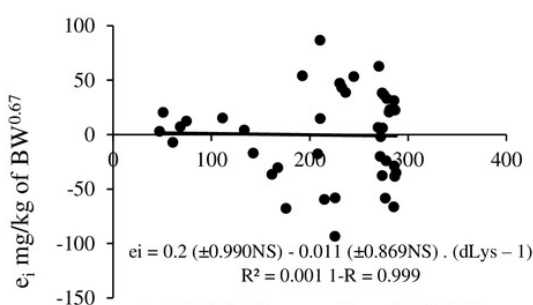
Figure 2

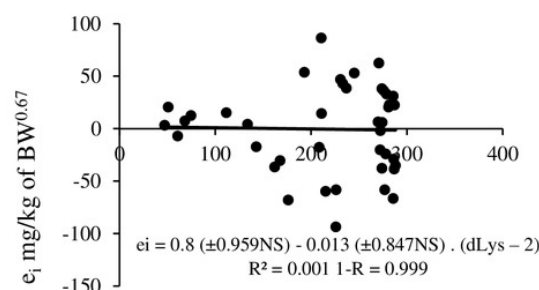
Relação entre predição residual (e $_i$) e valores preditos para lisina depositada (dLys) por diferentes modelos. Modelo 1 e 2: linear e Modelo 4,5,6,7 e 8: não linear. NS p>0,05; ** p<0,01.

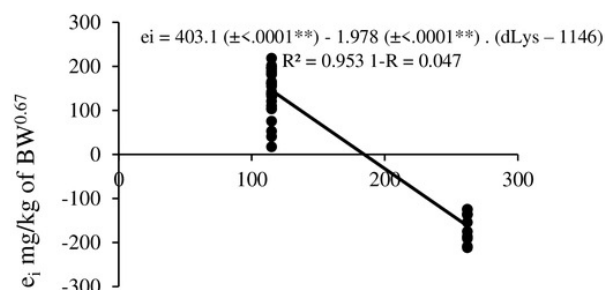
$e_i = 65.2 (\pm0.001^*) + -0.215 (\pm0.014^*) \cdot (dLys - 195)$
$R^2 = 0.186 \; 1\text{-}R = 0.814$

Model 1. dLys, mg/kg of BW$^{0.67}$

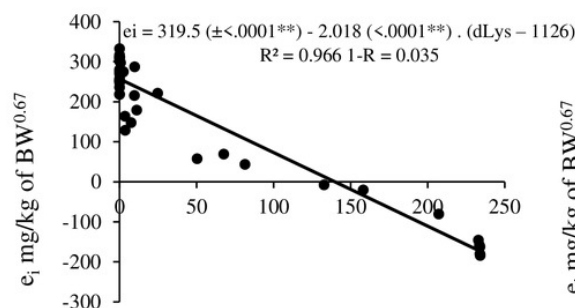
$e_i = 66.2 (\pm0.001^{**}) - 0.497 (\pm<.0001^{**}) \cdot (dLys - 231)$
$R^2 = 0.749 \; 1\text{-}R = 0.251$

Model 2. dLys, mg/kg of BW$^{0.67}$

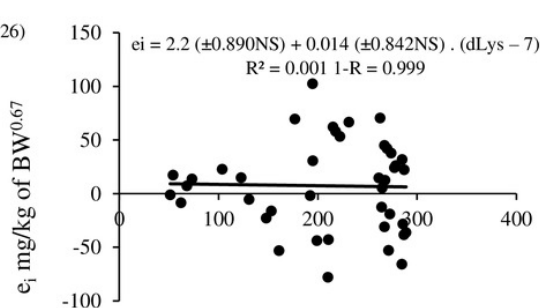
$e_i = 33.3 (\pm0.028^*) - 0.110 (\pm0.091NS) \cdot (dLys - 100)$
$R^2 = 0.092 \; 1\text{-}R = 0.908$

Model 3. dLys, mg/kg of BW$^{0.67}$

$e_i = 0.2 (\pm0.990NS) - 0.011 (\pm0.869NS) \cdot (dLys - 1)$
$R^2 = 0.001 \; 1\text{-}R = 0.999$

Model 4. dLys, mg/kg of BW$^{0.67}$

$e_i = 0.8 (\pm0.959NS) - 0.013 (\pm0.847NS) \cdot (dLys - 2)$
$R^2 = 0.001 \; 1\text{-}R = 0.999$

Model 5. dLys, mg/kg of BW$^{0.67}$

$e_i = 403.1 (\pm<.0001^{**}) - 1.978 (\pm<.0001^{**}) \cdot (dLys - 1146)$
$R^2 = 0.953 \; 1\text{-}R = 0.047$

Model 6. . dLys, mg/kg of BW$^{0.67}$

$e_i = 319.5 (\pm<.0001^{**}) - 2.018 (<.0001^{**}) \cdot (dLys - 1126)$
$R^2 = 0.966 \; 1\text{-}R = 0.035$

Model 7. dLys, mg/kg of BW$^{0.67}$

$e_i = 2.2 (\pm0.890NS) + 0.014 (\pm0.842NS) \cdot (dLys - 7)$
$R^2 = 0.001 \; 1\text{-}R = 0.999$

Model 8. dLys, mg/kg of BW$^{0.67}$

Composition (g/kg) of the diets used in the lysine assay

[a]HPD, high protein diet [b]NFD, nitrogen free diet [c]Content per kg of the diet - vit A 6.668 IU; vit D3 1.668 IU; vit E 8 IU; vit K 3.2 mg; vit B1 1 mg; vit B2 3.34 mg; vit B6 2 mg; vit B12 5 mcg/kg; niacin 21 mg; chlorine 0.13 g; pantothenate acid 8 mg; folic acid 0.46 mg/kg; biotin 0.05 mg/kg; copper 8 mg/kg; iron 60 g; manganese 70 g; zinc 25 g; iodine 6.25 mg; selenium 0.12 mg.

1   Table 1. Composition (g/kg) of the diets used in the lysine assay

Ingredient (g/kg)	HPD[a]	NFD[b]
Corn	356.97	-
Soybean meal	315.97	-
Corn gluten meal (60% CP)	181.22	-
Soybean oil	20.00	24.84
Dicalcium phosphate	10.13	15.02
Limestone	69.81	69.81
Salt	3.34	3.67
Choline chloride (60%)	0.84	3.40
Mineral premix[c]	0.25	0.25
Vitamin premix[c]	0.25	0.25
DL-Met (99%)	4.88	-
L-Lys HCl (78%)	5.72	-
L-Thr	2.71	-
L-Val	3.21	-
L-Ile	2.00	-
L-Arg	10.72	-
LTrp	1.81	-
Potassium chloride	-	11.95
Corn starch	-	249.03
Sugar	-	496.74
Rice husks	-	125.00

2   [a]HPD, high protein diet

3   [b]NFD, nitrogen free diet

4   [c]Content per kg of the diet - vit A 6.668 IU; vit D3 1.668 IU; vit E 8 IU; vit K 3.2 mg; vit B1 1

5   mg; vit B2 3.34 mg; vit B6 2 mg; vit B12 5 mcg/kg; niacin 21 mg; chlorine 0.13 g; pantothenate

6   acid 8 mg; folic acid 0.46 mg/kg; biotin 0.05 mg/kg; copper 8 mg/kg; iron 60 g; manganese 70 g;

7   zinc 25 g; iodine 6.25 mg; selenium 0.12 mg.

Nutritional levels of experimental diets

[a]HPD, high protein diet [b]NFD, nitrogen free diet [c]The nutrient content of the ingredients used

in the formulation was analyzed using a near-infrared spectrometer (NIR). [d]The total amino

acid content of the diets were analyzed HPLC and digestible content calculated using

coefficients from Rostagno et al. (2011) [e]NI, Not identified

2   Table 2. Nutritional levels of experimental diets

Itens	HPD[a]	NFD[b]
Calculated composition (g/kg)[c]		
Metabolizable energy (MJ/kg)	12.5	12.5
Calcium (g/kg)	30.0	30.0
Avaliable phosphorus (g/kg)	3.0	3.0
Analyzed composition (g/kg)		
Crude protein	350.0	NI[e]
[d]Digestible Lys	16.8	NI
Digestible Met + Cys	17.1	NI
Digestible Met	1.1	NI
Digestible Trp	0.3	NI
Digestible Thr	1.5	NI
Digestible Arg	2.5	NI
Digestible Val	1.7	NI
Digestible Ile	1.5	NI
Digestible Phe	1.9	NI

3   [a]HPD, high protein diet

4   [b]NFD, nitrogen free diet

5   [c]The nutrient content of the ingredients used in the formulation was analyzed using a near-

6   infrared spectrometer (NIR).

7   [d]The total amino acid content of the diets were analyzed HPLC and digestible content calculated

8   using coefficients from Rostagno et al. (2011)

9   [e]NI, Not identified

As formas funcionais utilizadas para descrever a relação entre a deposição de lisina (dLys) e a ingestão diária de lisina (LysIntake).

[M] Model. [Lysm] The daily intake of lysine for maintenance. [BW] Body weight. [a] The deposition of 1 mg Lys in the egg mass. [Rmax] The maximum response for dLys (mg/kg $BW^{0.67}$). [U] The rate of function growth. [R] The estimated value of LysIntake for Rmax (mg/kg $BW^{0.67}$). [Rmin] The minimum response for dLys (mg/kg $BW^{0.67}$). [k] The rate of decay of the function.

1   Table 3. The functional forms used to describe the relationship between deposition of lysine (dLys) and lisine intake (LysIntake) daily.

Functional form	Function	Characteristic	Reference
M1 = dLys = [LysIntake-Lysm×BW$^{0.67}$]/a	Linear	Linear model, estimates the average requirement of the population.	Silva et al. (2019)
M2 = dLys = R$_{max}$+U×(R-LysIntake), for LysIntake<R	Linear	Broken line, estimates the average requirement of the population.	Reis et al. (2018)
M3 = dLys = (R$_{max}$ - R$_{min}$)[1-e$^{-k(LysIntake-Lysm)}$]	Exponential	Addition of the R$_{min}$ parameter with the response on the ordinate axis.	Sousa et al. (2022)
M4 = dLys = R$_{max}$[1-e$^{-k(LysIntake-Lysm)}$]	Exponential	The function does not provide the parameter of R$_{min}$.	Kebreab et al. (2008)
M5 = dLys = R$_{max}$ [1-e$^{-kLysIntake}$] - R$_{min}$	Exponential	The R$_{min}$ parameter with the response on the abscissa axis.	Samadi & Liebert (2008)
M6 = dLys = R$_{min}$ + Range [1-e$^{(-e-k(LysIntake-Lysm))}$]	Exponential	It was a dual exponential model developed for the optimal response as a proportion of the asymptote.	Strathe et al. (2011)
M7 = dLys = R$_{max}$[1-e$^{(-e-k(LysIntake-Lysm))}$]	Exponential	It is similar to model 6, with modified parameters.	Strathe et al. (2011)
M8 = dLys = R$_{max}$ - (R$_{max}$ - R$_{min}$) [e$^{-k(LysIntake-Lysm)}$]	Exponential	This function was used to repair the Brody model.	Kops & Lamberson (2006)

2   [M] Model. [Lysm] The daily intake of lysine for maintenance. [BW] Body weight. [a] The deposition of 1 mg Lys in the egg mass. [Rmax] The
3   maximum response for dLys (mg/kg BW$^{0.67}$). [U] The rate of function growth. [R] The estimated value of LysIntake for Rmax (mg/kg
4   BW$^{0.67}$). [Rmin] The minimum response for dLys (mg/kg BW$^{0.67}$). [k] The rate of decay of the function.

Respostas aos níveis de lisina para consumo diário de ração, consumo de lisina, produção de ovos, peso do ovo, massa do ovo, taxa de conversão alimentar, deposição de lisina, peso corporal, mudança de peso corporal e mobilização de lisina

Geral Média geral

SEM O erro padrão de medição

1 Table 4. Responses to lysine levels for daily feed intake, lysine intake, egg production, egg weight, egg mass, feed conversion ratio,

2 lysine deposition, body weight, change body weight and lysine mobilization

Lysine In Diet	Feed Intake	Egg Production	Egg Weight	Lysine intake	Egg mass	Feed Conversion Ratio	Lysine Deposition In egg	Body Weight	Change In Body Weight	Lysine Mobilization
g/kg	g/bird	%	g	mg/bird	g/bird	g/g	mg/bird	kg	g/bird	mg/bird
1.7	15.2	21.9	8.4	45.2	1.8	8.40	16.4	0.136	-6.0	-4.0
3.4	18.7	45.8	8.6	83.4	3.9	4.81	34.7	0.145	-5.9	-4.0
5.0	22.9	62.5	9.9	136.6	6.3	3.81	55.7	0.159	-1.6	-1.0
6.7	23.2	89.1	10.5	173.0	9.5	2.51	83.8	0.165	0.7	0.5
8.4	25.1	93.8	10.6	261.5	10.0	2.53	88.5	0.165	-3.4	-2.3
11.8	24.3	93.8	10.5	289.3	9.8	2.48	86.4	0.172	-1.1	-0.7
16.8	23.5	91.3	11.2	350.1	10.1	2.36	89.5	0.173	7.3	4.9
General	22.0	71.9	10.0	200.1	7.4	3.77	65.6	0.160	-1.1	-0.727
SEM	0.5	4.8	0.2	16.7	0.6	0.37	5.1	0.002	1.4	0.971
P-Value										
Treatment	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0683	0.1480
Linear	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0043	0.0191
Quadratic	<.0001	0.0002	0.0032	0.0051	0.0003	<.0001	<.0001	0.0283	0.5759	0.5877

3 [General] General average

4 [SEM] The standard error of measurement

Estatísticas de ajuste para os modelos lineares, platô linear e funções monomoleculares para a relação entre deposição (Y) e consumo de lisina (X) de criadores de codornas japonesas

R^2 = R-Quadrado; R^2adj = ajuste de R-quadrado; AIC = Critério de Informação de Akaike; AICC = Critério de Informação de Akaike Corrigido; BIC = Critério de informação bayesiano.

[M1,] Modelo 1: dLys = (LysIntake – 36 × BW ^{0,67})/3,69

[M2,] Modelo 2: dLys = 293 – 0,47 × (682 – LysIntake)

[M3,] Modelo 3: dLys = (357 – 4) × [1 – $e^{(-0,0021 \times (LysIntake - 133))}$]

[M4,] Modelo 4: dLys = 444 × [1 – $e^{(-0,0027 \times LysIntake}$] – 117

[M5,] Modelo 5: dLys = 327 × [1 – $e^{(-0,0027 \times (LysIntake - 114))}$]

[M6,] Modelo 6: dLys = (119+170) × [1 – $e^{(-e^{(-1,025 \times (LysIntake - 511)))}}$)] [M7,] Modelo 7: dLys = 269 × [1– $e^{(-e^{(-0,0041 \times (LysIntake - 374))}}$)]

[M8,] Modelo 8: dLys = 314 – (314 – 17) × $e^{[-0,0028 \times (LysIntake - 139)}$]

1 Table 5. Fit statistics for the linear models, linear plateau and monomolecular functions for the

2 relationship between deposition (Y) and lysine intake (X) of Japanese quail breeders

Models		Regression	R²	R²adj	AIC	AICC	BIC
M1	Multiple linear	Linear	0.710	0.690	215	216	212
M2	Linear plateau	Linear	0.902	0.888	207	209	203
M3	Exponencial	Non linear	0.840	0.810	219	221	213
M4	Exponencial	Non linear	0.866	0.847	217	218	212
M5	Exponencial	Non linear	0.866	0.846	217	218	212
M6	Exponential double	Non linear	0.847	0.819	222	224	216
M7	Exponential double	Non linear	0.841	0.818	207	208	203
M8	Exponencial	Non linear	0.876	0.854	216	219	210

3 R² = R-Square; R²adj = R-square adjust; AIC = Akaike Information Criterion; AICC = Corrected

4 Akaike Information Criterion; BIC = Bayesian information criteria.

5 [M1,] Model 1: $dLys = (LysIntake - 36 \times BW^{0.67})/3.69$

6 [M2,] Model 2: $dLys = 293 - 0.47 \times (682 - LysIntake)$

7 [M3,] Model 3: $dLys = (357 - 4) \times [1 - e^{(-0.0021 \times (LysIntake - 133))}]$

8 [M4,] Model 4: $dLys = 444 \times [1 - e^{(-0.0027 \times LysIntake}] - 117$

9 [M5,] Model 5: $dLys = 327 \times [1 - e^{(-0.0027 \times (LysIntake - 114))}]$

10 [M6,] Model 6: $dLys = (119 + 170) \times [1 - e^{(-e(-1.025 \times (LysIntake - 511)))}]$

11 [M7,] Model 7: $dLys = 269 \times [1 - e^{(-e(-0.0041 \times (LysIntake - 374)))}]$

12 [M8,] Model 8: $dLys = 314 - (314 - 17) \times e^{[-0.0028 \times (LysIntake - 139)]}$

Observed and estimated values of the lysine deposition by linear and nonlinear factorial models

Input variable: observed lysine intake, mg/kg of BW$^{0.67}$. Output variable: deposition of lysine in the egg, mg/kg of BW$^{0.67}$. Error: difference between observed and estimated for deposition of lysine in the egg.

1 Table 6. Observed and estimated values of the lysine deposition by linear and nonlinear factorial

2 models

Observed and predicted variables	Lysine in diets, g/kg						
	1.7	3.4	5.0	6.7	8.4	11.8	16.8
Observed variables							
Lysine Intake	190.1	333.8	484.0	586.4	889.3	955.3	1155.7
Lysine Deposition in Egg	62.8	126.8	190.5	281.8	297.1	284.1	286.7
Predicted variables							
Model 1: LysIntake = 3.69×Deposition+36×BW$^{0.67}$							
Predicted lysine Intake	241.0	477.7	713.5	1050.7	1106.9	1059.3	1069.2
Predicted lysine Deposition in egg	53.8	96.4	140.9	171.3	261.5	281.0	340.6
Erro	10.4	30.4	45.8	105.6	36.5	2.8	-49.9
Model 2: LysIntake = 2.15×Deposition+52×BW$^{0.67}$							
Predicted lysine Intake	148.5	286.8	424.8	621.4	654.2	626.6	632.7
Predicted lysine Deposition in egg	82.1	148.6	218.1	265.5	406.4	436.9	530.1
Erro	-17.2	-21.8	-33.4	8.6	-107.9	-153.3	-237.1
Model 3: LysIntake = 133+(ln(357)-ln(357-Deposition))/0.0021							
Predicted lysine Intake	225.4	342.4	503.4	879.2	1043.3	911.7	945.3
Predicted lysine Deposition in egg	39.8	120.4	183.9	216.4	280.8	289.9	311.4
Erro	26.0	6.4	2.0	60.6	16.8	-5.8	-23.5
Model 4: LysIntake = 117+(ln(444)-ln(444-Deposition))/0.0027							
Predicted lysine Intake	173.6	241.7	327.0	490.7	533.7	498.6	507.2
Predicted lysine Deposition in egg	61.1	145.4	206.5	235.5	286.7	293.0	307.1
Erro	4.9	-18.6	-20.3	42.3	10.7	-8.9	-19.7
Model 5: LysIntake = 114+(ln(327)-ln(327-Deposition))/0.0027							
Predicted lysine Intake	193.3	296.1	446.0	857.2	994.1	924.3	997.3
Predicted lysine Deposition in egg	60.6	145.0	206.3	235.3	286.6	292.9	307.1
Erro	5.4	-18.3	-20.1	42.4	10.8	-8.9	-19.6
Model 6: LysIntake = 511+(ln(288)-ln(288-Deposition))/1.025							
Predicted lysine Intake	511.2	511.6	512.1	514.1	513.6	513.8	513.1
Predicted lysine Deposition in egg	288.0	288.0	287.5	118.0	118.0	118.0	118.0
Erro	-225.2	-161.2	-96.6	163.8	179.1	166.1	168.7
Model 7: LysIntake = 374+(ln(269)-ln(269-Deposition))/0.0041							
Predicted lysine Intake	439.2	530.0	692.4	.	1044.6	1071.8	1070.1
Predicted lysine Deposition in egg	236.8	186.0	126.9	92.4	30.8	24.2	11.0
Erro	-175.3	-59.2	68.4	194.5	265.9	259.9	275.1
Model 8: LysIntake = 139+(ln(314)-ln(314-Deposition))/0.0028							
Predicted lysine Intake	219.0	324.2	482.3	974.3	1382.5	1161.4	1096.2
Predicted lysine Deposition in egg	56.4	140.5	200.7	228.8	277.6	283.5	296.5
Erro	9.6	-13.7	-14.3	49.1	19.8	0.6	-9.1

3   Input variable: observed lysine intake, mg/kg of BW$^{0.67}$.

4   Output variable: deposition of lysine in the egg, mg/kg of BW$^{0.67}$.

5   Error: difference between observed and estimated for deposition of lysine in the egg.

Estatísticas para avaliação do erro de predição da deposição de lisina (Y) de codornas japonesas em função do consumo de lisina (X) calculado pelo modelo fatorial linear e não linear

1 Table 7. Statistics for assessment the error of prediction of the lysine deposition (Y) of Japanese quail breeders as a function of the lysine

2 intake (X) calculated by the linear and ==non linear== factorial model

Models		Regression	e	$b0$	P-value	$b1$	P-value	R^2	Scalar error	Prediction bias	$1-R^2$
M1	Multiple linear	Linear	33.5	65.2	0.001	-0.215	0.014	0.186	195	0.64	0.814
M2	Linear plateau	Linear	28.7	66.2	0.001	-0.497	<.0001	0.749	231	1.73	0.251
M3	Exponencial	Non linear	33.4	33.3	0.028	-0.110	0.091	0.092	100	0.33	0.908
M4	Exponencial	Non linear	33.4	0.2	0.990	-0.011	0.869	0.001	1	0.03	0.999
M5	Exponencial	Non linear	33.5	0.8	0.959	-0.013	0.847	0.001	2	0.04	0.999
M6	Exponential double	Non linear	35.2	403.1	<.0001	-1.978	<.0001	0.953	1146	5.62	0.047
M7	Exponential double	Non linear	28.4	319.5	<.0001	-2.018	<.0001	0.966	1126	7.11	0.035
M8	Exponencial	Non linear	32.2	2.2	0.890	0.014	0.842	0.001	7	0.04	0.999