Sigmoid Model for the Evaluation of Growth and Production Curves in Laying Hens

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The aim of this study was to choose the best predictive model for the accurate description of the average flock growth of laying hens and for the daily egg mass being produced by the layers during the productive period. The calculations were undertaken with the generalised data on the weight growth and daily egg mass, produced by the commercial flock of a Shaver White laying hens breed. The model, represented as the ratio of the polynomials of the third and the second powers, was deduced by the authors for the prediction of the growth and daily egg mass production curves. This Narushin–Takma model was tested for the accuracy of the results prediction in comparison with the following growth models: the logistic, the Gompertz, the von Bertalanffy, the Richards, the Weibull and the Morgan–Mercer–Flodin functions. The egg production model used for comparison were the Adams–Bell, the logistic-curvilinear, the compartmental and the Lokhorst functions. Fitting criteria were estimated as the coefficients of determination $R^2$ and the final loss $L_f$ of the loss function: sum of observed minus predicted data in the second power. The Narushin–Takma model was found to be the best in description of the both curves, values for $R^2$ of 0.9997 and for $L_f$ of 0.005 for the evaluation of the body growth data and values for $R^2$ of 0.996 and $L_f$ of 0.001 for the description of the egg mass producing function. The accuracy of the other models was high and almost the same for all functions. The order of the accuracy for the compared models was as follows: for the body growth curve — the Weibull model, the Gompertz, the von Bertalanffy, the Morgan–Mercer–Flodin, the logistic and the Richards functions; for the egg mass producing curve — the logistic-curvilinear model, the compartmental, the Lokhorst and the Adams — Bell functions.

1. Introduction

The contemporary egg production is highly mechanised and automated industry. The feed consumption is calculated by several factors, e.g. breed of hen, its weight, averaged daily house temperature, and the weight of an egg being produced (Chwalibog, 1992; Chwalibog & Baldwin, 1995; Rabello et al., 2000). The data are processed by a computer program and transferred to the feeder dosing system. Measuring the average temperature within the poultry house is straightforward by means of a thermometer, but measuring data relating to the birds and eggs produced is a more complex process, requiring additional equipment. This leads to an increase of production costs. It is much easier to indirectly predict the daily egg mass production by the hen housed and the average weight of the hen. For this purpose, predictive models are needed for the calculation of daily growth and egg mass production.

1.1. Growth models

The models of growth curves, i.e. equations, which describe the increase of a body weight against time, differ according to the number of parameters in the equation being calculated by the measured data. The most in use are three-parameter growth functions (logistic, Gompertz and Von Bertalanffy) and four-parameter equations (Richards, Weibull and Morgan–Mercer–Flodin) (Maruyama et al., 1998, 2001). Some authors proposed to improve the above equations by...
adding or replacing some coefficients and/or variables (Jolicoeur, 1985; France et al., 1996; Lopez et al., 2000). Mostly, the growth models are used for evaluating the curves of meat-type poultry species or the pullets during their growing period. The best models were found to be the Gompertz function for the description of the chicken growth curve (Anthony et al., 1991b; Gous et al., 1999; Mignon-Grasteau et al., 1999, 2001; Yakupoglu & Atıl, 2000); laying-type pullets during the growing period (Martin et al., 1994); turkeys (Anthony et al., 1991a, 1991b); and quails (Anthony et al., 1991b; Du Preez & Sales, 1997). Some data resulted in the mostly accurate description of chicken growth by the logistic function (Grossman et al., 1985; Grossman & Bohren, 1985). Among the four-parameter equations, the Richards function was found to describe accurately the growth curves of major poultry species: chickens (Knizetova et al., 1991b), ducks (Knizetova et al., 1991a), geese (Knizetova et al., 1994) and quail (Hyankova et al., 2001). In trying to approximate the growth of male and female turkeys, Maruyama et al. (1998) concluded that all sigmoid growth curves (the logistic, Gompertz, von Bertalanfly, Richards, Weibull, and Morgan–Mercer–Flodin) demonstrated a lack of fit.

1.2. Egg production models

Usually, the flock egg production is investigated as a curve of either an average of its percentage or a number of eggs recorded depending on the layer age (Grossman et al., 2000). A typical egg production curve in both implementations increases during the first 8–9 weeks of a production cycle and then decreases to the end of the production period (North & Bell, 1990). There were several models elaborated for predicting layer productivity. The models of the average productivity of a flock consist of two sections. The first, which is usually a logistic function, describes the period of growth of the productivity, and the second one shows the decrease in egg output and is reported to be a linear function (Adams & Bell, 1980), an exponential function (Cason & Britton, 1988; Yang et al., 1989; Cason, 1990) or a polynomial function (Lokhorst, 1996). All the models were found to be quite effective, producing rather high mean values for the coefficient of determination $R^2$ when fitted to egg production data.

Egg mass producing is basically considered in the literature as the average weight of the whole egg in relation to the age of the hen (Shalev & Pasternak, 1993; Minvielle et al., 1994; Lokhorst, 1996; Hartmann et al., 2000). The mathematical models for the evaluation of the egg weight during the laying cycle, as, for example, proposed by Minvielle et al. (1994) or Lokhorst (1996), are not of practical use for adjusting the feeding rate, as there is no allowance for calculating the energy consumption of a hen housed for daily synthesis of the egg mass.

The above review yields the following conclusions:

1. The growth and egg production models are an important tool for adjusting the food consumption in relation to the growth rate and the shape of the curve.

2. There is no consensus among the authors as to which model is most optimal for both growth curve and egg production curve.

3. The model for predicting the full growing period of the laying hens and also the daily egg mass production model was not found in the literature.

The objective of this study was to choose the best predictive model for the accurate description of the average flock growth of laying hens and for the daily egg mass being produced by the layers during the productive period.

2. Materials and methods

The generalised data on the weight growth and daily egg mass, produced by the commercial flock of Shaver White laying hens (Anonymous, 2000/2001), were considered for calculations. The graphical representation of the data is plotted in Figs 1 and 2. Parameters were estimated by Levenberg–Marquardt iteration algorithm using SPSS (1998). A convergence criterion was $1.0 \times 10^{-8}$. All starting values of the parameters were taken from previous studies.

The reviewed formulae for predicting the weight and egg production of poultry consist of a sum or a product of simple algebraic functions. No model in the form of a ratio of two or more functions was mentioned. Taking into account that any function can be expanded in a power series (Boyce & DiPrima, 1996), it was decided to test the model of a ratio of two polynomials. Both the growth curve and egg mass production curve have two inflection points. It can therefore be concluded that the polynomial in a numerator of the ratio should be of a third power (Savelov, 1960). The power of the polynomial in the denominator of the ratio should be investigated.

3. Results

The following formulae were considered for the best approximation of the growth and egg mass producing
curves:

\[ y = \frac{at^3 + bt^2 + ct + d}{t + e} \]  

\[ y = \frac{at^3 + bt^2 + ct + d}{t^2 + et + f} \]  

\[ y = \frac{at^3 + bt^2 + ct + d}{t^3 + et^2 + ft + g} \]  

in which \( y \) is the body weight or daily egg mass, respectively; \( t \) is the age of the hen or its productive cycle; \( a, b, c, d, e, f \) and \( g \) are the coefficients of proportionality.

Fitting criteria were estimated as coefficients of determination \( R^2 \) and goodness-of-fit, determined as a final loss \( L_f \) of a loss function: sum of observed minus predicted data in the second power.

The results of approximation are presented in Table 1.

The formula types of Eqns (2) and (3) give extra accurate results of approximation which are quite similar. Considering that Eqn (2) has six coefficients, which need to be estimated, instead of seven in Eqn (3), the following formulae were chosen as the models for description of growth and production curves in laying hens:

\[ W = \frac{0.01t^3 + 0.215t^2 + 51.07t + 0.2}{t^2 - 15.801t + 769.166} \]  

\[ M_e = \frac{-0.002t^3 + 0.433t^2 - 0.328t + 0.067}{t^2 - 1.085t + 11.665} \]

where \( W \) and \( M_e \) are the body weight and egg mass in kg, respectively, at time \( t \) in weeks.

To estimate the efficiency of usage of the deduced Narushin–Takma models, the results of prediction by Eqns (4) and (5) were compared with those obtained by calculation with the most widely used models.
The results of approximation of the formulae for predicting body weight growth and egg mass producing by Shaver White breed of laying hens are presented in Tables 2 and 3, respectively.

### Discussion

The results showed that all evaluated models fitted well the investigated curves of body weight growth and egg mass producing by Shaver White breed of laying hens. The values of all the coefficients of determination exceed 0.97 for description of egg mass producing curve and 0.98 when approximating the body growth. That is apparently due to the investigation of the average data amount of a big number of measurements of the investigated parameters (Anonymous, 2000/2001). The investigated average data represent the very smooth curves without error spans. The deduced Narushin–Takma model [Eqns (4) and (5)] was compared with the ones of the previous studies [Eqns (6)–(15)] and was found to be the best in description of both the curves.

The fitting criteria of Eqn (4) for the evaluation of the body growth data were values for $R^2$ of 0.9997 and final loss $L_f$ of 0.005. The good results of the approximation were also obtained for the Weibull model [Eqn (10)] with values for $R^2$ of 0.999 and $L_f$ of 0.017, the Gompertz function [Eqn (7)] with values for $R^2$ of 0.999 and $L_f$ of 0.024, and von Bertalanffy [Eqn (8)] with values for $R^2$ of 0.999 and $L_f$ of 0.026.

The fitting criteria of Eqn (5) for the description of the egg mass producing function required the following values: $R^2 = 0.996$ and $L_f = 0.001$. The logistic-curvilinear model [Eqn (13)] was the best ($R^2$ = 0.986 and $L_f$ = 0.005) of all the evaluated models.
The Lokhorst model was found to be the same as the Adams–Bell model in our experiments. Both formulae consist of the logistic function, describe the period of growth of the productivity, and the decrease in productivity, which is linear in the Adams–Bell model (Adams & Bell, 1980) and polynomial in the Lokhorst one (Lokhorst, 1996). The iteration procedure yielded the coefficient of proportionality which equals zero in the polynomial function of the Lokhorst model, and that led to a transformation of the polynomial function into a linear one, which is the same as for the Adams–Bell model.

The formulae being in use for predicting the body growth [Eqns (6)–(11)] consists of three to four proportionality coefficients and the ones for egg production [Eqns (12)–(15)] consists of four to five coefficients, whilst the deduced Narushin–Takma model [Eqns (4) and (5)] consists of six coefficients of proportionality. The increase of the coefficients does not lead to more tedious calculations, as usage of the specialised statistical programs allows to simplify significantly the implementation of the iteration procedures.

5. Conclusions

The results of the research yield the following conclusions:

(1) The investigated growth models (the logistic, the Gompertz, the von Bertalanffy, the Richards, the Weibull, and the Morgan–Mercer–Flodin functions and the egg production models (the Adams–Bell, the logistic-curvilinear, the compartmental and the Lokhorst functions) can be used for the accurate description of the body weight change of the laying hens for the whole period of their growth, and for the prediction of the values of daily egg mass production.

(2) The deduced Narushin–Takma model, represented as the ratio of the polynomials of the third and the second powers, gave the most accurate results in

| Table 2 |
The parameters estimates and coefficients of determination $R^2$ derived from egg production models for the egg mass producing by Shaver White breed of laying hens

<table>
<thead>
<tr>
<th>Adams–Bell</th>
<th>Logistic-curvilinear</th>
<th>Compartmental</th>
<th>Lokhorst model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>0.005</td>
<td>0.413</td>
<td>0.446</td>
</tr>
<tr>
<td>$b$</td>
<td>0.792</td>
<td>0.004</td>
<td>0.006</td>
</tr>
<tr>
<td>$c$</td>
<td>0.00002</td>
<td>0.732</td>
<td>0.220</td>
</tr>
<tr>
<td>$d$</td>
<td>-0.996</td>
<td>3.747</td>
<td>0.435</td>
</tr>
<tr>
<td>$e$</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.973</td>
<td><strong>0.986</strong></td>
<td>0.974</td>
</tr>
<tr>
<td>Final loss</td>
<td>0.090</td>
<td><strong>0.006</strong></td>
<td>0.010</td>
</tr>
</tbody>
</table>

$a$, $b$, $c$, $d$, $e$, coefficients.

| Table 3 |
The parameters estimates and coefficients of determination $R^2$ derived from growth curve models for the body weight producing by Shaver White breed of laying hens

<table>
<thead>
<tr>
<th>Logistic</th>
<th>Gompertz</th>
<th>Von Bertalanffy</th>
<th>Richards</th>
<th>Weibull</th>
<th>Morgan–Mercer–Flodin</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>1.754</td>
<td>1.768</td>
<td>1.775</td>
<td>1.619</td>
<td>1.765</td>
</tr>
<tr>
<td>$b$</td>
<td>0.184</td>
<td>0.130</td>
<td>0.113</td>
<td>0.030</td>
<td>0.069</td>
</tr>
<tr>
<td>$c$</td>
<td>12.139</td>
<td>8.763</td>
<td>7.083</td>
<td>0.090</td>
<td>1.520</td>
</tr>
<tr>
<td>$d$</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.335</td>
<td>7.483</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.995</td>
<td>0.999</td>
<td>0.999</td>
<td>0.982</td>
<td><strong>0.999</strong></td>
</tr>
<tr>
<td>Final loss</td>
<td>0.102</td>
<td>0.024</td>
<td>0.026</td>
<td>1.776</td>
<td><strong>0.017</strong></td>
</tr>
</tbody>
</table>

$a$, $b$, $c$, $d$, coefficients.
prediction of both growth and daily egg mass production curves.

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