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MATHEMATICAL MODELS FOR EGG PRODUCTION IN BROILER BREEDER HENS*

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Abstract

Broiler breeders hens (meat-type hens) have lower reproductive potential than laying-type hens. Statistical models for predicting potential laying pattern are important for economically optimal breeding strategy of egg production in a poultry flock. The aim of the study was to find the most suitable function for describing the egg-laying rate and egg weight during the broiler breeders' production period and to characterize laying pattern in groups of hens with different egg production. The following four mathematical models were used: gamma, Narushin–Takma, logistic-curvilinear, and compartmental. The daily recorded egg production data from 100 broiler breeder hens were used. Hen-weekly egg production was described using laying rate during successive weeks after reaching sexual maturity (26 weeks of age) and daily recorded egg weight. On the basis of the total number of eggs laid (NEggs), groups of hens with low (21%), intermediate (52%), and high (27%) egg production were created. The differences between the goodness-of-fit criteria values (AIC, R^2, MSE) were small, with all the examined models having the same quality of curve fitting for egg-laying rate and egg weight. The logistic-curvilinear model was able to fit well both egg-laying rate and egg weight of the whole broiler breeder hens' flock, and also when hens were divided into three egg production groups. This model could be considered in a long-term prediction of the reproductive potential in the commercial management. Moreover, the presented model could be useful in the research on different reproduction parameters of individual hens.

Key words: broiler breeders, mathematical models, egg production, egg weight

Domestic chickens (*Gallus gallus domesticus*) have biologically and economically optimal egg production pattern. Egg production starts after sexual maturity, reaches its peak relatively quickly and then declines, following a more or less linear pattern (Meijerhof, 2002; Narinc et al., 2014). Broiler breeders, also known as

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meat-type hens, are bred and kept only for the production of hatching eggs. Egg production pattern of these hens is characterized by shorter egg sequences and greater number of out-of-lay oviposition rhythm compared to laying-type hens (Gumułka and Kapkowska, 1996; Gumułka et al., 2010). For these reasons, and also because of problems with maintaining the optimal body weight for reproduction (Romero et al., 2009; Decuypere et al., 2010; Richards et al., 2010; Leksrisompong et al., 2014) the costs of breeding meat-type hens are relatively high.

In poultry research, mathematical models have been applied to fit egg production, egg weight, growth rate, and feed intake curves (Faridi et al., 2011). In the literature, modeling of egg production is limited compared to studies modeling growth in broiler chickens, probably due to the longer time required to follow egg production (Narinc et al., 2014). The use of mathematical models to estimate laying curves is very important for evaluating egg production over the breeding period. The laying curve in hens is relatively similar in shape to the lactation curve in cattle. Therefore, functions describing lactation curve shape were adapted for modeling egg production (Wolc et al., 2015). Till now, mathematical models have been used mainly to fit egg production pattern in flocks of laying-type hens (Savegnago et al., 2011, 2012; Narinc et al., 2014; Wolc et al., 2015). The models used in the literature to fit egg production can have curve parameters with a biological interpretation (Savegnago et al., 2012). Up-to-date models in which the above-mentioned parameters are included are sparse in relation to eggs weight pattern during production period. The most often applied model of laying curve was gamma function because it is simple to apply, easy to interpret, and best fitting to the data. In previous studies (Wood, 1967; Dematawewa et al., 2007) this model was purposed for the milk yield curve and parameters of the model have a biological interpretation. Also, compartmental model and its modifications, logistic functions, and exponential functions were used. Other kinds of models exploited polynomial functions which proved best in fitting egg production curves in laying hens (Narinc et al., 2014).

The study of usefulness of mathematical models for the prediction of egg production pattern in broiler breeders is sparse (Gous and Nonis, 2010; Gous, 2012; Faridi et al., 2011; Nonis and Gous, 2013; Ferreira et al., 2015). Gous and Nonis (2010) used linear, exponential, and allometric functions to predict egg performance in meat-type hens including oviposition sequence length and weight changes in egg components in order to evaluate long-term feeding requirements. Moreover, Nonis and Gous (2013) adopted these mathematical models to describe egg component changes in hens of different strains and age during laying period. Recently, Ferreira et al. (2015) studied the suitability of using allometric functions to predict changes in the proportion of egg components and egg production in individual broiler breeders. It seems that at this moment there is a need for more precise estimation of variability of parameters used in evaluations as well as for distinguishing among production level groups. Only then mathematical models for the prediction of laying curve may be effective and have practical implications for management optimization in flocks of breeding broiler hens. The objectives of the study were (1) to compare four mathematical functions and to choose the most suitable function for describing egg-laying rate and egg weight during the production period of broiler breeders and (2) to characterize laying pattern in groups of hens with different egg production with the use of mathematical models.

Material and methods

Flock, management, and egg production

The study was carried out on 100 broiler breeders hens. Hens were kept in individual cages at the Experimental Station belonging to the University of Agriculture in Kraków. All breeding management conditions complied with the rules recommended for reproductive flocks of meat-type hens and with protocols approved by the First Local Ethical Committee on Animal Testing of the Jagiellonian University in Kraków, Poland.

The pullets were obtained at 19 weeks of age from a commercial reproduction farm. During the egg production period (25–69 weeks of age) laying rate was the basis of daily feed administration. Dietary ratio of commercial mixture (11.6 MJ ME_N/kg, 15.1% CP/kg – according to the producer's specifications) ranging from 100 g to 160 g per day and hen was used. Water was provided *ad libitum*. Photostimulation was applied from the age of 22 weeks (+15 min/week) to achieve 15L:9D at the age of 25 weeks. During the laying period, a light schedule of 16L:8D was used.

Additional information about the characteristics of laying pattern was obtained from the results of egg production recorded in the previous experiment (Gumułka et al., 2010). Oviposition for each hen was recorded automatically with reed sensors (Agroboss S.C., Poznań, Poland) and eggs were collected several times during daylight. Individual patterns of oviposition for all hens were observed. From the number of eggs produced every week, the weekly laying rate was calculated for each hen separately and for all hens kept in successive weeks (hen-weekly egg production) of production. During the period from 19 to 69 weeks of age (from onset until the end of study) 14 hens were removed because of physical conditions or mortality.

The hens were divided into three groups based on the total number of eggs laid during laying period (NEggs). The low egg production (low EP) group corresponds to the number of eggs NEggs≤190, the intermediate egg production (intermediate EP) group – to 191≤NEggs≤220 and the high egg production (high EP) group – to NEggs≥221 eggs/period. All studied parameters were presented for these three groups.

Mathematical models

The following mathematical models were fitted to egg-laying rate and egg weight (Narushin and Takma, 2003; Narinc et al., 2014):

1. Gamma: $$y = a \cdot t^b \cdot e^{-c \cdot t},$$

2. Narushin–Takma: $$y = \frac{a \cdot t^3 + b \cdot t^2 + c \cdot t + d}{t^3 + e \cdot t^2 + f \cdot t + g},$$

3. Logistic-curvilinear: $$y = a \cdot \left(\frac{e^{-b \cdot t}}{1 + e^{-c \cdot (t-d)}} \right),$$

4. Compartmental: $$y = a \cdot \left(e^{-b \cdot t} - e^{-c \cdot t} \right),$$

where:

y is the egg-laying rate or the egg weight at week t,
a, b, c, d, e, f, g are the parameters to be estimated.

When egg-laying rate curve is modeled the gamma and compartmental functions have curve parameters with a biological interpretation. In gamma model a is the initial production, b is the rate of increase to the peak and c is the rate of decrease after the peak. Additionally, the week of peak production (b/c) and persistency of peak production ($-(b + 1)\times \ln c$) were derived from the model parameters (Narinc et al., 2014). In the case of compartmental model a is asymptotic value of egg production at the peak of egg-laying, b is rate of production decrease after the peak (eggs/hen-day decrease per week) and c is intermediate rate of weekly increase in egg-laying (Savegnago et al., 2012).

The above four functions were fitted to the data set including all hens and to the data divided into three egg production groups. The nonlinear regression procedure (NLIN) within the SAS 9.4 software (SAS Institute Inc, 2014) was used. The models fitted to the data were compared by using three goodness-of-fit statistics (Narinc et al., 2010):

1. Akaike Information Criterion (AIC): $$AIC = n \cdot \ln\left(\frac{SSE}{n} \right) + 2k$$

2. Mean Square Error (MSE): $$MSE = \frac{SSE}{n-k}$$

3. Coefficient of determination (R^2): $$R^2 = 1 - \frac{SSE}{SST}$$

where:

n is the number of observations,
k is the number of parameters,
SSE is sum of squares of errors,
SST is total sum of squares.

Statistical analysis

The effect of egg production group (NEggs≤190, 191≤NEggs≤220, and NEggs≥221 eggs/period) on the egg-laying rate and the egg weight was investigated by the one-way analysis of variance by the GLM procedure of SAS. The Tukey test was used for multiple comparisons (SAS Institute Inc, 2014).

Results

Sexual maturity and egg production

Table 1 presents the mean values and standard errors (SE) of egg-laying rate and egg weight. The hens in flock matured sexually (onset of egg production) on average at the age of 182.0 days (SE=2.9 days), i.e. 26 weeks of age (Figure 1A). At this time, the mean egg weight value was 48.9 g (SE=0.8 g) and then slowly increased to on average more than 66.0 g during the laying period (Figure 1B). The peak egg production period was noted after 7 weeks of egg production at the age of 32 weeks (Figure 1A) with the mean egg-laying rate at the level of 90.4% with SE=1.4% (Table 1). At the age of 53 weeks, the decrease in the laying rate by about 30.0% was observed. The laying rate remained constant (57%–64%) up to 59 weeks of age. At the end of egg production, i.e. 69 weeks of age, laying rate decreased to 44.7%. The mean laying rate within 44 weeks was 71.3% (SE=0.3%) with the average egg weight of 62.3 g (SE=0.04 g). The mean total number of eggs per hen was 211 (SE=2.3).

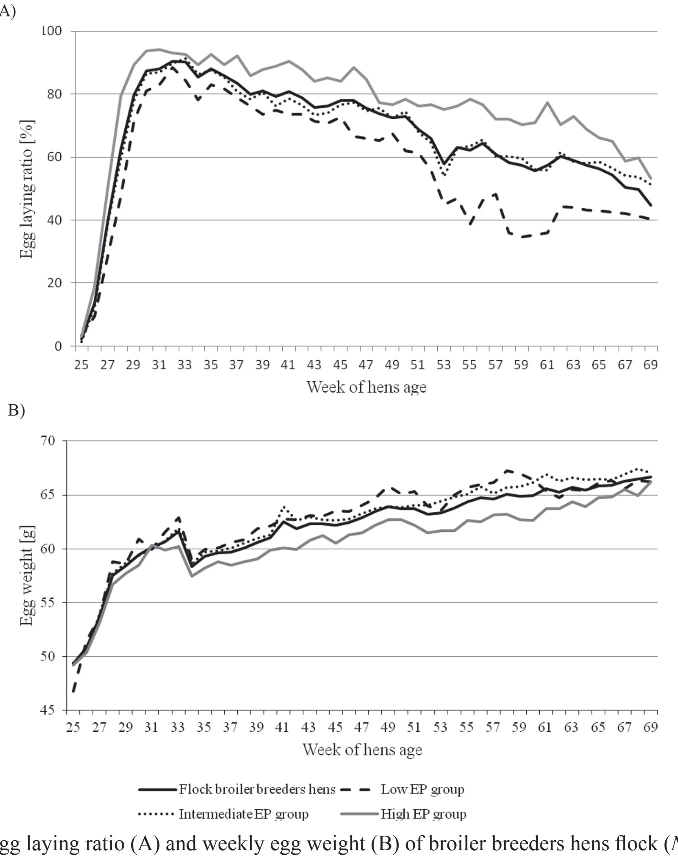

Figure 1. Egg laying ratio (A) and weekly egg weight (B) of broiler breeders hens flock (*N=100*) during successive week after sexual maturity (25 week of age). Low EP group (*n=21*) – hens with total number of laid eggs NEggs≤191 eggs/period. Intermediate EP group (*n=52*) – hens with 191≤NEggs≤220 eggs/period. High EP group (*n=27*) – hens with NEggs≥221 eggs/period. Egg laying ratio % − (number of eggs/number of hens available in flock × 7 days) × 100

Table 1. Means and standard errors (SE) of egg laying ratio and egg weight of broiler breeders hens flock (*N=100*)

Egg production class[1)]	Number of birds	Egg laying ratio (%)		Egg laying ratio at peak (%)		Egg weight (g)	
		mean	SE	mean	SE	mean	SE
Low EP	21	64.06 A	0.79	88.4	2.6	62.92 A	0.09
Intermediate EP	52	70.17 A	0.44	91.2	1.2	62.82 B	0.07
High EP	27	78.66 A	0.56	94.2	1.7	60.99 AB	0.06
Total	**100**	**71.34**	**0.33**	**90.4**	**1.4**	**62.26**	**0.04**

[1)]Low EP group (*n=21*) – hens with total number of laid eggs (NEggs)≤190 eggs/period. Intermediate EP group (*n=52*) – hens with 191≤NEggs≤220 eggs/period. High EP group (*n=27*) – hens with NEggs≥221 eggs/period.

Egg laying ratio % − (number of eggs/number of hens available in flock × 7 days) × 100.

A, B – values within the same column marked by the same letters differ significantly at P<0.01.

Significant differences (P<0.01) in egg-laying rate were observed between low EP, intermediate EP, and high EP groups (Table 1). Egg production period for hens classified in low, intermediate, and high EP groups peaked at a rate of 88.4% (SE=2.6%), 91.2% (SE=1.2%), and 94.2% (SE=1.7%), respectively (Figure 1A). The mean laying rate was about 14% lower for the low EP group in comparison to the high EP group (Figure 1A). Moreover, shorter period of peak production was detected for low EP production group. The laying rate decreased to 43.6% at age 54 weeks. Significant differences (P<0.01) in the daily egg weight were observed between low EP and high EP groups and between intermediate EP and high EP groups. In low EP group (Table 1), mean egg weight was the highest (62.9 g with SE=0.09 g) and in high EP group the lowest: 60.9 g (SE=0.06 g).

Mathematical modeling

Table 2 shows the values of parameter estimates and three different goodness of fit criteria (AIC, R^2, MSE) used for comparing four models of the egg-laying rate and the egg weight. The model with the highest coefficient of determination (R^2) and the lowest both Akaike information criterion (AIC) and mean square error (MSE) showed the best fit to the data. The AIC and MSE criteria reached the lowest values when egg-laying rate was modeled by logistic-curvilinear function and the highest when modeled by compartmental model. Coefficients of determination were high for all functions (R^2>0.965) except the compartmental model (R^2=0.102). In the case of the logistic-curvilinear function, the highest R^2 was calculated. According to the above mentioned three criteria, the logistic-curvilinear function gave the best fit to the egg-laying rate data and the compartmental model the worst. According to goodness of fit criteria the fitted curve may present a good fit, but does not indicate proper shape of the fitted curve. The four models of the egg-laying rate are presented in Figure 2A. The compartmental model was not appropriate to fit egg-laying rate curve, because of the low values of the estimates (from 3.20 to 3.73%). Two functions: logistic-curvilinear and Narushin–Takma had a good fit at peak, however Narushin–Takma model did not present a good fit after the egg-laying rate peak. The Narushin–Takma function showed minimum and maximum after 57 week of hens age. The gamma model did not have a good fit at the egg-laying rate peak, and the estimated peak production was at 40 weeks of hens' age. Thus, the logistic-curvilinear function showed the best shape of weekly egg production curve during all production period (Figure 2A).

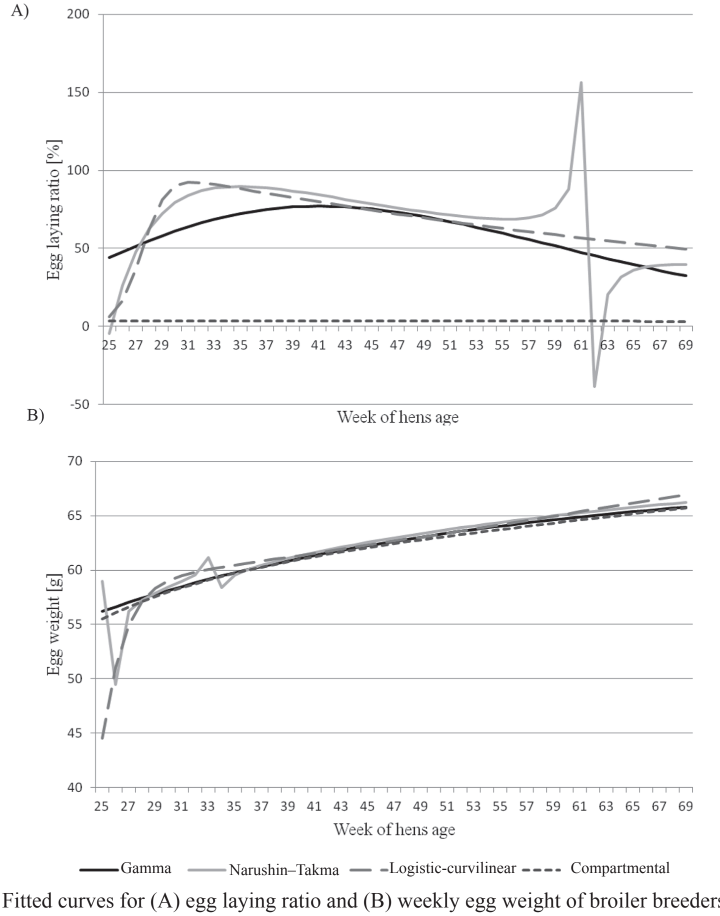

Figure 2. Fitted curves for (A) egg laying ratio and (B) weekly egg weight of broiler breeders hens flock (*N=100*) using four models during successive week after sexual maturity (25 week of age)

When the egg weight was modeled, the AIC criterion varied from 21,049 (Narushin–Takma model) to 21,112 (gamma function). In the case of all four models, R^2 was equal 0.992. The lowest MSE was observed when the egg weight was modeled by Narushin–Takma function and the highest by gamma function. Taking into account the AIC, R^2, and MSC criteria, the Narushin–Takma and the compartmental functions modeled egg weight slightly better than other models (gamma and logistic-curvilinear). Figure 2B shows the fitted models to the egg weight. Similar curves were modelled by the gamma and compartmental functions. The Narushin–Takma model did not present proper fit to the egg weight at the beginning of the curve. This function modeled egg weight with additional extremes.

Table 2. Estimates of goodness-of-fit criteria and model parameters (a, b, c, d, e, f, g) for curves fitted to laying ratio and egg weight in broiler breeder hens flock (N = *100*)

Model	Goodness-of-fit criteria[1)]			Parameter						
	AIC	R^2	MSE	a	b	c	d	e	f	g
				Egg laying ratio (%)						
Gamma	237	0.965	180.23	4.1×10^{-5}	5.3255	0.13				
Narushin–Takma	183	0.991	50.61	–16.21	5,546	–386,600	6,468,840	–91.4	2,068	–14,031
Logistic-curvilinear	168	0.993	38.57	160	0.017	1.088	27.53			
Compartmental	382	0.102	4,560.93	–27.46	0.029	0.020				
				Egg weight (g)						
Gamma	21,112	0.992	158.71	27.11	0.242	0.002				
Narushin–Takma	21,049	0.992	156.17	75.76	–3,935.9	32,625	477,183	–41.03	–214.5	15,663
Logistic-curvilinear	21,060	0.992	156.67	54.43	–0.003	0.723	23.41			
Compartmental	21,107	0.992	158.49	57.30	–0.002	0.100				

[1)]AIC – Akaike information criterion, R^2 – coefficient of determination, MSE – mean square error.

Table 3. Estimates of goodness-of-fit criteria and model parameters (a, b, c, d, e, f, g) for curves fitted to laying ratio and egg weight in broiler breeder hens from different egg production groups

Model	Egg production group[1)]	Goodness-of-fit criteria[2)]			Parameter						
		AIC	R^2	MSE	a	b	c	d	e	f	g
					Egg laying ratio (%)						
Gamma	Low EP	228	0.961	147.28	5.59×10^{-8}	7.85	0.1975				
	Intermediate EP	240	0.961	194.64	0.000075	5.08	0.1213				
	High EP	242	0.969	202.38	0.000333	4.55	0.1066				
Narushin–Takma	Low EP	162	0.990	36.36	–48.41	8,914	–470,723	6,975,590	–90.76	2.378	–22,697
	Intermediate EP	188	0.990	56.14	27.35	–1.751	–6.651.5	841.116	–107.4	3.474	–37,001
	High EP	197	0.845	69.44	–27.50	9,469	–682,418	1,1589,810	–75.81	356.8	17,603
Logistic-curvilinear	Low EP	170	0.990	40.55	237	0.0292	0.883	28.22			
	Intermediate EP	173	0.992	42.79	152	0.0162	1.1078	27.55			
	High EP	186	0.991	57.60	142.3	0.0122	1.3326	27.07			
Compartmental	Low EP	368	0.114	3,352.95	–24.95	0.0315	0.0205				
	Intermediate EP	382	0.103	4,508.33	–27.84	0.0287	0.0196				
	High EP	393	0.092	5,855.40	–28.98	0.0280	0.0194				
					Egg weight (g)						
Gamma	Low EP	10,549	0.995	20.16	20.65	0.3487	0.00449				
	Intermediate EP	40,649	0.989	43.60	26.06	0.2546	0.0019				
	High EP	17,580	0.996	15.67	35.28	0.1434	–0.00003				
Narushin–Takma	Low EP	10,422	0.995	19.42	68.79	–6,022	171,727	–1,580,181	–85.72	2,375	–20,958
	Intermediate EP	40,586	0.989	43.33	86.12	–2,338	–81,483	2,178,842	0.56	–2,545	48,073
	High EP	17,546	0.996	15.58	79.59	–3,265	–54,677	2,368,695	–19.13	–2,170	54,247
Logistic-curvilinear	Low EP	10,519	0.995	19.98	55.63	–0.0028	0.74	23.66			
	Intermediate EP	40,559	0.989	43.23	54.16	–0.0033	0.75	23.59			
	High EP	17,373	0.996	15.17	53.73	–0.0028	0.76	23.45			
Compartmental	Low EP	39,129	0.989	42.03	183.7	0.0406	0.0481				
	Intermediate EP	40,40	0.989	43.56	57.3298	–0.0023	0.0978				
	High EP	17,557	0.996	15.62	54.8533	–0.0025	0.118				

1)Low EP group (n = 21) – hens with total number of laid eggs (NEggs)≤190 eggs/period. Intermediate EP group (n = 52) – hens with total number of laid eggs 191≤NEggs≤220 eggs/period. High EP group (n = 27) – hens with total number of laid eggs NEggs≥221 eggs/period.

2)AIC – Akaike information criterion, R^2 – coefficient of determination, MSE – mean square error.

The estimated parameters and the goodness-of-fit criteria (AIC, R^2, and MSE) for the compared functions in three groups of egg production (NEggs≤190; 191≤NEggs≤220; NEggs≥221 eggs/period) are presented in Table 3. According to all the criteria used, the egg-laying rate modeled by logistic-curvilinear equation had the best fit to the data and that by compartmental function the worst, in all the three egg production groups. However, comparing AIC, R^2, and MSE, all the functions provided the best fit for the egg-laying rate in low EP group and the worst fit in high EP group. All the four models (gamma, Narushin–Takma, logistic-curvilinear, and compartmental) showed a best fit for egg-laying rate in the high EP group. Slightly worse goodness of fit was observed in the low EP and the intermediate EP groups, respectively. Additionally, the Narushin–Takma function modeled egg-laying rate in three egg production groups also with unexpected extremes (own information).

The egg weight was also modeled in three EP groups (Table 3). The lowest AIC values (10,422–10,549) were observed in the low EP group for all the functions tested, with one exception – compartmental model (39,129). The highest AIC was calculated in the intermediate EP group for all the models (>40,000). In the three EP groups, the coefficients of determination were high (R^2≥0.989) for all the functions. The lowest MSE values, i.e. the best fit to the data, were observed in the high EP group, whereas the highest MSE were calculated in the intermediate EP group, in the case of all functions. Summarizing, the intermediate EP group had the worst-fitted egg weight, whereas the low EP and the high EP groups showed a slightly better fit. However, the compartmental function, in comparison with other three models (gamma, Narushin–Takma, logistic-curvilinear), modeled egg weight worst. The Narushin–Takma function modeled egg weight in egg production groups with unexpected extremes. Additionally, this function fitted negative, i.e. less than zero egg weight before 40 weeks of age, and low egg weight after 40 weeks of age in high egg production group (own information).

Discussion

The broiler breeder hens differ in many aspects from the laying-type hens, which is connected with different selection criteria and usage of both hen types in the poultry industry. Till now, the main practical application of the egg production modeling for broiler breeder flocks is the prediction of the feed requirements for optimal reproduction (Gous and Nonis, 2010; Nonis and Gous, 2013; Ferreira et al., 2015). The proper mathematical models of laying curve, which include (co)variation between birds in flock, may increase effectiveness of production. These models may be helpful to estimate the financial loss caused by a decline in egg production, as evidenced by a deviation from the expected curve (Savegnago et al., 2011).

The flock egg production observed in the present study was at a higher rate in comparison to results obtained for different lines of meat-type hens kept in cages in commercial conditions in Poland (Wencek et al., 2015) in which the production period was about 30 days longer with laying rate higher by about 15%. However, a similar range in the total number of eggs laid was noted by Ferreira et al. (2015) and Leksrisompong et al. (2014) for hens managed on litter. It should be noted that during our study, we tried to create optimal husbandry conditions with individual daily feed restriction for each hen. Thus, the observed variation in the results between egg production groups seems to be caused more by the differences in the reproduction potential on the biological level than by the variation in the management and/or keeping conditions. However, the results obtained for the low EP group were more similar to those for hens in the second reproduction season noted in the husbandry conditions (Wencek et al., 2015).

In the broiler hens breeder flock analyzed in the present study, the egg-laying rate had the best goodness of fit when the logistic-curvilinear function was used and the worst when the compartmental model was applied. Additionally, when the shape of fitted curves was analyzed, Narushin–Takma model did not present enough flexibility, and modeled egg-laying rate with unexpected extremes. This function did not have a good fit at the end of egg-laying period, and was sensitive to outliers. In contrast, the logistic-curvilinear model had good fit during all production period, and gamma model underestimated the egg-laying rate at peak. The peak production estimated using gamma function was at 40 week of age, which differs from the peak egg production of the analyzed broiler breeder flock. Moreover, when the egg-laying rate was modeled in three egg production groups, i.e. low, intermediate, and high, the same results were obtained. In addition, the best fit for egg-laying rate was in low EP group and the worst fit in high EP group. It should be noted that the differences between low, intermediate, and high EP groups were small. For easiest calculation modeling the egg-laying rate in the broiler breeder flock without division into EP groups is more useful. Egg production in the individual broiler breeder hens is related to the length of the oviposition sequences, duration of the pauses between oviposition, and internal laying occurrences (Tumova et al., 2014; Ferreira et al., 2015). It may be suggested that in hens from low EP group compared to high EP group, irregular oviposition pattern with short egg sequences and long period of time between successive eggs negatively affected the laying rate. Moreover, shorter period of the peak production in this group may result from the short prime sequence length. A more detailed analysis of those data showed that there were no outliers in low and high EP groups in which getting better fit was easiest in those groups.

A reasonable starting point in the process of projecting an optimal feeding program for broiler breeders is to describe the potential egg production (the rate of laying and egg weight) of birds during the laying period. In practice, it should be stated that the logistic-curvilinear function provided an acceptable fit to the data and modeled the egg-laying rate with the best shape of curve. Faridi et al. (2011) concluded that three different Narushin–Takma models are able to fit all the investigated variables, including egg weight and egg production ratio in broiler breeder flocks. Those authors suggested that the Narushin–Takma function, specified as in this paper, gave a better prediction in most cases because of its greater number of parameters. The results of the present study showed that the differences between the values for the goodness of fit criteria were small and that the models had the same quality of curve fitting. Savegnago et al. (2012) and Narinc et al. (2014) in hen flocks, and Narinc et al. (2013) in Japanese quail flock came to similar conclusions. Additionally, Savegnago et al. (2012) recommended the logistic function to modeling weekly egg production, while compartmental model was the worst. In addition, those authors observed that McNally function (i.e. modified version of the gamma model) and two compartmental models did not present enough flexibility at the point of inflection to properly fit the egg production rate at peak. Some authors recommended models with biologically interpretable parameters. Narinc et al. (2014) concluded that almost all functions (including gamma model and modified compartmental model) have been developed to allow modeling based on flock averages. Savegnago et al. (2012) found that models presented parameters estimated with biological interpretations are important for the poultry industry and research. By contrast, Narushin and Takma (2003) and Faridi et al. (2010) suggested that models with empirical structure are useful for modeling egg-laying rate curves.

It is now accepted that in the domestic hens, the eggs' weight increases in accordance with the progress in production period as a result of decrease in laying and changes in egg formation rate (Tumova et al., 2014; Javid et al., 2016). Consequently, as was expected, the differences in the egg weight between the production groups were noted. In the present study, all the functions used to model egg weight for broiler breeder flocks were at a similar level of accuracy. However, depending on goodness of fit criteria, the Narushin–Takma and the compartmental functions modeled egg weight slightly better than the other two models (gamma and logistic-curvilinear). On the other hand, the graphical analysis presented that Narushin–Takma model did not show enough flexibility at the beginning of egg weight curve, i.e. before 35 weeks of hens' age. What is important, the logistic-curvilinear model fitted egg weight properly, and compartmental and gamma functions overestimated the egg weight at the onset of egg production period. When the egg weight was modeled in three EP groups, the best fits were in low and high EP groups and the worst fit was in intermediate EP group with one exception – compartmental model in low EP group. It should be noted that both egg-laying rate and egg weight had the best fit in low EP group. In the case of three EP groups, our results differed from the results for broiler breeder flocks: the gamma, the Narushin–Takma, and the logistic-curvilinear functions modeled egg weight at similar level, while the compartmental model was the worst. Nonis and Gous (2013) modeled egg components of broiler breeder hens and proposed to calculate egg weight as the sum of the weights of three components, i.e. yolk, albumen, and shell because the proportions of those components change over time. Ferreira et al. (2015), who also modeled the egg components of broiler breeder hens, wrote that models estimating egg weight directly as the function of age are fitting better than models estimating each component separately. Narushin and Takma (2003) found that the variation of the Narushin–Takma model, defined as the ratio of the polynomials of the third and second degree, gave the most accurate results in daily egg mass production curves in the laying-type hens. Faridi et al. (2011) also concluded that a Narushin–Takma model was able to predict many productive traits, including egg weight.

In conclusion, the results of this study illustrate that the logistic-curvilinear model is able to predict well both egg-laying rate and egg weight during the production period of broiler breeder hens, and also when hens are divided into three egg production groups. From a practical point of view for the easiest calculation, the egg-laying rate and the egg weight could be modeled in broiler breeder flock without the division into EP groups. In addition, simple model, with smaller number of parameters, i.e. the logistic-curvilinear, was recommended to be applied because of their ease of calculation. This model should be considered in a long-term prognostic for the reproductive potential in the commercial management practice. Moreover, the presented model could be useful in the research on different reproduction parameters of individual hens.

Conflict of interest

The authors declare that there is no conflict of interest related to this study.

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