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# SIGMOID MODELS FOR THE GROWTH CURVES IN MEDIUM-GROWING MEAT TYPE CHICKENS, RAISED UNDER SEMI-CONFINED CONDITIONS*

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**Abstract**

**The study analyzed the growth of medium-growing chickens of the CCGP experimental line, using Gompertz, Logistic, and Richards models as well as body gain curves. The birds were reared until 9 wk of age. To fit BW values to the applied models, determination coefficients ($R^2$, $\check{R}^2$) and standard error of the mean (±SE) were calculated for 487 male and 493 female chickens. The comparison of results obtained demonstrated the Gompertz model to be the most precise equation to describe the growth of both sexes of CCGP chickens, though in all examined models the determination coefficients were approximating 99%. According to the Gompertz model, the chickens may reach the maximum BW at the age of 16 wk (5900 g – males and 4000 g – females), whereas the maximum daily BW gain – on day 47 (69.0 g) in males and on day 41 (50.0 g) in females. Values achieved in the Logistic model were the most diverging from the values obtained with other models, whereas the Richards model may be successfully applied to estimate BW of chickens. Females were reaching the maximum BW gains earlier, but the curve of their BW gain was proceeding with two peaks (at ca. 4 wk – 313.09 g/wk and at 6 wk – 327.59 g/wk), which was probably due to partial growth deceleration as a result of allowing the birds to use free ranges on day 14. In the case of males, the maximum BW gain (727.35 g/wk) was reached at 6.2 wk.**

**Key words: chickens growth models, medium-growing, semi-confined conditions**

Owing to its significance in the production process and easy control procedures, growth has become the main characteristic taken into account during meat type poultry selection. By definition, it is understood as a process that covers a change in

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animal BW in respect of its age, till it reaches maturity. A useful tool in the analysis of results of genetic selection and in depicting differences between genetic groups turned out to be mathematical functions applied to describe bird growth curves. Mignon-Grasteau and Beaumont (2000) ascribed four equations as best fitting to particular species: Richards – chicken, turkey, quail, duck, goose; Gompertz – chicken, turkey, quail; Logistic – quail; and Janoschek – duck. Earlier, however, Gille and Salomon (1998) presented Janoschek estimation as an appropriate tool to describe the growth of muscles of only wild and domestic *Anas platyrhynchos*, that was not necessarily fitted to describe BW gain. In turn, Ersoy et al. (2006) claimed the Gompertz and Richards models to be the most appropriate for the characteristics of the growth of chickens, ostriches, turkeys and emus. Conflicting concluding by various authors upon the use of the same functions may result from the use of different genetic groups of birds in experiments. When analyzing the growth of turkeys selected for BW gain for 7 generations, Porter et al. (2010) demonstrated that Morgan equation was the most appropriate for generation 1 and poorly fitted for generation 7. In turn, Nahashon et al. (2006 b) report that high genetic variability of pearl gray guinea fowl in the United States requires individual adjustment of particular functions to the growth of productive flocks of these birds separated from each other.

Most frequently, the growth of meat type chickens is presented with the use of Gompertz curve (Aggrey, 2002; Darmani Kuhi et al., 2003; Wang and Zuidhof, 2004), although it has some restriction in the form of a stable inflexion point at 1/e (= 0.368), when the bird reaches the maximum BW gain (Thornley and France, 2007). Most of these experiments, however, refer to fast-growing commercial lines. Today, increasing interest is observed in the production of medium-growing chickens in the semi-intensive system. As a consequence, information appears in literature on novel genotypes of chickens that are often hybrids of slow- and fast-growing lines. In order to reach the maximum BW, these hybrids require different rearing period depending on the parental material applied. The use of the appropriate mathematical function allows, with some margin of error, estimating BW to be reached at the specified age of birds. In turn, graphical presentation of these models eliminates irregular fluctuations of body weight by randomized effects of the environment (Nahashon et al., 2006 b), that are common in the semi-intensive production.

The available literature lacks information on the analysis of the growth rate of medium-growing chickens produced in the semi-intensive system with the use of known mathematical functions. For this reason, the objective of this study was to characterize the growth rate of slow- and fast-growing hybrid chickens using selected mathematical functions: with a stable inflexion point of the curve – Gompertz and Logistic, and with flexible curve having a variable inflexion point of the curve – Richards.

## Material and methods

All procedures were performed according to the guiding principles for the care and use of research animals and were approved by the Local Ethics Commission.

A total of 1000 day-old medium-growing chickens of the experimental CCGP line (500 males and 500 females) were used in the study. The experimental line was the second generation of crossing Polish native Greenleg Partridge and fast-growing commercial chickens (Michaczuk et al., 2013). The chickens were randomly distributed to 10 floor pens (stock density in a pen reached 11 birds per $m^2$). Each chick was weighed and marked with a tag attached in the right wing, each tag had a number to identify each bird. For the first two weeks, the chickens were kept indoors under heat radiator and at 24 h light cycle. Afterwards, they were allowed to use free ranges (2 birds per $m^2$) and provided 18 h of lighting in the building. Weather conditions during the experiment were as follows: the average daily mean temperature and humidity were 18.3°C and 84.9%, respectively. There were 4 d of rain and total precipitation was at 71.6 mm. All birds were fed *ad libitum* with wheat-corn-soy based diets (Table 1).

Table 1. Nutritional composition of diets for chickens

| Item | 0 to 14 d | 15 to 35 d | 36 to 49 d | 50 to 56 d |
|---|---|---|---|---|
| Nutritional composition (% of weight) | | | | |
| gross energy (MJ/kg) | 12.52 | 12.76 | 13.20 | 13.47 |
| crude fat | 3.67 | 4.00 | 5.14 | 5.92 |
| crude protein | 21.99 | 20.78 | 19.26 | 18.51 |
| methionine | 0.70 | 0.63 | 0.57 | 0.50 |
| methionine + cysteine | 1.08 | 1.01 | 0.92 | 0.84 |
| lysine | 1.38 | 1.28 | 1.19 | 1.08 |
| crude ash | 5.83 | 5.35 | 4.96 | 4.67 |

Nutritional composition was determined by AOAC (2005).

Chicks hatching weight was considered as body weight at week zero. Afterwards, body weights were measured (±0.01) weekly till 9 wk. Since 3 wk, body weight measurements were always conducted after switching on the light and before feed administration. Mortality rate of the chickens was recorded, however BW values of dead birds were not considered in calculations.

The statistical analysis was carried out using Statistica 10.0 software (Statistica, 2011). Normality of chicken BW values distribution was checked with Kolmogorov-Smirnov test. All variables, except hatching BW, had normal distribution. T test was applied to calculate differences in BW values between male and female chickens, and differences were found significant at $P \leq 0.01$. The effect of sex on hatching BW was estimated with the non-parametric Mann-Whitney test. The variability of the investigated traits was expressed by the standard error of the mean (±SE).

The growth of chickens was characterized with the use of three mathematical models: Gompertz, Logistic and Richards. The following equation describes sequentially the:

Gompertz model growth curve (Mignon-Grasteau and Beaumont, 2000):

$$Y = a*exp(-exp(-b*(x-c)))$$
$$x = c\text{, so } y = a/e \approx a/2.7 \text{ ie. } 36.79\%\ a\text{, so } y' = ab/e$$

where:

$y$ – BW (g);

$x$ – age (wk);

$a$ – upper horizontal asymptote (maximal BW to be reached by a bird);

$b$ – parameter which influences growth rate (BW gain rate);

$c$ – abscissa of inflexion point (the moment of shifting from the phase of accelerated growth to the phase of inhibited growth; the moment of zeroing of the second derivative meaning the maximum of the first derivative; the moment when a chick reaches 36.79% of the maximum BW and its growth rate is the highest).

Logistic model growth curve (Robertson, 1923):

$$Y = a/(1+exp(-b*(x-c))$$
$$x = c\text{, so } y = a/2 \text{ ie. } 50\%\ a\text{, so } y' = ab/4$$

where:

$y$ – BW (g);

$x$ – age (wk);

$a$ – upper horizontal asymptote (maximal BW to be reached by a bird);

$b$ – parameter which influences growth rate (BW gain rate);

$c$ – abscissa of inflexion point (the moment of shifting from the phase of accelerated growth to the phase of inhibited growth; the moment of zeroing of the second derivative meaning the maximum of the first derivative; the moment when a chick reaches 50% of the maximum BW and its growth rate is the highest).

Richards model growth curve (Richards, 1959):

$$Y = a*((1+exp(-b*(x-c)))\hat{}d)$$
$$x = x^* = c + ln(-d)/b\text{, so } y = a((-(d-1))\hat{}d)*((-d)\hat{}(-d)\text{, } y' = y(x^*)*b*d/(d-1)\text{, } y'' = 0$$

where:

$y$ – BW (g);

$x$ – age (wk);

a – upper horizontal asymptote (maximum BW to be reached by a bird);

$b$ – parameter which influences growth rate (BW gain rate);

$c$ – shape parameter, with the property; $d$ – relative weight at age at maximum rate of growth (wk); $x^*$ = c+ln(-$d$)/$b$ – abscissa of inflexion point (the moment of shifting from the phase of accelerated growth to the phase of inhibited growth; the moment of zeroing of the second derivative meaning the maximum of the first derivative).

The value of determination coefficient ($R^2$), which indicates the percentage fit of the selected growth model to observed data, was calculated using the equation by Pérez-Lara et al. (2014):

$$R^2 = \sum (w_i - \overline{w}_m)^2 - \sum (w_i - w_e)^2 / \sum (w_i - \overline{w}_m)^2$$

where:

$R^2$ – determination coefficient;
$w_i$ – BW real value at certain moment;
$w_e$ – estimated BW with the model at certain moment;
$\overline{w}_m$ – average BW.

Average growth rate, which is defined by the change of BW at a certain interval of time, was calculated according to the formula:

$$\overline{D}W_m = \Delta W/\Delta t(g/wk)$$

where:

$\overline{D}W_m$ – average growth rate; $W$ – BW at any moment; $t$ – time.

## Results

Table 2 presents BW values of male and female chickens since 0 wk to 9 wk. The statistical analysis of results demonstrated a significant (P≤0.01) effect of sex on BW values of chickens in all measuring intervals (weeks), except for hatching BW. Chicken mortality rate was low, i.e. 13 male and 7 female chickens died till the 9 wk, which constitutes 2.6 and 1.4% of the initial number of birds in the flock.

Graphical presentation of chicken growth demonstrates that all three models were very well describing the dependency of birds BW on age (Figure 1). The investigated average data represent the very smooth curves without error spans. Partial misfit of the models to the observed data was only observed for male chickens in 7 and 8 wk. In addition, in the case of Gompertz, Logistic and Richards estimation, the coefficient of determination ($R^2$) and adjusted coefficient of determination ($\check{R}^2$) reached >0.99 in both sexes, which means that 99% of chicken BW variability was explained by the discussed models (except for $\check{R}^2$ for male chickens in Logistic model) (Tables 3 and 4). However, even percentages of variation exceeding 99%, did not necessarily indicate an excellent fit. In the case of Gompertz and Logistic models, the analyzed parameters (*a*, *b*, *c*) were estimated with high precision, which was indicated by relatively small mean errors of the estimates (±SE). In contrast, large mean errors of the estimated means, and thus low values of T-Student's statistics, were observed for both sexes in Richards estimation (Tables 3 and 4).

Table 2. Means and standard error for BW (g) at different ages (wk) in medium-growing experimental line CCGP chickens

| Age (wk) | Male (n = 487) | Female (n = 493) | Significance of differences |
|---|---|---|---|
| Hatching (0) | 38.60±0.26 | 38.24±0.24 | NS |
| 1 | 143.13±1.39 | 135.26±1.16 | ** |
| 2 | 351.79±4.73 | 323.31±3.21 | ** |
| 3 | 604.78±5.87 | 532.72±6.82 | ** |
| 4 | 1012.18±10.40 | 850.41±9.82 | ** |
| 5 | 1377.18±12.47 | 1139.60±11.55 | ** |
| 6 | 2104.53±19.41 | 1469.17±13.23 | ** |
| 7 | 2555.88±30.23 | 1697.84±22.82 | ** |
| 8 | 2908.07±25.85 | 2126.99±28.47 | ** |
| 9 | 3202.39±34.11 | 2391.99±32.62 | ** |

** difference significant at P<0.01; NS – difference not significant.

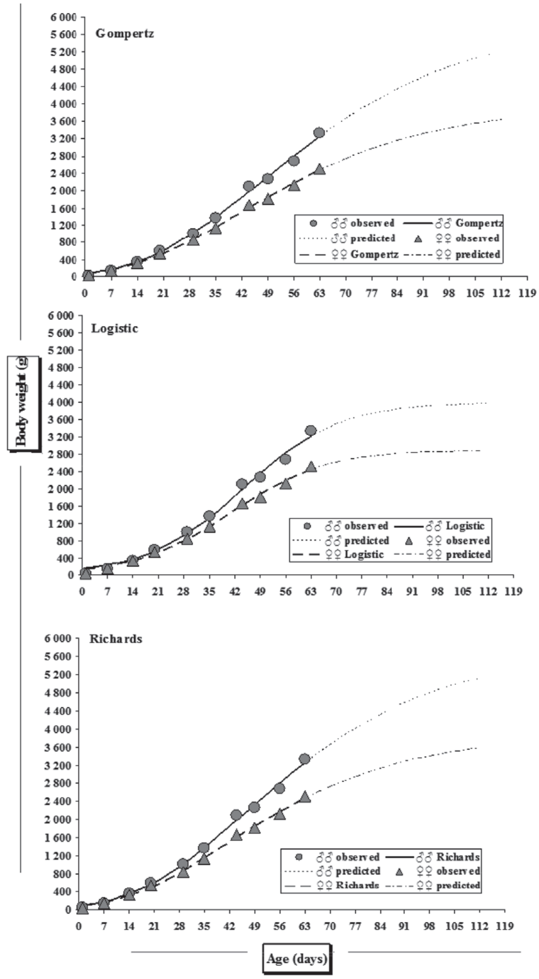


Figure 1. Observed and predicted growth curves in medium-growing CCGP male and female chickens

Table 3. Values of parameters (a, b, c, d) of growth models (Gompertz, Logistic, Richard) for medium-growing experimental line CCGP male chickens

| Model Parameters | Males | | | | | | |
|---|---|---|---|---|---|---|---|
| | BW value (g) | ±SE | T-value | $R^2$ | DF Adj $\check{R}^2$ | Fit ±SE | F-value |
| Gompertz | | | | | | | |
| a | 5921.75 | 934.67 | 6.34 | | | | |
| b | 0.03 | 0.00 | 7.21 | 0.9963 | 0.9944 | 79.5551 | 939.1740 |
| c | 46.82 | 5.40 | 8.67 | | | | |
| Logistic | | | | | | | |
| a | 3986.74 | 379.12 | 10.52 | | | | |
| b | 0.07 | 0.01 | 9.19 | 0.9928 | 0.9892 | 110.5697 | 484.5059 |
| c | 44.02 | 3.15 | 13.96 | | | | |
| Richards | | | | | | | |
| a | 5729.99 | 2705.66 | 2.12 | | | | |
| b | 0.03 | 0.03 | 1.30 | 0.9962 | 0.9931 | 87.04 | 523.05 |
| c | –51.66 | 506.17 | –0.10 | | | | |
| d | –26.34 | 385.27 | –0.07 | | | | |

T-value – T-Student value; $R^2$ – Coefficient of determination; DF Adj $\check{R}^2$ – adjusted determination coefficient; Fit – standard deviation of residuals; F-value – F statistic value (Fisher-Snedecor).

Table 4. Values of parameters (a, b, c, d) of growth models (Gompertz, Logistic, Richard) for medium-growing experimental line CCGP female chickens

| Model Parameters | Females | | | | | | |
|---|---|---|---|---|---|---|---|
| | BW value (g) | ±SE | T-value | $R^2$ | DF Adj $\check{R}^2$ | Fit ±SE | F-value |
| Gompertz | | | | | | | |
| a | 3963.79 | 338.41 | 11.71 | | | | |
| b | 0.03 | 0.00 | 11.51 | 0.9982 | 0.9973 | 42.0351 | 1957.4458 |
| c | 41.11 | 2.81 | 14.62 | | | | |
| Logistic | | | | | | | |
| a | 2888.20 | 183.64 | 15.73 | | | | |
| b | 0.08 | 0.01 | 11.83 | 0.9954 | 0.9930 | 67.8024 | 750.2009 |
| c | 40.86 | 2.16 | 18.89 | | | | |
| Richards | | | | | | | |
| a | 3847.68 | 909.14 | 4.23 | | | | |
| b | 0.04 | 0.02 | 2.24 | 0.9981 | 0.9966 | 46.4606 | 1068.1101 |
| c | –43.33 | 252.35 | –0.17 | | | | |
| d | –21.64 | 171.39 | –0.13 | | | | |

T-value – T-Student value; $R^2$ – Coefficient of determination; DF Adj $\check{R}^2$ – adjusted determination coefficient; Fit – standard deviation of residuals; F-value – F statistic value (Fisher-Snedecor).

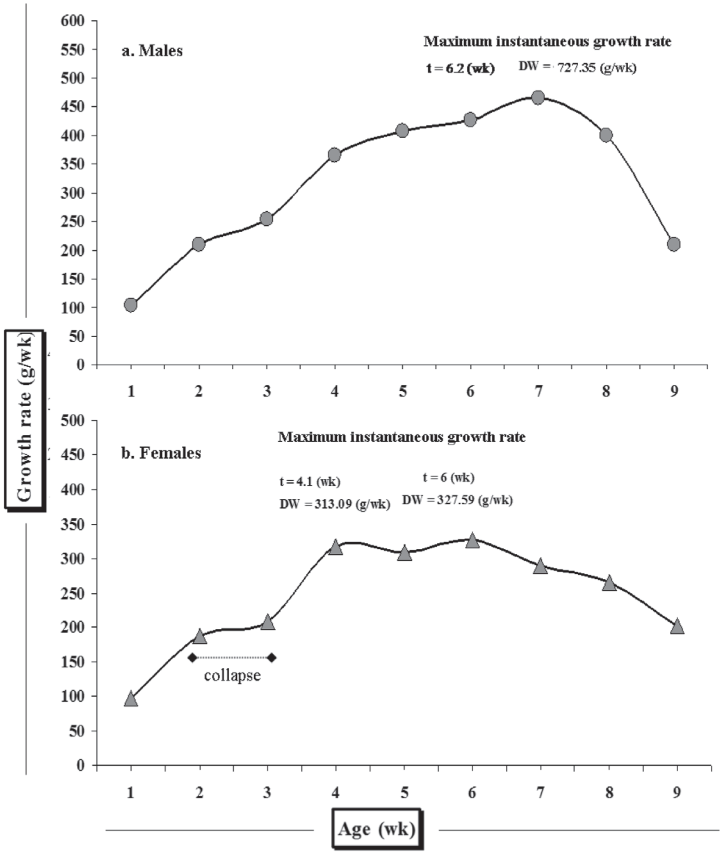


Figure 2. Growth rate of medium-growing experimental line CCGP chickens

According to the investigated models, birds could reach the maximum BW in ca. 16 wk of life. Then, the BW values (parameter *a*) would account for: 5900 g (Gompertz), 4000 g (Logistic) and 5700 g (Richards) in the case of male chickens as well as for: 4000 g (Gompertz), 2900 g (Logistic) and 3800 g (Richards) in the case of females. Regarding this trait, values achieved using the Logistic model were the most divergent from values obtained with the other two models. The maximum BW gain of male chickens was observed in 6 wk, i.e. 727.35 g (Figure 2 a). In turn, the growth curve of female chickens proceeded with two peaks, the first of which occurred in ca. 4 wk (313.09 g), and the second – in 6 wk (327.59 g) (Figure 2 b). The value of parameter *c* (Tabled 3 and 4) indicates that, according to Gompertz model, the maximum daily BW gain reached 69.0 g on 47 d for male chickens and 50.0 g on 41 d for female chickens. According to Logistic model, male chickens reach their maximum body weight gain slightly earlier – on d 44, whereas female chickens – on the same day (41 d), however in this model values of BW gains are higher for both sexes (75.0 g and 55.0 g, respectively). Results of Richards estimation demonstrate that female chickens reach the greatest gains (69.0 g) at BW 1800 g (y(x*) on 46 d (x*), whereas female chickens (50.5 g) at BW 1500 g (y(x*) on 41 d (x*) (Table 3 and 4).

## Discussion

Very high values of determination coefficients ($R^2$; $\check{R}^2$) and small mean errors of the estimates demonstrate that the growth of CCGP chickens was best described by the Gompertz model. Narinc et al. (2010) also indicated this model as the most appropriate for the analysis of BW changes in time for medium-growing chickens reared indoors. These authors pointed out that among the three evaluated formulas, only values achieved with the Logistic model were the most divergent from the values obtained with the other analyzed models (Gompertz, Bertalanffy), which was also confirmed in our study (Gompertz, Richards). It may, therefore, be hypothesized that the Gompertz estimation is the most appropriate for medium-growing chickens irrespective of the production system, because it is the origin of birds that has a greater impact on model fitting to BW values varying in time. It was demonstrated by Eleroğlu et al. (2014), who showed that the Logistic model was more appropriate for the description of growth curves of two lines of slow-growing chickens (GB-JA and S757), reared in the organic system.

Age at which the birds reached the highest BW gains, estimated via Gompertz model at 47 d for males and at 41 d for females, was similar to that reported by Santos et al. (2005) – 48 d and 44 d, respectively, and by Narinc et al. (2010) – 48 d and 45 d, respectively. For the fast-growing lines of chickens, this parameter is estimated at 32 d and 40 d respectively (Marcato et al., 2008), whereas for the slow-growing birds – at 49 d (both sexes) (N'dri et al., 2006). The maximum BW predicted with the Gompertz model for CCGP chickens was higher than that predicted for medium-growing chickens in the study by Narinc et al. (2010): 4362 g (for males) and 3657 g (for females), however these authors did not state the estimated age at which the birds may reach such BW. This difference may also result from the use of different parental material for crossing. The correctness of the estimated parameters of the maximum BW of CCGP chickens may be confirmed by results of BW control of CCGP chickens at 18 wk of life. Exactly, 350 females and 50 males were left for further reproduction and kept at the experimental station RZD Wilanów-Obory (SGGW, Poland). The average BW was then 5810 g (±611.08) for males and 3892 g (±403.27) for females (unpublished data). It is easy to notice that both the Gompertz and the Richards models appear as very precise tools in estimating BW of medium-growing chickens based on data collected within the first 9 wk of birds rearing. The maximum BW of CCGP chickens estimated with the Logistic equation turned out to be highly underestimated, which strongly limits the use of this model for growth curve description in the discussed group of chickens. Similar conclusions were earlier presented by Nahashon et al. (2006 b), who analyzed the growth of slow-growing pearl gray guinea fowl with the use of Gompertz, Richards and Logistic models. Interestingly, the same Logistic formula was observed to overstate the estimated parameters in the case of fast-growing meat type guinea fowl, compared to Gompertz and Richards formulas (Nahashon et al., 2006 a).

The effect of sexual dimorphism on BW values has already been confirmed for chickens with different growth rates (Santos et al., 2005; Eleroğlu et al., 2014). When investigating medium-growing chickens, Narinc et al. (2010) demonstrated that males were significantly heavier than females as early as between 14 and 21 d of rearing, which is slightly later than the CCGP chickens analyzed in our study (Table 2). Similar values of determination coefficients ($R^2$; $\check{R}^2$; Table 3 and 4) indicate that in the case of both sexes the varying BW values were similarly fitted to individual mathematical models. Earlier investigations confirm that the growth formula for females and females within one genetic group of birds is the same, irrespective of the species (Nahashon et al., 2006 b; Pérez-Lara et al., 2014) or selection trend (Mignon-Grasteau and Beaumont, 2000).

Eleroğlu et al. (2014) pointed out that the application of mathematical functions to describe the growth of birds was useful in estimating production termination deadline and formulation of appropriate feed mixtures. In turn, the elimination of irregular fluctuations of BW values caused by effects of the environment through the graphical presentation of growth curves (Nahashon et al., 2006 b), impairs the investigation of the impact of the rearing system itself on birds' growth. In this case, plotting body weight gain curves turns out to be useful. The analysis of changes in the values of BW gains of CCGP chickens enabled observing an irregular collapse of the curve between 14 d and 21 d of rearing, that was significantly more intensified in the females (Figure 2 b) compared to males (Figure 2 a). Significant is also the fact that the collapse occurred after the 14 d of life, i.e. immediately after the birds were allowed to use free ranges. Though the decision of allowing the birds to use free ranges in this term was caused by favorable weather conditions, stress linked with the change of environment resulted in the instantaneous deceleration of growth. Considerably more visible collapse of the growth curve of females (Figure 2 b) compared to males (Figure 2 a) could be due to the fact that on 14 d of life the females had already significantly lower BW values (Table 2). As a consequence, the growth curve of the females has two peaks, in contrast to one-peak course of the curve plotted for birds reared under controlled conditions of the intensive production system (Pérez-Lara et al., 2014). Presumably, such a response of birds may be due to the compensation growth that occurred once the bird had accustomed to new environmental conditions. It has been proved in several studies that chicken growth compensation occurs after a sudden and instantaneous malnutrition of birds, which is also induced by stress. The course of this phenomenon depends on the character and intensity of the growth-inhibiting factor, age at which its effect had begun and its duration (Zubair and Leeson, 1996; Saber et al., 2011).

In summary, it was demonstrated that data regarding the growth parameters of medium-growing chickens of the CCGP experimental line, reared in the semi-intensive system, would be best interpreted with the use of Gompertz model. For pure estimation of chicken BW, it will also be advisable to use Richards formula. In addition, significant sexual dimorphism in BW values, earlier growth deceleration and stronger response of the females after allowing the birds to use free ranges on 14 d of life indicate that the CCGP females should begin using free ranges later than the males (on ca. 21 d of rearing). These results suggest that separate rearing of females and males should be considered in the future in the semi-intensive production of medium-growing chickens, as in the case of turkeys and Muscovy ducks.

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