# Diphasic Analysis of Growth in Japanese Quail

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**ABSTRACT :** A line of Japanese quail selected for increased body weight for 15 generations (C) and an unselected control line (K) were used to examine the impact of selection for body weight on the growth curve of Japanese quail. In addition, the effect of sex on the growth curve in each line was also studied, namely females of C (CF), males of C (CM), females of K (KF) and males of K (KM). The monophasic and diphasic growth models were studied for adequacy in describing growth curves of quail in both sexes of the C and K lines. The monophasic function provided almost the same growth rate for both sexes in both lines. However, the growth rates calculated by means of the diphasic function differed between sexes for both lines, except for those calculated for C during the second growth phase. While there were 2-3 days difference between sexes in age at maximum gain in both lines with a monophasic model, the difference between sexes in the age at maximum gain in both lines became greater according to the diphasic model. There were 5 and 7 days difference between sexes in the age at maximum gain in line C for the first and second growth phases, respectively. A difference between sexes of 18 and 11 days in the age at maximum gain for the first and second phases, respectively, was estimated for line K when the diphasic function was fitted. The use of diphasic functions provides more detailed information on growth patterns. The results showed that the use of the diphasic function was better because it provided greater insights into understanding the biology of growth. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 9 : 1281-1285)***

**Key Words :** Japanese Quail, Growth Curves, Monophasic Function, Diphasic Function, Asymptotic Weight, Growth Rate

## INTRODUCTION

Growth in biological terms is related to changes in size and shape. The bases for growth are the processes of hyperplasia, hypertrophy and cell differentiation. However, these processes can be affected by the environment, including nutrition and random events, causing growth to fluctuate (Aggrey, 2003).

The purpose of fitting growth curves is to express temporal changes in shape and live weight, as influenced by genetic and environmental factors. The fitted curves display the pattern of growth in time. Growth functions also allow for the study of growth rate and estimation of changes in the shape of curve during selection (Hyankova et al., 2001). The type of growth curve to be selected depends on type of biological material and type of growth. In fitting growth curves, researchers ideally should seek growth functions with biologically meaningful parameters.

Most growth patterns can be described by sigmoid growth curves. The Gompertz, logistic and von Bertalanffy growth curves are commonly used to describe growth over time (Werker and Jaggard, 1977). These are all monophasic growth models. Monophasic growth models can sometimes be inadequate to express growth over time realistically because of the small number of parameters used to explain the pattern of growth from birth to maturity phase. These functions treat growth as a continuous process (Koops and Grossman, 1991). However, it is possible to obtain systematic deviations from observed values in continuous processes, which causes overestimation of some parameters (Koops et al., 1987). In the presence of systematic deviation, weight-age growth should be expressed as multiphasic to obtain more realistic parameters. Multiphasic analysis of growth permits estimation of successive growth phases, each phase building on the previous stage (Grossman and Koops, 1988). In animal growth, many researchers have shown the existence of growth phases (Eisen 1976; Grossman and Koops, 1988; Koops and Grossman, 1991; Kwakkel et al., 1993).

This study was undertaken to describe weight-age growth for Japanese quail selected and unselected for 5 week increment in body weight by using monophasic and multiphasic growth curves, and to compare the fitted monophasic and diphasic curve parameters with each other.

## MATERIALS AND METHODS

The quail studied were from a line (C) selected for 5-week body weight gain for 15 generations and an unselected control line (K). Quail were classified into male and female groups according to their feather color. Thus, four groups, namely female of C (CF), males of C (CM), females of K (KF) and males of K (KM), were studied. Males and females of the same line were kept together.

A number of eggs from each line were hatched in an incubator. At hatching, chicks from each line were randomly selected and wing banded. The chicks from each line were reared in separate compartments of battery brooders in order to prevent inter line competition.

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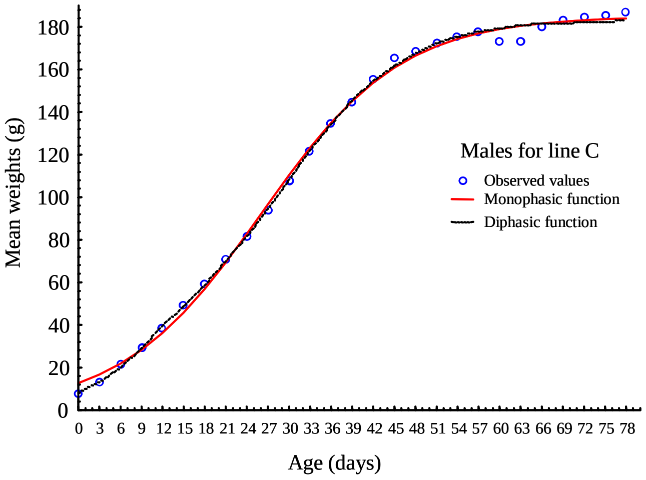

**Figure 1.** Observed mean body weights and predicted values using the monophasic and diphasic growth functions plotted against age for line C males.

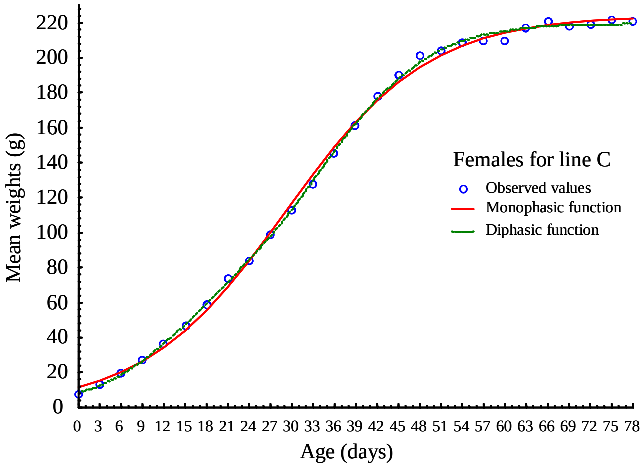

**Figure 2.** Observed mean body weights and predicted values using the monophasic and diphasic growth functions plotted against age for line C females.

The experiment started with approximately 60 chicks in CM, CF, KF and KM groups but decreases in the number of quail occurred due to deaths during the growing period. Therefore, data recorded from 40 quail in each group were used in the growth analyses. The quail were weighed, starting at hatching, every 3 days up to the age of 78 days.

The quail were reared in colony cages with feed including 24.5% protein and 3,000 metabolic energy and water available *ad libitum*. Temperature of the room where the experiment was run was held at 30°C with constant lighting.

Multiphasic growth functions describe growth as a function of age including n sigmoid curves each of which clarifies a growth phase (Kwakkel et al., 1993). The multiphase growth function modified by Peil and Helwin (1981) can be written as the sum of logistic functions in the hyperbolic tangent form as follows:

$$y_t = \sum_{i=1}^{n}(a_i(1+\tanh(b_i(t-c_i)))) \qquad (1)$$

Where, $y_t$ is body weight at age t (t=0, 3, 6, 9….78 days) and n is number of growth phases. Each phase is determined by three parameters: $a_i$ is half asymptotic weight (grams), $b_i$ is growth rate relative to $a_i$ (days$^{-1}$) and $c_i$ is age at maximum gain ((age at point of inflection, (days)).

The number of parameters to be predicted in a multiphasic growth function depends on the number of phases. While a monophasic function has three parameters, a diphasic function has six and a triphasic function has nine parameters. The number of phases during growth depends on the type of material studied and the frequency of measurements. In this study, the number of phases was limited to two and the parameters estimated for diphasic growth functions because of the small number of observations (t=27 as days) compared to the large number of parameters.

In some studies, multiphasic growth functions have not been applied to curves of individual body weight measurements. Such individual growth curves often show temporary fluctuations because of problems with health, feed intake, hormonal activity or differences in growth rate of body components (Koops et al., 1987; Koops and Grossman 1991).

Brody (1921) emphasized that the diphasic nature of growth can be quantified easily and examined carefully to obtain more detailed information. A diphasic function was also appropriate to fit weight data for male and female chickens (Grossman and Koops, 1988).

Equation (1) was fitted to mean weight data for the monophasic and diphasic functions by the nonlinear estimation technique of Statistica 6.0.

Residual variances, R-squareds and Durbin-Watson statistics were calculated to judge adequacy of fit of monophasic and diphasic functions. The Durbin-Watson statistic is a measure of serial correlation of residuals. A value for the Durbin-Watson statistic of 2 indicates no autocorrelation, a lower value than 2 indicates positive autocorrelation and a higher value than 2 indicates negative autocorrelation (Koops, 1986).

The diphasic function of weight-age growth was compared with the monophasic function in order to investigate the multiphasic nature of growth by using the above-mentioned statistics. In addition, the parameters of the monophasic and diphasic functions fitted for growth curves of mean weights for males and for females of each line were compared with each other.

## RESULTS AND DISCUSSION

The observed mean body weights and fitted monophasic

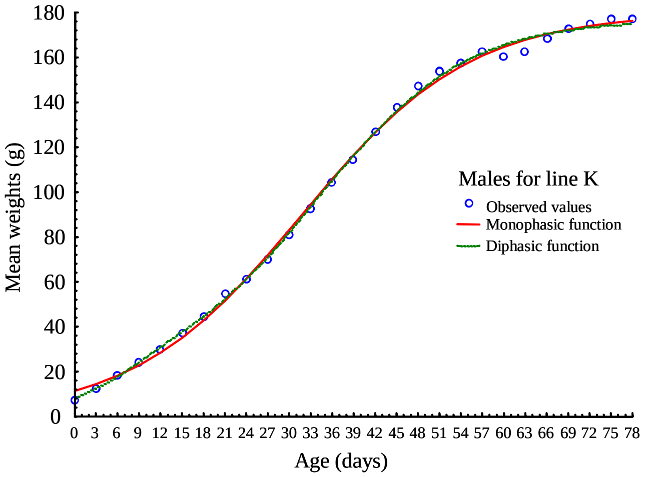

**Figure 3.** Observed mean body weights and predicted values using the monophasic and diphasic growth functions plotted against age for line K males.

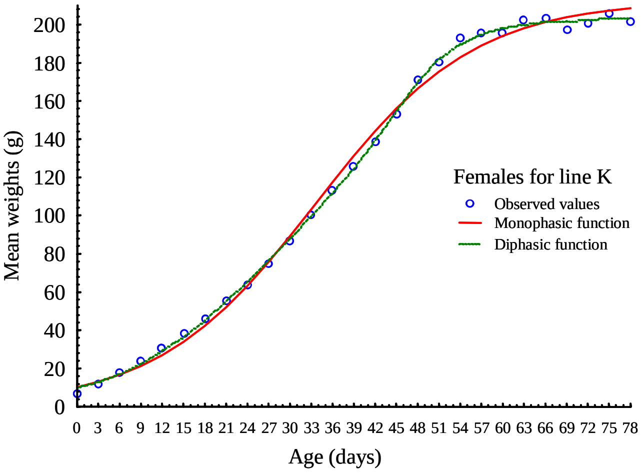

**Figure 4.** Observed mean body weights and predicted values using the monophasic and diphasic growth functions plotted against age for line K females.

and diphasic growth functions for CM, CF, KM and KF groups were plotted against age (days) in Figures 1, 2, 3 and 4, respectively. As seen in the figures, the diphasic growth function provided a better fit to the observed growth pattern of Japanese quail than did the monophasic growth function.

Residual variances, R-squareds and Durbin-Watson statistics for monophasic and diphasic growth functions are shown in Tables 1 and 2.

As seen in Table 1 and 2, diphasic growth functions provided smaller residual variances than did monophasic growth functions. Durbin-Watson statistics also showed that there was a higher positive autocorrelation among the residuals for monophasic functions than for diphasic functions. It can be concluded that the diphasic function, with smaller residual variances and less highly correlated residuals, described the growth pattern of quail more accurately than did the monophasic function.

The half asymptotic weight (a) estimated for the monophasic function was higher for CF and KF than those for CM and KM. The monophasic growth function provided the same growth rate (b) for CM and CF, and almost the same for KM and KF, being 0.05 for CM and CF, and 0.042 and 0.045 for KM and KF, respectively, which indicates that the duration of the growth period was 40 days for C, and 48 days for KM and 44 days for KF (duration of growth period is calculated as $2b^{-1}$). Results for growth rate are consistent with those reported by Grossman and Koops (1988). The predicted age at maximum gain (c) was later for females than for males for both lines.

Fitting diphasic functions showed that 17% of asymptotic weight for CM and 34% of asymptotic weight for CF were attained during the first phase. While 11% of asymptotic weight was achieved during the first phase for KM, 70% of asymptotic weight for KF was reached during the first phase. While CF reached twice the fraction of asymptotic weight that CM achieved during the first phase of the growth, the fraction of asymptotic weight achieved by KF was six times that of KM during the same phase.

Regarding the second phase of growth, while 83% of asymptotic weight for CM was completed during the second phase, CF achieved 66% of asymptotic weight during the second phase. This result is in agreement with

**Table 1.** The estimated parameters for monophasic growth function

| Line | Sex | a | b | c | Residual variance | R-squared | Durbin-Watson statistic |
|---|---|---|---|---|---|---|---|
| C | Males | 92.46 | 0.050 | 26.13 | 8.9 | 0.997 | 0.68 |
| | Females | 112.00 | 0.050 | 29.16 | 10.3 | 0.998 | 0.67 |
| K | Males | 89.96 | 0.042 | 31.78 | 6.5 | 0.998 | 0.64 |
| | Females | 106.20 | 0.045 | 33.62 | 21.5 | 0.996 | 0.65 |

**Table 2.** The estimated parameters for diphasic growth function

| Line | Sex | $a_1$ | $a_2$ | $b_1$ | $b_2$ | $c_1$ | $c_2$ | Residual variance | R-squared | Durbin-Watson statistic |
|---|---|---|---|---|---|---|---|---|---|---|
| C | Males | 15.52 | 76.14 | 0.12 | 0.06 | 8.05 | 29.73 | 6.60 | 0.998 | 1.91 |
| | Females | 37.04 | 72.81 | 0.08 | 0.07 | 13.83 | 38.80 | 4.00 | 0.999 | 1.85 |
| K | Males | 9.54 | 79.18 | 0.12 | 0.05 | 7.27 | 34.32 | 5.18 | 0.998 | 1.81 |
| | Females | 71.13 | 30.79 | 0.05 | 0.12 | 25.65 | 45.07 | 5.24 | 0.999 | 1.86 |

those reported by Koops et al. (1987). However, 89% and 30% of asymptotic weight for KM and KF was accomplished during the second phase, respectively.

A growth rate ($b_1$) of 0.12 for CM was estimated, indicating about 17 days of the first phase for CM. However, the predicted first growth phase for CF was much longer, being 25 days. The longer first growth phase for CF than that for CM is consistent with more than twice the percentage of asymptotic weight reached for CF during the first growth phase, being 37.04 g for CF and 15.52 for CM. The estimated growth rates ($b_2$) for CM and CF during the second phase were almost identical, resulting in about 30 days growth for the second phase.

The fact that the calculated growth rate ($b_1$) during the first phase was 0.12 for KM and 0.05 for KF, meant that this growth phase was 17 and 40 days for KM and KF, respectively. However, the growth rates calculated for KM and KF were completely reversed during the second growth phase ($b_2$). Because reversing the calculated growth rates resulted in a longer second phase for KF, being 40 days, KF attained 70% of asymptotic weight during this phase.

As seen in Table 2, the estimated age at maximum gain for males in C, was lower than that for females in both phases. Similar results were also obtained for K.

The age at maximum gain during the first phase showed differences in growth pattern between CM and CF, which indicated that females reached maximum gain at the age of 14 days, being 6 days later than males. This result is in agreement with those reported by Grossman and Koops (1988). A similar difference was also maintained for the second phase.

There was a larger difference between ages at maximum gain for males and females in the K line. While females reached maximum gain 18 days later than did males during the first growth phase, they also attained maximum gain 11 days later during the second phase.

It is possible to compare parameters of the monophasic function with those of the equivalent diphasic function. The estimated parameter a for the monophasic function is the sum of a's for the diphasic function. The sum of a's is 91.66 for CM and 109.85 for CF, 88.72 for KM and 101.92 for KF (Table 2), which were lower than corresponding values for the monophasic function (Table 1).

The parameter b for the monophasic function is approximately the reciprocal of the harmonic sum of b's for the diphasic function because b is measured as the reciprocal of days. The reciprocal of the harmonic sum of b's was 0.04 for CM and 0.037 for CF. The reciprocal of the harmonic sum of b's was 0.035 for KM and KF which were slightly lower than corresponding values for the monophasic function. Results for parameters a and b are in consistent with those reported by Koops et al. (1987).

Parameter c for the monophasic function is approximately the weighted average of c's for the diphasic function, weighted by corresponding values of parameter a. The weighted average c is 26.07 for CM and 28.30 for CF. The weighted average c is 31.41 for KM and 31.52 for KF. The values estimated from the diphasic function are almost identical to corresponding values for the monophasic function for males of both lines. These estimated values were, however, lower than the corresponding values from the monophasic function for females.

The following conclusions can be drawn from the results obtained in this study:

i) The monophasic function provided almost the same growth rate for both sexes in both lines. However, the growth rates calculated by means of the diphasic function differed between sexes for both lines, except for those calculated for C for the second phase.

ii) While there were 2-3 days differences in age at maximum gain between sexes in both lines for monophasic functions, the differences between the ages at maximum gain between sexes in both lines increased according to the diphasic functions. There were 5 and 7 days difference between sexes in the age at maximum gain in line C for the first and second phases, respectively. Differences of 18 and 11 days between sexes in the age at maximum gain in line K for the first and second phases respectively, were observed.

iii) Any differences between sexes in parameters b and c that might occur in the first and second phases of growth would be overlooked when using a monophasic function.

iv) The use of diphasic functions provides more detailed information on growth pattern. For example, the half asymptotic weight attained in KF during the first growth phase (71.13 g) was found to be heavier than that for CF (37.04 g) depending upon the growth rate calculated and the duration of phase for K. However, the calculated half asymptotic weight reversed between sexes during the second phase according to the obtained growth rates. This information would not be available using monophasic functions.

It is clear that using a multiphasic function to describe growth pattern in quail provides a greater insight for understanding the biology of growth. Consequently, the growth curves fitted by means of multiphasic functions to each growth phase taking place through the whole growth period make it possible to examine changes in parameters for each growth phase depending on sex, breeding system and the selection criteria to be applied.

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