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A mathematical model for the feed utilization of Japanese quail

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ABSTRACT

A general mathematical description of the feed utilization was aimed in this study. Three different plumage colour lines of Japanese quail were raised to collect their growth and feed consumption data at three-day intervals up to 48 days of age.

The model equation is in the linear fashion with two parameters, which of both have biological meanings. The regression coefficient is the measure of the net feed need to produce one unit live quail weight while the intercept coefficient is the measure of the net feed need just for supporting the daily activities of quail. The regression coefficient values have ranged from 0.7430 to 1.1327 g feed/g liveweight gain. The regression coefficient for brown quail differs from the one for wild quail. The intercept coefficient has ranged from 0.1238 to 0.1342 g feed/g quail weight/day. The proposed linear model can be used together with the growth model to perform the computer simulation of quail raising for developing economic farming practices.

KEY WORDS*:* poultry, quail, feed conversion, animal modelling

INTRODUCTION

The Japanese quail, *Coturnix coturnix japonica*, is a migratory, gallineous, ground dwelling game bird native to east Asia and Japan. Japanese quail is an interesting domesticated economic species for commercial egg and meat production besides chicken because it has fast growth, early sexual maturity, high rate of egg production, short generation interval and short incubation period (Ernst, 2000). Nutrition is one of the most important factors required to maintain quails

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in good physical condition and to obtain normal growth and egg production (Shim and Vohra, 1984). The selection of the quail genotypes with high growth rate, high final body weight together with less feed consumption has been studied by Marks (1978, 1991), Anthony et al. (1996) and Hyánková et al. (1997, 2001). These studies provided more general measures such as feed conversion ratio (total feed consumption/total weight gain) between two consecutive sampling points or between the beginning and the end of growth experiments. They reported the decrease of feed conversion ratio over time and the change of feed conversion ratio among the lines. These results are not in the form of a mathematical equation describing the feed utilization of quails, which can be used for the computer simulation of quail farming/raising. The objective of this study was to develop a general mathematical equation having biologically meaningful and distinct parameters for describing the feed consumption data of three plumage colour lines of Japanese quails.

MATERIAL AND METHODS

The growth experiments were conducted at the Gaziosmanpasa University Quail Breeding Unit. Three plumage colour lines of Japanese quail were used. One of the lines was wild-type European-originated. The other two lines are the extended brown and dotted-white mutant quails generated from the hatching collected from commercial hatcheries and the Quail Breeding Unit. The dotted white quail shows white plumage with a small coloured spot on the head and/or back and an autosomal recessive gene controls this plumage colour (Tsudzuki et al., 1992). Extended brown is incompletely dominant to wild-type. Homozygous brown individuals have uniformly dark brown plumage with a small area of white feathers around the beak. The lines hereafter are referred as wild, white and brown. Before the study was started, the lines were maintained as folks constituted 60 females and 20 males and reared at this unit for 12 generations without selection for any productive traits but taking special care to avoid inbreeding.

All birds used in this study were hatched at the same day. When the chickens hatched (day 0) they were weighted, labelled with wing-rings and placed in the quail battery brooders by line at a stocking density of 70 cm^2/chick. At 6 days of age quails randomly divided into 8 replicates by line (10 quails per replicate) and stocking density raised to 250 cm^2/bird. Thereafter, feed consumption of the groups was recorded. Because of the difficulties of sex determination in chickens especially within colour types, groups were also formed randomly according to the sex. All birds and the feed available to the groups were weighted at 3-day intervals up to 48 days of age with a 0.01 g sensitivity electronic balance. The adjustments of temperature, lighting regime and feeding were applied as common practice in the industry. The temperature started at 36°C and every week temperature were decreased 3°C and fixed at 24°C after four weeks of age. Birds were housed for the first three weeks at 24 h lighting, following weeks at 16:8 light:dark cycle. Birds were allowed to *ad libitum* access to feed and water. They were fed with 24% crude protein (CP) and 3200 kcal ME/kg starter diet for 21 days, 19% CP and 3000 kcal ME/kg grower diet between 21 and 35 days of age and thereafter 17% CP and 2750 kcal ME/kg breeder diet.

Model development

The mathematical models for the feed consumption of animals range from simple allometric equations (Nagy, 1987) to a set of equations describing simultaneously various metabolic activities (Emmans, 1997). The complexity of any biological model increases the amount of experimental and/or theoretical work that should be performed to calibrate the model parameters. On the other hand, pure curve-fitting does not shed any light on the mechanism of biological processes (France and Thornley, 1984; Haefner, 1996). Therefore, complex models can be preferred to enhance the fundamental knowledge about the biological process while curve-fitted equations can be preferred to summarize the extensive experimental data and to perform optimization studies. The mathematical model developed for the feed consumption of both cell cultures (Doran, 1999) and animals (Woodward, 1998) was modified to describe the feed consumption rate of quails. The mathematical equation is as follows:

$$SFCR = \frac{SGR}{Y_F} + \frac{SPFR}{Y_P} + m_F \qquad (1)$$

where SFCR is the specific feed consumption rate (g feed consumption/g quail weight/day); SGR is the specific growth rate (1/day);Y_F is the real weight yield coefficient (g quail weight gain/g feed consumption); SPFR Y_P is the specific product formation rate (g product formation/g quail weight/day); is the product yield coefficient (g product formation/g feed consumption); and m_F is the maintenance coefficient (g feed consumption/g quail weight/day).

In this study, the term for production formation in equation 1 was omitted since the growth period considered in this study covered the pre-laying period. Then, equation one was rewritten as follows:

$$SFCR = \frac{SGR}{Y_F} + m_F \qquad (2)$$

Parameter estimation

The growth and feed consumption data were numerically differentiated to get the growth rates and feed consumption rates over time (Mathews, 1992). The values of SFCR were linearly related to the values of SGR to estimate the intercept and the slope of equation 2. As shown in equation 2, its intercept is equal to maintenance coefficient while its slope is equal to the inverse of weight yield coefficient. The curve fitting process including the estimation of parameters, the analysis of variance for the linear model and t-tests for the significance of model parameters was performed by using SigmaPlot software (SigmaPlot, 1995). In addition, the parameters of linear equations for the quail lines were compared with each other as described in the literature (Zar, 1996).

RESULTS AND DISCUSSION

The mean liveweight changes over time of three plumage colour quail lines are presented in Figure 1 while their cumulative feed consumption data are presented in Figure 2. Liveweight shows initially rapid increase and slow increase later in time. However, cumulative feed consumption constantly increases in time.

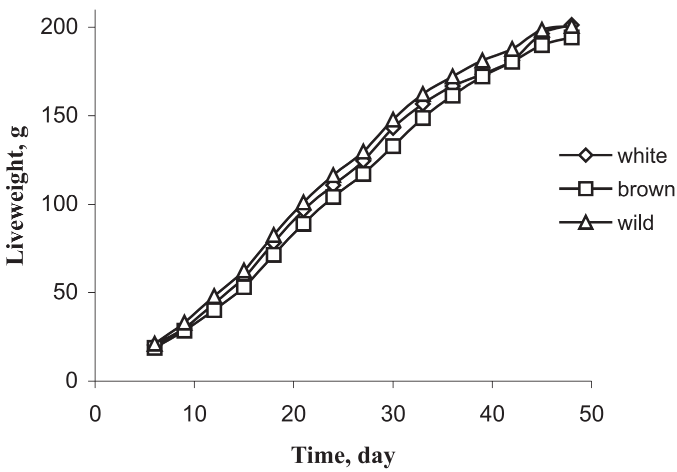

Figure 1. Mean growth data of three plumage colour quail lines over time

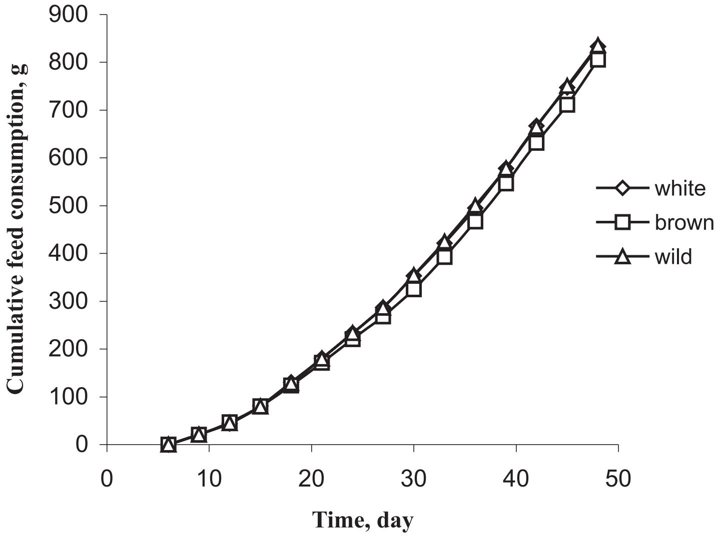

Figure 2. Feed consumption data of three plumage colour quail lines over time

This result indicates the existence of a complex relationship between feed consumption and liveweight change. Therefore, simple feed conversion ratio used in the literature are not sufficient for the thorough mathematical description of the feed utilization of the quail lines. For this reason, the relationship between specific feed consumption rate (SFCR) and specific growth rate (SGR) were investigated to develop a simpler and more meaningful correlation between growth and feed consumption. The plots of SFCR over SGR for white, brown and wild quail lines were given in Figures 3, 4 and 5, respectively.

The linear equation for white quail fitted to the experimental data is as follows:

$$SFCR = 0.1325+0.9155 \times SGR \quad (R^2 = 0.930 \text{ and P-value} < 0.0001) \qquad (3)$$

The model predictions stay within the experimental data as shown in Figure 3.

The linear equation for brown quail line is as follows:

$$SFCR + 0.1238 + 1.1327 \times SGR \quad (R^2 = 0.824 \text{ and P-value} < 0.00001) \qquad (4)$$

The model predictions do not show consistent deviations from the experimental data as shown in Figure 4. The linear equation for wild quail line is as follows:

$$SFCR + 0.1342 + 0.743 \times SGR \quad (R^2 = 0.780 \text{ and P-value} < 0.00001) \qquad (5)$$

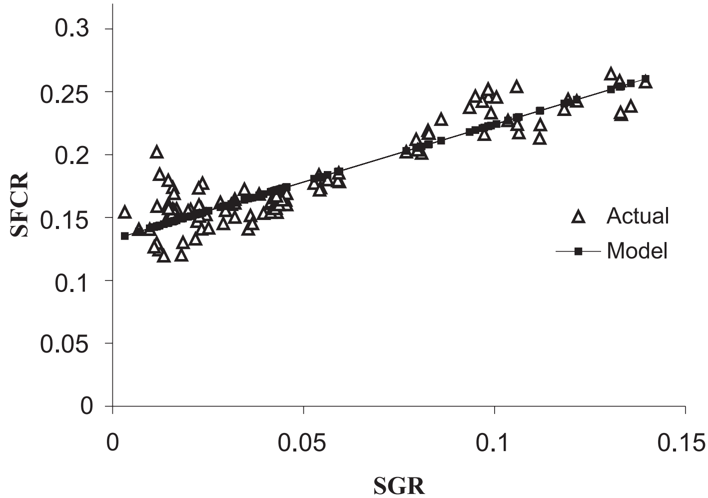

Figure 3. Plot of specific product formulation rate (SCFR) over specific growth rate (SGR) for white quail line

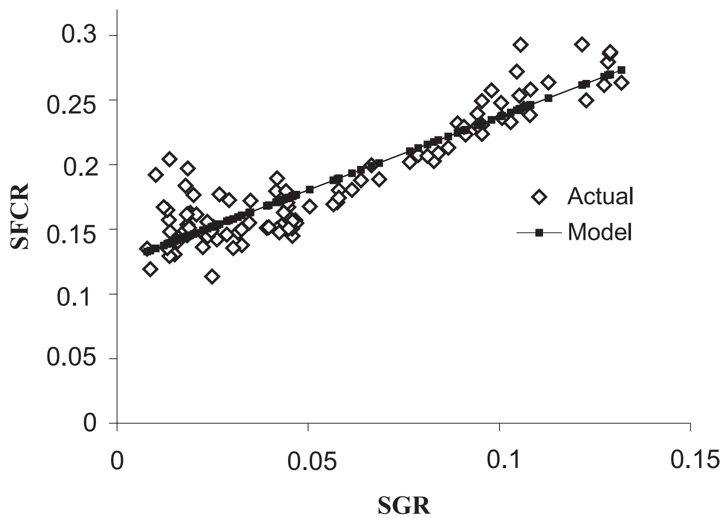

Figure 4. Plot of specific product formulation rate (SCFR) over specific growth rate (SGR) for brown quail line

The last equation has the lowest coefficient of determination value (R^2=0.780), but its predictions do not show consistent deviation from the experimental data, either as shown in Figure 5.

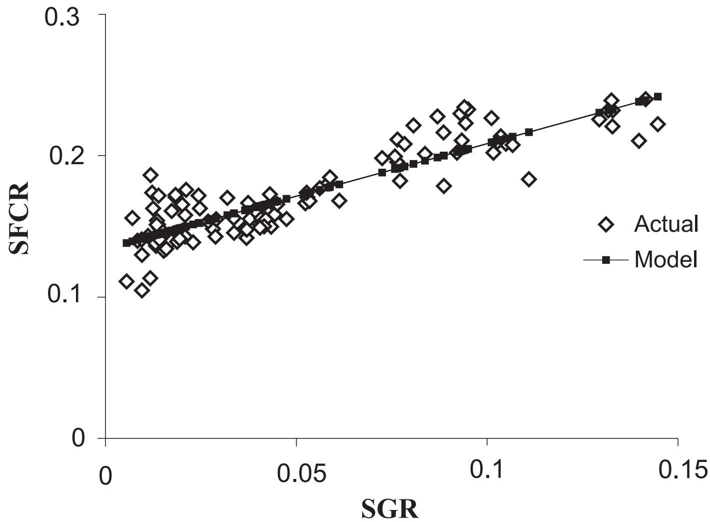

Figure 5. Plot of specific product formulation rate (SCFR) over specific growth rate (SGR) for wild quail line

The model separates the feed consumption into two main metabolic activities: liveweight gain and daily maintenance. This approach explained 78 (for wild) to 83% (for white) of variation in specific feed consumption rate. The unexplained part of the variation can be minimized by accounting the egg production in the models to consider some unexpected early laid-eggs and/or by using unique model parameter values for each bird diets used during the growth experiments.

Two different statistical analyses were performed over the model parameters. The first statistical test has shown that the slope and intercepts values of all three equations differ from zero (Table 1.) All model parameters differ from zero ($P<0.01$). Therefore, the omission of any model parameter reduces the prediction accuracy of a future computer simulation.

The second statistical test was to compare the parameter values with each other (Table 2). The only slopes of equations 4 and 5 differ from each other ($P<0.05$). The slope of equation 3 does not differ from the slopes of equations 4 and 5 ($P>0.05$). The intercepts of these three equations do not differ from each other ($P>0.05$). The weight yield coefficients calculated are 1.092, 0.883 and 1.346 g quail weight gain/g feed consumption, respectively for white, brown and wild lines. The weight yield coefficients can be used to select the quail lines, which are

TABLE 1

The results of curve fitting process

Parameter		Quail		
		white	brown	wild
Intercept	Value	0.1325**	0.1238**	0.1342**
	Standard error	0.0027	0.0034	0.0025
Slope	Value	0.9155**	1.1327**	0.7430**
	Standard error	0.0412	0.0519	0.0391

** superscripts indicates that parameter values differs from zero at P<0.01

efficient meat producers for commercial practices. For instance, the brown quails converted feed to body weight less efficiently than the wild quails. The comparisons of model parameters revealed that the brown quails should consume 52.4% more feed than the wild quails to gain 1 g liveweight.

TABLE 2

The results of the statistical comparison of model parameters ($t_{0.05/2,204}=1.972$)

Parameter		Quail		
		white-brown	white-wild	brown-wild
Intercept	Difference (a_1-a_2)	0.0087NS	0.0017NS	0.0104NS
	Standard error (S_{a1-a2})	0.0136	0.0144	0.0139
Slope	Difference (b_1-b_2)	0.2172NS	0.1725NS	0.3897*
	Standard error (S_{b1-b2})	0.1620	0.1740	0.1670

superscript NS indicates that difference is statistically non-significant
* superscript indicates that difference is statistically significant at P<0.05

The quails also need 0.1238 to 0.1342 g feed per their liveweight per day to sustain their life as symbolized by maintenance coefficients. The maintenance need of quails did not vary among the lines. The quails must be supplied with feed more than maintenance coefficients to increase their liveweight. On the contrary, if the quails consume less feed than the amount equal to the multiplication of maintenance coefficients by their liveweights, they can be said under the condition of feed starvation. This situation may cause weight loss and stress in quails. Therefore, the maintenance coefficients can guide the development of feeding management.

The models developed in this study can also be used to explain the results reported in the previous literature (Hyánkova et al., 1997, 2001). It was reported that the feed conversion ratios decreased as growth went into retardation. During the early phase of the growth, the quails utilize the big portion of feed consumption to weight gain as associated with higher specific growth rates. During the late phase of the growth, the quails have very low specific growth rates, which reduce the portion of feed consumption to weight gain while the heavier quail weights increase the maintenance need of quails to sustain their life. Heavier quail weight need more feed for managing daily routines of the life under reduced growth conditions like the late phase of growth. All these changes can be easily followed by the model because of its comprehensive formulation.

The computer simulation of feed consumption can be done to manage optimally quail meat production by using the model suggested in this study. However, the specific growth production rates over time are needed to run the simulation. These values can be obtained by using the growth models previously developed for following the quail growth (Hyánková et al., 1997, 2001; Aggrey, 2003). Furthermore, it is expected that this model study on quails may be considered as preliminary for the studies on the other farm animals (for example, chickens) that has long reproductive cycle since common results may apply to them.

CONCLUSIONS

The model is in a linear fashion and has two biologically meaningful parameters (the inverse of true weight yield coefficient and maintenance coefficient). The proposed linear model can be used together with the growth model to perform the computer simulation for quail selection and the development of good feeding management. It may also be adapted to the other farm animals.

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STRESZCZENIE

Model matematyczny wykorzystania paszy przez przepiórki japońskie

Celem pracy była konstrukcja modelu matematycznego opisującego wykorzystanie paszy przez przepiórki japońskie. Badania przeprowadzono na trzech odmianach barwnych przepiórki japońskiej, zbierając dane dotyczące ich wzrostu i zużycia paszy. Pomiarów cech dokonywano w trzydniowych przedziałach czasowych do 48 dnia życia.

Równanie modelu jest funkcją liniową z dwoma parametrami o znaczeniu biologicznym, współczynnik regresji jest miarą zużycia paszy netto na jednostkę przyrostu masy ciała, punkt przecięcia jest natomiast miarą ilości paszy potrzebnej do zaspokojenia potrzeb bytowych. Wartości współczynników regresji mieściły się w przedziale od 0,7430 do 1,1327 g paszy/g przyrostu masy ciała. Wartość współczynnika regresji dla przepiórek brązowych różniła się od odpowiedniej wartości dla odmiany dzikiej. Wartości punktu przecięcia mieściły się w przedziale od 0,1238 do 0,1342 g paszy/g masy ciała przepiórki/dzień.

Zaproponowany model liniowy może być wykorzystany w połączeniu z modelem wzrostu do komputerowej symulacji odchowu przepiórek w warunkach produkcyjnych.