

# AGE-SPECIFIC CHANGES IN THE MAJOR BODY COMPONENTS AND CALORIC VALUE OF GROWING JAPANESE QUAIL

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BIOENERGETIC studies of birds have often been hampered by a lack of accurate caloric conversion factors for the live-weight biomass of the species being studied. This has been particularly true in studies of the energy-conversion efficiencies of growing nestlings, whose biomass may show significant changes in caloric value with increasing age (Ricklefs 1967a, Brisbin 1969). It is also possible that the pattern of such age-specific changes might differ between species showing altricial and precocial growth patterns. Although several altricial species have been studied in this regard (Brenner 1964, Ricklefs 1967a, Brisbin 1969, Myrcha and Pinowski 1970), very few comparable data are available for the more economically important precocial species, especially those within the order Galliformes.

Biomass analyses of gallinaceous birds are often complicated by the fact that these species usually have large body sizes, requiring extensive homogenization and subsampling to estimate accurately their composition and caloric value (Brisbin 1968). A combination of small body size and rapid attainment of adult weight makes the Japanese Quail (*Coturnix coturnix japonica*) an ideal subject for studying growth-related changes in the major body components and caloric values of a precocial gallinaceous species.

To make the results of this study directly comparable with those of other species, changes in biomass composition and caloric density are expressed as functions of increasing age. Age, in turn, is expressed as percent of the total growing period. Although the Japanese Quail has been the subject of numerous growth analyses (Ernst and Coleman 1964, Collins and Abplanalp 1968, Marks and Lepore 1968, Woodard et al. 1969), none of these studies provides data that will allow the accurate calculation of the time required for this species to attain asymptotic weight under the conditions of this study. Therefore we used a refinement of the procedure described by Ricklefs (1967b) to analyze the growth of the birds.

## MATERIAL AND METHODS

Birds used in this study were obtained from a commercial dealer who raised Japanese Quail primarily for egg-laying and the pet trade. This was done to minimize the possibility of using birds derived from a strain that had recently been subjected to selection pressures for particular growth characteristics such as

described by Collins and Abplanalp (1968), Marks and Lepore (1968), Collins et al. (1970), or Lepore and Marks (1971). The nutritional regime under which this strain of birds developed probably closely approximated that of the random-bred (control) line of Japanese Quail developed and described by Marks and Lepore (1968) and Lepore and Marks (1971). No attempt was made to evaluate sex differences in either growth characteristics or biomass changes.

Quail were obtained at the age of 1 day and raised in battery brooders through an age of 10 weeks. Brooder floor space averaged 10 birds per square foot throughout the growing period. Ernst and Coleman (1964) found that growth is not significantly affected in this species at bird concentrations as high as 20 birds per square foot. A commercial game bird starter containing a minimum of 30.0% crude protein, a minimum of 2.5% crude fat and a maximum of 6.5% crude fiber was provided *ad libitum* throughout the study. This feed was supplemented by the manufacturer with various amounts of required vitamins, minerals, and sulfaquinoxaline (0.0175%). Howes (1965) found no weight differences between groups of Japanese Quail fed diets containing between 18–36% protein.

Six groups of 10 birds each were used in the growth analysis. Data were recorded as the average weight per bird for each of the six groups. The method of Ricklefs (1967b) was used to obtain initial estimates of the growth constants describing three sigmoid growth models as follows:

$$(1) \text{ Logistic model: } y = A / (1 + e^{-k(x-T_1)})$$

$$(2) \text{ Gompertz model: } y = Ae^{-e^{-k(x-T_1)}}$$

$$(3) \text{ von Bertalanffy model: } y = A [1 - 1/3e^{-k(x-T_1)}]^3$$

where:  $y$  equals the weight at age  $x$ ;  $k$  represents a constant proportional to the overall growth rate;  $T_1$  represents the age at which the curve attains the point of inflection,  $A$  equals the asymptotic weight of the growth curve, and  $e$  equals the base of natural logarithms. Details of the characteristics of these three models are given by Ricklefs (1967b). Briefly, both the Gompertz and von Bertalanffy models respectively describe progressively longer and more gradual approaches to upper asymptotic weight, as compared to the logistic model. Initial estimates for the growth constants  $A$ ,  $k$ , and  $T_1$ , as obtained by Ricklefs' method, were then further refined by generalized computer programs making least-squares fits to the three growth models described above. Total growing periods were considered to be the age at which 99% of the asymptotic weight was attained.

A total of 44 birds were sacrificed for whole-body biomass analyses as follows: 10 at the age of 1 day, 10 at 9 days, and 6 each at the ages of 17, 27, 41, and 60 days. Determinations were made for total body water, fat, lean dry weight, and lean dry caloric density, following the procedure of Rogers and Odum (1964) and as later modified by Child (1969). Using the procedure of Brisbin (1968), larger birds were homogenized and subsampled before processing. Briefly this processing consisted of drying biomass samples to constant weight in a vacuum oven at 40°C and extracting lipids with 95% ethanol in a blender, followed by subsequent extractions in boiling petroleum ether. Remaining lean dry residues were then ground in a mill and 0.5–1.0 g random aliquots were burned in an adiabatic oxygen bomb calorimeter, using techniques described by Odum et al. (1965). Live-weight caloric values were calculated by using these caloric values for the lean dry biomass and assuming 9.00 kcal/g extracted fat (Odum et al. 1965, Barrett 1969). Caloric determinations were made for five randomly-selected individuals from the day-old birds and for four individuals from all other age groups.

TABLE 1  
GROWTH CONSTANTS FOR LEAST-SQUARES FITS TO THREE SIGMOID GROWTH MODELS  
FOR JAPANESE QUAIL<sup>1</sup>

	Logistic model	Gompertz model	von Bertalanffy model
Asymptotic weight (grams)	132.7 (2.7) ( $t = 7.88^{**}$ )	148.6 (4.6) ( $t = 7.17^{**}$ )	161.7 (6.4)
Growth-rate constant ( $k$ ) <sup>2</sup>	0.115 (0.005)	0.0665 (0.004)	0.0501 (0.004)
Age at point of inflection (days)	21.0 (0.60) ( $t = 45.3^{**}$ )	17.3 (0.68) ( $t = 51.6^{**}$ )	15.1 (0.70)
Age at which asymptotic weight is attained (days) <sup>3</sup>	61.3 (2.3) ( $t = -11.6^{**}$ )	87.7 (4.6) ( $t = -9.77^{**}$ )	111.8 (7.0)
Correlation coefficient ( $r$ )	0.980 (0.0186) ( $t = 1.19$ )	0.979 (0.0199) ( $t = 1.30$ )	0.978 (0.0199)
Root-mean-square deviation (RMSD)	1.69 (0.070) ( $t = 4.13^{**}$ )	1.99 (0.034) ( $t = 5.08^{**}$ )	2.37 (0.077)

<sup>1</sup> Figures represent the means and standard errors (in parentheses) of six replicate groups of 10 birds each. Single and double asterisks represent means that are significantly different at the 0.05 and 0.01 probability levels, respectively, as determined by  $t$ -tests for paired observations.

<sup>2</sup> Growth-rate constants are not directly comparable between models, and therefore no  $t$ -test comparisons have been made.

<sup>3</sup> Calculated by solving the appropriate growth equation for the age at which 99% of asymptotic weights is attained.

Considering age to be the treatment variable, one-way analyses of variance and Duncan's multiple-range tests (Steel and Torrie 1960) were conducted for fat indices (g fat/g lean dry weight), water indices (g water/g lean dry weight), and lean dry and live-weight caloric values. Bartlett's test (Freese 1967) was used to test for homogeneity of variance for each parameter showing a significant  $F$  ratio. A test for lack of fit (Ostle 1966) was conducted to determine the adequacy of a linear model for describing changes in each parameter showing significant changes with age.

## RESULTS

Table 1 presents the results of the growth analyses. The average correlation coefficients for the logistic, Gompertz, and von Bertalanffy sigmoid models showed no significant differences. Thus these values could not be used to determine which model best approximated the quails' growth, even though there were frequently highly significant differences ( $P \leq 0.01$ ) between the average values of the growth parameters (Table 1). There were, however, highly significant differences between the average root-mean-square deviations of the three models. These values were therefore used to evaluate the fit to each model and they

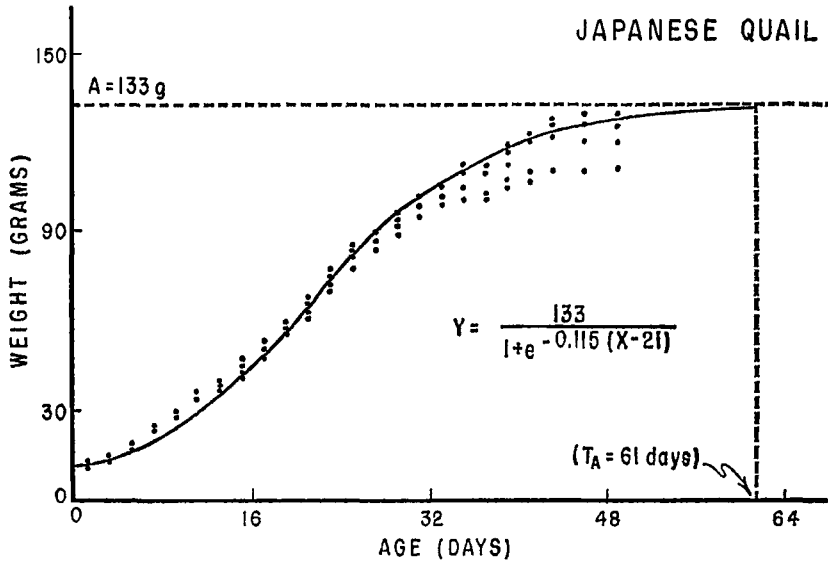


Figure 1. Growth curve of laboratory-raised Japanese Quail. Data are fitted to a logistic sigmoid model defined by average values for the growth constants presented in Table 1. Each point represents the average weight of a group of 10 birds. Points occurring close enough together to be indistinguishable are drawn as a single point, thus often serving to weight the mean value at a given age away from what might appear to be the arithmetical mean of the points plotted.  $A$  = average asymptotic weight, and  $T_A$  = average age at which asymptotic weight is attained.

indicated that the growth of the quail was best approximated by the logistic model (Table 1 and Figure 1). As explained by Ricklefs (1967b), direct statistical comparisons could not be made between the growth-rate constants ( $k$ ) of the different sigmoid models. The average amount of time required to attain 99% of asymptotic weight was 61 days, and ages were converted to percent of the total growth period on the basis of this value.

Figure 2 shows the results of the biomass analyses. Bartlett's test indicated a homogeneity of variance between age groups for water index and lean dry and live-weight caloric values. The failure of fat indices to show homogeneity of variance ( $X^2 = 27.77$ ;  $df = 5$ ;  $P \leq 0.01$ ) required the application of a square root transformation, which was performed by taking the square root of each individual fat index value, and all further analyses of fat indices were based upon such transformed data. One-way analyses of variance indicated a highly significant effect of age upon fat index ( $F = 35.68$ ;  $df = 5,38$ ;  $P \leq 0.01$ ), water index ( $F = 7.68$ ;

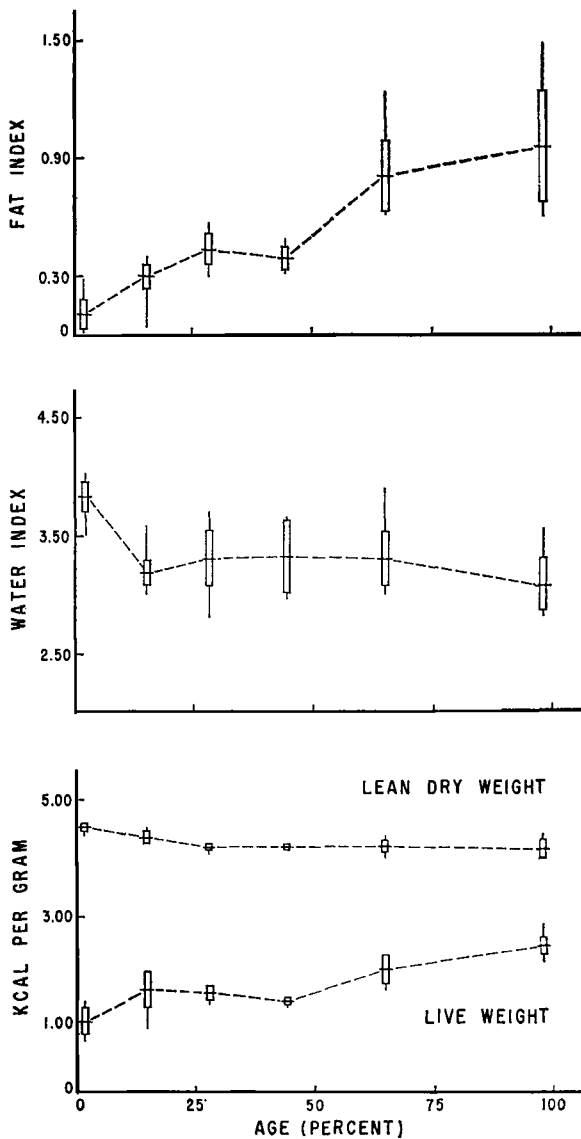


Figure 2. Changes in fat indices (g fat/g lean dry weight), water indices (g water/g lean dry weight), and lean dry and live-weight caloric values of growing Japanese Quail. Age is expressed in terms of percent of a total growth period of 61 days (Figure 1). Horizontal lines represent means, rectangles represent  $\pm$  two standard errors of the mean, and vertical lines represent the range. Sample sizes for fat and water indices were 10 birds each at 1.6 and 14.8% and 6 birds each at all other ages. Sample sizes for caloric values were 5 birds at 1.6%, and 4 birds each at all other ages.

TABLE 2  
RESULTS OF DUNCAN'S MULTIPLE-RANGE TESTS APPLIED TO DATA FOR FAT INDICES,  
WATER INDICES, AND LEAN DRY AND LIVE-WEIGHT CALORIC VALUES OF GROWING  
JAPANESE QUAIL<sup>1</sup>

Fat index: <sup>2</sup>						
Age: <sup>3</sup>	1.6	14.8	44.3	27.9	67.2	98.4
Water index:						
Age: <sup>3</sup>	1.6	44.3	27.9	67.2	14.8	98.4
Lean dry caloric value:						
Age: <sup>3</sup>	1.6	14.8	27.9	67.2	44.3	98.4
Live-weight caloric value:						
Age: <sup>3</sup>	1.6	44.3	27.9	14.8	67.2	98.4

<sup>1</sup> Age-groups underscored by the same line are not significantly different at the 0.05 level of probability.

<sup>2</sup> Analysis of data for fat index is based on a square-root transformation.

<sup>3</sup> Ages are expressed in terms of percent of the total growing period (61 days, as calculated by the logistic model), and are ordered from left to right with respect to increasing fat index and live-weight caloric value and decreasing water index and lean dry caloric value.

df = 5,38;  $P \leq 0.01$ ), lean dry caloric value ( $F = 9.93$ ; df = 5,19;  $P \leq 0.01$ ), and live-weight caloric value ( $F = 16.95$ ; df = 5,19;  $P \leq 0.01$ ). Tests for lack of fit indicated that only the changes in live-weight caloric value were satisfactorily approximated by a linear model ( $F = 1.40$ ; df = 4,19;  $P > 0.05$ ). Age-related changes in live-weight caloric value were described by the regression equation:  $y = 1.24 + 0.013x$  ( $r = 0.87$ ), where  $y = \text{kcal/g live weight}$ , and  $x = \text{age, expressed as percent of the total growth period of 61 days}$ . Duncan's multiple-range tests (Table 2) indicated a tendency for fat indices to plateau between 14.8 and 44.3% and again between 67.2 and 98.4% of the growth period. Significant increases occurred between these two levels and prior to 14.8%. Significant decreases in water indices and lean dry caloric values occurred only in the younger birds. After 27.9% of the growth period was attained, no further changes occurred in either of these parameters. Live-weight caloric value, like fat index, tended to plateau between 14.8 and 44.3%, suggesting a close relationship between the two.

## DISCUSSION

Growth analyses indicate that serious errors in the estimation of growth constants may result from the uncritical use of a single sigmoid model. In the Japanese Quail, for example, the uncritical use of a von Bertalanffy model would have overestimated the age at which asymptotic weight was attained by nearly twofold. Significant errors would also have occurred in the estimation of other growth constants (Table 1), despite

correlation coefficients that averaged 0.979 and indicated highly significant correlations ( $P \leq 0.01$ ) for all groups. Computer programs making least-squares fits to these sigmoid models have allowed more objective and statistically reliable selections of the most appropriate model than the graphical hand-fit method of Ricklefs (1967b). Ricklefs's graphical fits were successful in identifying the logistic model as being most appropriate for the Japanese Quail, and gave initial growth-constant estimates of:  $A = 134$  g,  $k = 0.116$ ,  $T_I = 20$  days, and  $T_A = 60$  days. Ricklefs's method has proved highly successful in providing the initial estimates of these constants required to program least-squares fits. Possibly the growth of Japanese Quail and other birds might show even better conformation to some sigmoid model other than one of the three presented here.

Using graphical hand-fits, Ricklefs (1968) analyzed the growth of Harlequin Quail (*Cyrtonyx montezumae*) and California Quail (*Lophortyx californicus*). Like the Japanese Quail, the growth of the Harlequin Quail was best described by a logistic model, although the Harlequin's growth-rate constant (0.080) was much lower than that found in the present study, and it attained a larger asymptotic weight. The growth of the California Quail was best described by a Gompertz model, as was that of larger and more slowly-growing gallinaceous species such as the Ruffed Grouse (*Bonasa umbellus*) (Ricklefs 1968) and Sharp-tailed Grouse (*Pedioecetes phasianellus*) (McEwen et al. 1969), although in the latter case no other sigmoid model was evaluated. Roseberry and Klimstra (1971) report that Bobwhite Quail (*Colinus virginianus*) attain an asymptotic weight of 180 g in about 200 days, although no sigmoid model was described. Lyon (1962) indicated that the growths of Japanese and Bobwhite Quail are similar through an age of 35 days, at which point the growth rate of the former begins to decrease and approach an asymptotic level close to that reported in the present study. Lyon (1962) reported that the Japanese Quail reached this asymptotic weight at about 8 weeks of age, agreeing closely with the value of 61 days calculated here (Figure 1). Apparently the logistic growth curve of the Japanese Quail results in one of the most rapid attainments of asymptotic weight reported for any gallinaceous species. Possibly such rapid growth is related to the birds' relatively small body size, as shown by Taylor (1968).

Woodard and Abplanalp (1971) showed that long-term gradual increases may be expected in the adult weights of male Japanese Quail, while long-term decreases may be expected in the weights of females as they approach senility and the ovaries regress in size. Data presented by these authors indicate that an asymptotic weight of 133 g is probably

less than the average long-term adult weight of the species under captivity conditions. Weight increases above asymptotic weight could result from, among other things, captive-obesity induced under conditions of stimulatory lighting (Woodard and Abplanalp 1971). Ricklefs (1968) has shown that the ratios of asymptotic to adult weight in wild California and Harlequin Quail are 1.01 and 1.00, respectively. Varying regimes of genetic selection (Marks and Lepore 1968, Collins et al. 1970), manipulation of various environmental conditions (Woodard et al. 1969), or varying states of nutrition (Weber and Reid 1967) could drastically alter both the magnitude and rate, as well as possibly the form of the growth curve in this species.

In general, age-specific changes in the major body components and caloric values of the precocial Japanese Quail are similar to those reported for growing altricial nestlings of several species, taking into consideration that precocial birds hatch at a more advanced stage of physiological development. Thus the changes the quail showed throughout their entire post-hatching growth period are similar to those the altricial species showed during the latter stages of their post-hatching growth. The decrease in water indices of the quail, for example, shows a pattern that could be considered as the latter portion of an exponential decrease similar to that shown by several altricial birds (Ricklefs 1967a, Brisbin 1969) and mammals (Brisbin 1970). The higher water indices of the very young altricial individuals are presumably passed in the egg prior to hatching by the precocial embryos. Water indices of 2.5 to 3.0 seem to be typical of most all species of birds as they approach asymptotic weight, regardless of the growth pattern exhibited.

As in the present study, Lepore and Marks (1971) showed that both water and fat, expressed as percent of live body weight, showed significant changes with age in growing Japanese Quail. They further found that selection under differing nutritional environments could alter the percent fat in the quail. Expressed in terms of percent live body weight, the newly-hatched quail analyzed in this study contained 77.2% water, which is lower than a comparable value of 85.2% reported by Medway (1958) for week-old White Leghorn chickens. This value is, however, nearly identical to that of 76% water reported by Lepore and Marks (1971) for newly hatched quail from their random-bred control line. The body-water content of grown Japanese Quail (61.4% as calculated in this study, 65.0% as calculated by Lepore and Marks (1971) is greater than the 55.0% body water reported for leghorns that had nearly completed their growth period (Medway 1958).

Marcstrom (1966) showed that high fat levels in newly-hatched precocial ducklings serve both as stored food reserves and as a means of



thermal insulation. Although the fat indices of growing altricial species frequently fail to show well-defined trends over the entire growing period, several of these species often show increases of fat indices during the latter portion of their growth period (Ricklefs 1967a, Brisbin 1969, 1970). The precocial quail showed this same tendency throughout their entire growth period, again emphasizing the similarities of the patterns in the altricial and precocial forms. The older quail attained much higher fat indices than those reported for the altricial species as they approached asymptotic weight, but in no case did the quail fat indices approach the magnitude of those shown by migrant passerines, whose indices may range as high as 2.5 to 3.0 (Odum et al. 1965).

Lepore and Marks (1971) found that the body fat of their growing random-bred Japanese Quail, expressed as percent of live body weight, doubled (from about 5 to 10 percent) from hatching to 8 weeks of age. Comparably aged birds analyzed in the present study increased their fat content from 2.62 to 19.01% of live body weight in the same period.

Expressed as percent of dry body weight, the fat content of the Japanese Quail ranged from 11.5 to 28.1 and 49.2% for birds at 1.6, 44.2 and 98.4% of their growth periods, respectively. These are larger than most comparable values reported by Robel (1969) for wild adult Bobwhite Quail whose fat contents averaged between 10 and 15 with a maximum of 28% of dry body weight. The fat indices of Japanese Quail at all ages were higher than those West and Meng (1968) reported for adult Willow Ptarmigan (*Lagopus lagopus*), whose indices ranged seasonally between 0.06 and 0.16. The higher fat content of the Japanese Quail could be a species characteristic or an artifact of captive-rearing. Caldwell and Connell (1968) reported that laboratory-raised *Peromyscus polionotus* had fat indices twice as large as those of wild-caught individuals. The results of the biomass analyses reported here may not, therefore, be directly applicable to free-living wild birds, even of the same species.

The relationship between the increase of the quail's fat indices and live-weight caloric values is probably due to the high caloric value of fat and the tendencies of water content and lean dry caloric value to remain relatively constant throughout most of the growing period. In this respect, the changes in the quails' live-weight caloric values are unlike those reported by Gorecki (1965), Myrcha (1968), and Myrcha and Pinowski (1970) who found that the caloric values of tissues of several species of birds and mammals depended primarily on the water content and only secondarily on the fat content.

Although both altricial and precocial species apparently increase in live-weight caloric value as they approach asymptotic weight, quail that

had attained 80% or more of their growth period showed live-weight caloric values higher than any of those summarized by Ricklefs (1967a) for adult passerines. The live-weight caloric values of quail that had attained asymptotic weight were only exceeded by those reported for adult Mourning Doves (*Zenaidura macroura*), which averaged  $2.61 \pm 0.10$  kcal/g (Brisbin 1968).

Lean dry caloric values of the growing Japanese Quail were lower than those reported for nestling Ring Doves (*Streptopelia risoria*) (Brisbin 1969) and are closer to those of adult passerines (Odum et al. 1965). Data presented here indicate that it is not always possible to assume a constant lean dry caloric value for growing birds, as suggested by earlier studies (Brisbin 1969, 1970).

Perhaps the most important aspect of this study is the format used for data presentation. Similar approaches to the biomass analyses of additional altricial and precocial species should eventually allow the construction of summary predictive models that would allow direct comparisons and accurate calculations of caloric conversion factors for both these growth patterns, regardless of the length of the growth periods involved.

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#### SUMMARY

Least-squares analyses were used to evaluate the fit of growth data of laboratory-raised Japanese Quail to logistic, Gompertz, and von Bertalanffy sigmoid models. Although differences between correlation coefficients were not significant, significant differences were demonstrated between the growth constants generated by the three models. Root-mean-square deviations indicated that quail growth was best approximated by the logistic model, with the attainment of an asymptotic weight of 133 g at an age of 61 days. This represents the most rapid attainment of asymptotic weight reported in the literature for any gallinaceous species.

Significant increases in fat index (g fat/g lean dry weight) and live-weight caloric value occurred throughout the growing period. The latter was approximated by the linear model:  $y = 1.24 + 0.013x$ , where  $y =$  kcal/g live weight, and  $x =$  age, expressed as percent of the total growth period. Significant decreases in water index and lean-dry caloric value occurred only in younger birds. After 27.9% of the total growth period had been attained, no further changes occurred in either of these parameters. Growth-related changes in the major body components and caloric values of the precocial Japanese Quail were similar to those reported for growing altricial birds and mammals, taking into consideration that a precocial bird hatches at a more advanced stage of physiological development.

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