PHYSIOLOGY AND REPRODUCTION

Effect of Early Feed Restriction on Reproductive Performance in Japanese Quail (*Coturnix coturnix japonica*)

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ABSTRACT Reproductive performance of quail (*Coturnix coturnix japonica*) was evaluated following feed restriction (100, 85, and 70% of ad libitum) between 2 to 5 wk of age with three replicates of 12, 2-wk-old chicks per replicate. Body weight, feed conversion, and leucocyte distribution were measured during feed restriction. After experimental feed treatment, BW, age at first egg, egg production, fertility, hatchability, and embryonic mortality were evaluated from five replicates of two females and one male per treatment. Feed-restricted female chicks had lower BW from 3 to 5 wk of age, but male weights were depressed only during the most severe restriction at 4 and 5 wk. No treatment differences were observed among BW within a sex from 6 to 13 wk. Body weights at first egg were significantly heavier for females fed 70% ad libitum than for birds on other treatments. Fertility, age at first egg, feed conversion, egg production, and egg weight were unaffected by feed restriction. Although hatchability was unaffected by feed restriction, percentage of late dead and total dead embryos were significantly reduced in eggs from restricted quail. Thirty quail fed 70% of ad libitum control intake had significantly increased egg specific gravity. Feed restriction increased the percentage of heterophils and basophils and the heterophil/lymphocyte ratio, whereas the percentage of lymphocytes and eosinophils decreased. Feed can be restricted to 85 or 70% of ad libitum feed intake from 2 to 5 wk of age without detrimentally affecting reproductive parameters between 6 to 13 wk of age.

(*Key words*: feed restriction, quail, fertility, hatchability, leucocyte)

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INTRODUCTION

The poultry industry has employed a number of managerial and nutritional schemes to maintain fecundity. This action is necessary because of the negative correlation between BW and reproduction (Siegel, 1980). Many different feed restriction programs have been applied to control BW: 1) mechanical or physical limitation of the quantity of feed (Crouch et al., 2002a,b), 2) high-fiber or low-energy diets (Lee, 1987; Hester and Stevens, 1990), 3) low dietary protein levels (Lee, 1987; Renema et al., 1995), 4) skip-a-day feeding (Balloun, 1974; Lee, 1987), 5) use of distasteful compounds in the feed, such as propionic acid (Pinchasov and Nir, 1993), 6) altered energy-to-protein ratios (Balloun, 1974; El Winger, 1982), and 7) diets deficient in selected essential amino acids (Scott et al., 1999). Similar techniques are also applied to prevent excessive deposition of fat because a negative correlation exists between excess body fat and egg production, fertility, and hatchability (Wilson and Harms, 1986). In addition, greater pullet BW increases the energy requirement for maintenance and fosters early onset of egg production, which yields small eggs unsuitable for incubation (Bornstein et al., 1984). To retard growth for a prolonged period, severe feed restriction is required.

Early feed restriction has been applied to control prelay characteristics in turkeys (Balloun, 1974; Cherms et al., 1976; Potter et al., 1978; Voitle and Harms, 1978; Meyer et al., 1980; Owings and Sell, 1980; Nestor et al., 1981; Ferket and Moran, 1986; Miles and Lesson, 1990), laying chickens (Combs et al., 1961; Lee, 1981), and quail (Sabine et al., 1995). Therefore, this experiment was planned to study the effect of feed restriction on fertility and other parameters of reproductive performance in Japanese quail.

MATERIALS AND METHODS

Experimental Design

One hundred eight unsexed, 2-wk-old Japanese quail chicks (*Coturnix coturnix japonica*) were obtained from the colony maintained by the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt. They were housed in quail brooding batteries with 86 × 50 × 25 cm pens from hatch until 5 wk of age. Chicks were randomly distributed

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TABLE 1. Composition of quail starter and breeder diets

Ingredient	Ration: Starter	Ration: Breeder
Item		
Maize (%)	54	62
Soybean meal, 44% CP (%)	33	22
Concentrate[1] (%)	10	10
Wheat bran (%)	3	—
Limestone (%)	—	5.7
Sodium chloride (%)	—	0.3
Calculated nutrient content		
Metabolizable energy (kcal/kg)	2,825	2,809
Crude protein (%)	24.8	20.2
Methionine (%)	0.46	0.65
Cysteine (%)	0.33	0.26
Methionine + Cysteine (%)	0.21	0.21
Crude fiber (%)	3.99	3.06
Crude fat (%)	3.02	3.15
Linoleic acid (%)	1.37	1.45
Calcium (%)	0.84	2.95
Available phosphorus (%)	0.49	0.46

[1]Protein mineral-vitamin premix provided the following per kilogram of diet: crude protein, 520 g; vitamin A, 120,000 UI; vitamin E, 100 mg; vitamin K_3, 21 mg; vitamin B_1, 10 mg; vitamin B_2, 40 mg; vitamin B_6, 15 mg; pantothenic acid, 100 mg; vitamin B_{12}, 0.1 mg; niacin, 200 mg; folic acid, 10 mg; biotin, 0.5 mg; choline chloride, 5,000 mg; Fe, 0.3 mg; Mn, 600 mg; Cu, 50 mg; Co, 2 mg; Se, 1 mg; and Zn, 450 mg.

among three feeding treatments. They received a quail starter ration (24.8% CP; 2,825 kcal/kg ME) from 2 to 5 wk of age (Table 1). Control quail received feed ad libitum, and quail assigned to restricted regimes were fed 85 or 70% of the feed consumed by control chicks fed ad libitum on the previous day. Mean feed intake for ad libitum and 15% and 30% restricted intakes were 11.3, 9.6, and 7.9 g/d during wk 3; 16.3, 13.8, and 11.4 g/d for wk 4; and 18.8, 15.9, and 13.1 g/d for wk 5, respectively. Each treatment was replicated three times with 12 birds per replicate. All treatments were allowed water ad libitum and were provided continuous lighting exposure to 5 wk of age. Individual BW were recorded weekly, mortality was recorded daily, and feed conversion was calculated for each group from 2 to 5 wk of age. At 5 wk of age, six females and six males from each treatment group were killed. Blood samples were collected to evaluate the leucocyte population distribution.

From the remaining quail, for each treatment five replicates of two females and one male were housed in individual breeding cages (21 × 20 × 27 cm) from 5 to 13 wk of age. These quail were used to study the effect of early feed restriction on subsequent reproductive performance. Quail were transferred into and subjected to a 16L:8D cycle until the end of the study. All experimental groups received a quail breeder ration (20.2% CP; 2,809 kcal/kg ME) and water ad libitum (Table 1). Individual BW were recorded weekly from 6 to 13 wk of age for both sexes. Mortality was recorded daily. Age and BW at first egg and weekly egg production were recorded from 6 to 13 wk of age. Egg specific gravity, fertility, hatchability, and embryo mortality were determined.

Measurements

Egg samples were taken during the first 3 consecutive d of each week and individually weighed to the nearest 0.01 g. Collected eggs were stored overnight in the same room before specific gravity was determined. Egg specific gravity was determined using the floating method (Harms et al., 1990), in which solutions of specific gravity (1.060 to 1.090 g/mL) were used to determine specific gravity in increments of 0.005. Eggs were stored, set, and incubated at standard conditions and transferred into hatching baskets at 14 d of incubation. Hatchability was calculated, and unhatched eggs were examined to determine the extent of embryonic mortality. Unhatched eggs were classified as infertile, early dead, late dead, or dead pipped. Both hatchability and fertility were determined weekly.

Blood Smears

At the end of the experimental feeding period, blood smears were obtained from six males and six females from each treatment. The blood smears were air dried and stained with 1 part Giemsa:20 parts distilled water for 20 min prior to fixation in ethyl alcohol for 3 min. Smears were washed in running tap water for 1 min. One hundred leucocytes were counted, and the relative proportions of lymphocytes, heterophils, eosinophils, basophils, monocytes, and the heterophil/lymphocyte ratios were determined (Gross and Siegel, 1983).

Statistical Analysis

Two-way ANOVA was used to separate the effects of sex and feeding level on BW and leukocyte population distributions. One-way ANOVA was used to determine the effect of feeding level on measures of egg production, fertility, hatchability, and embryonic mortality. All proportional data were transformed to arc sine square root before analysis. When significant treatment effects were noted, differences among treatments were separated by Duncan's new multiple-range test (Duncan, 1955). Threshold for significance was $P \leq 0.05$.

RESULTS

Body Weight and Growth Rate

Body weights of chicks assigned to the control and restricted feeding treatment groups were not significantly different at 2 wk of age when the experiment began (Table 2). No interactions were observed among treatments and sex at any age. Growth of male and female quail was significantly reduced due to restricted feeding. Females had reduced BW at both restriction levels by 3 wk of age, whereas male BW were not significantly affected until 4 wk of age at the highest level of restriction. By 5 wk of growth, females restricted to 85% of ad libitum feed intake had BW that were lower than those of controls, and BW

TABLE 2. Mean body weights (± SEM) of Japanese quail from 2 to 13 wk of age as affected by ad libitum, and 15 and 30% feed restriction from 2 to 5 wk of age[1]

		Feed restriction (%)		
Age (wk)	Sex[2]	0	15	30
		(g)		
2	F	31.4 ± 1.7	30.7 ± 1.2	32.1 ± 1.6
	M	29.6 ± 1.6	31.8 ± 1.9	32.8 ± 1.4
3	F	60.3 ± 2.5[a]	54.5 ± 1.4[b]	52.9 ± 2.7[b]
	M	55.4 ± 2.7	55.9 ± 3.0	50.3 ± 1.6
4	F	89.5 ± 2.7[a]	78.1 ± 2.0[b]	72.1 ± 4.1[b]
	M	79.9 ± 3.7[a]	78.3 ± 4.2[a]	65.4 ± 1.9[b]
5	F	118.3 ± 2.6[a]	107.9 ± 4.3[b]	95.6 ± 5.3[c]
	M	106.3 ± 4.2[a]	106.0 ± 2.9[a]	93.3 ± 2.7[b]
6	F	111.2 ± 3.9	112.8 ± 2.2	104.7 ± 1.4
	M	95.3 ± 5.6	99.2 ± 5.1	101.3 ± 3.6
7	F	155.9 ± 3.4	148.2 ± 2.7	149.8 ± 3.3
	M	131.9 ± 5.4	153.0 ± 10.1	150.0 ± 5.0
8	F	193.2 ± 1.5	190.9 ± 5.1	189.8 ± 3.6
	M	155.4 ± 4.5	154.2 ± 2.6	163.2 ± 4.5
9	F	196.2 ± 2.1	187.6 ± 3.8	182.9 ± 9.7
	M	154.0 ± 4.6	156.2 ± 2.2	160.3 ± 6.1
10	F	204.3 ± 3.1	199.5 ± 3.6	194.1 ± 3.4
	M	166.8 ± 4.1	163.8 ± 4.9	171.5 ± 4.4
11	F	200.6 ± 5.0	192.6 ± 3.9	191.8 ± 4.1
	M	166.9 ± 7.8	170.8 ± 3.3	172.3 ± 6.2
12	F	199.2 ± 6.7	200.9 ± 4.1	195.5 ± 7.3
	M	168.7 ± 4.9	174.3 ± 2.9	172.5 ± 6.3
13	F	209.9 ± 10.5	205.2 ± 3.1	199.1 ± 8.4
	M	172.5 ± 6.3	178.2 ± 2.9	166.9 ± 6.3

[a–c]Means within a row that do not share a common superscript are significantly different ($P \leq 0.05$).

[1]No significant interaction was found among treatments and sex at any age.

[2]M = male; F = female.

of the 70% females were lower than those of the 85% females. Similar to results from the previous week, males fed at 85% of controls had BW not different than the controls, whereas BW of the 70% males were lower than for controls and the 85% males. These results agree with previous observations in laying hens (Donaldson and Millar, 1962), breeder turkeys (Voitle and Harms, 1972; Owings and Sell, 1980), broiler breeders (Brown and McCartney, 1986), and quail (Sabine et al., 1995). However, the results disagree with the observations of (Touchburn et al., 1968) in turkeys and (McCartney and Brown, 1980; Lilburn et al., 1990) in broiler breeders. One week after termination of the feed restriction treatment, at 6 wk of age, no significant differences in BW were observed among treatments in both sexes (Table 2).

Japanese quail that reach sexual maturity rapidly (6 to 7 wk of age) may be less adversely affected by feed restriction than chickens, which require a longer growing period prior to maturity. Alternatively, due to their early age at sexual maturity, quail may exhibit an accelerated growth following early feed restriction in order to obtain the minimum BW required for sexual maturity (Sabine et al., 1995). Feed restriction-induced BW depression observed at 3 to 5 wk of age corresponds with the characteristics of BW reduction and compensatory growth that occurs in less mature birds. When feed is limited for short periods during early life, chicks overcome growth depression by compensatory accelerated growth (Plavnik et al., 1986). Similarly, quail in this study overcame the effects of feed restriction on BW within 1 wk when ad libitum feeding followed the end of feed restriction at 6 wk of age. Plavnik and Hurwitz (1985) and Plavnik et al. (1986) concluded that sex, age, duration of restriction, and severity of restriction determine whether compensatory growth to within control ad libitum fed levels will be achieved following re-alimentation.

Mortality Rate

No differences in mortality were observed among treatments with only one death (2.8%) each within control and 15% restricted treatments and two deaths (5.6%) within the 30% restricted treatment. Similar results were observed by Gowe et al. (1960) and Lee (1981) in laying hens and Sabine et al. (1995) in quail. Quail restricted to 30% of ad libitum intake exhibited intensive feather picking behavior. This behavior may be attributed to stress, a more competitive and aggressive environment, and possibly marginal nutritional deficiencies.

Feed Conversion

No significant differences were observed in feed conversion for either sex or among treatments during the

TABLE 3. Effect of early feed restriction in Japanese quail on measures of egg production, reproduction, and embryonic mortality during 6 to 13 wk of age

Parameter	Feed restriction (%)		
	0	15	30
Egg production			
Age at first egg (d)	50.3 ± 4.4	50.3 ± 5.2	52.4 ± 4.5
Body weight at first egg (g)	182.4 ± 11.3[b]	181.3 ± 4.0[b]	192.9 ± 9.5[a]
Egg number	28.7 ± 4.4	31.4 ± 5.1	30.2 ± 4.7
Egg weight (g)	10.7 ± 11.3	10.6 ± 4.0	10.4 ± 9.5
First egg weight (g)	8.5 ± 1.1	9.0 ± 1.1	9.1 ± 1.1
Specific gravity (g/mL)	1.070 ± 0.012[a]	1.069 ± 0.013[a]	1.096 ± 0.011[b]
Reproductive parameter			
Fertility (%)	82.9 ± 3.9	81.2 ± 4.1	81.3 ± 3.6
Hatchability (%)	80.8 ± 3.4	83.2 ± 4.28	86.3 ± 3.1
Embryonic mortality			
Total dead embryos (%)	16.1 ± 2.4[a]	9.1 ± 2.0[b]	9.4 ± 1.9[b]
Early dead (%)	4.3 ± 1.6	1.4 ± 0.9	2.9 ± 1.4
Late dead (%)	11.0 ± 2.1[a]	5.8 ± 1.6[b]	5.7 ± 1.5[b]
Pipped dead (%)	0.7 ± 0.4	1.9 ± 0.7	0.8 ± 0.6

[a,b]Means ± SE within a row that do not share a common superscript are significantly different ($P \le 0.05$).

feed restriction periods of 3, 4, and 5 wk (data not shown). These results agree with results obtained by others (Mitchell et al., 1962; Balloun, 1974; Borron et al., 1974; McCartney et al., 1977; Andrews and Morrow, 1978; Meyer et al., 1980; Owings and Sell, 1980) in turkeys and Combs et al. (1961) in laying hens. However, these results disagree with the observations of Nestor et al. (1981) in turkeys. A higher feed conversion value following feed restriction would suggest that restriction retards growth and, therefore, reduces feed efficiency. However, feed restriction induces a higher efficiency of maintenance (Plavnik, 1985). Improved feed efficiency of maintenance would augment improved efficiency of growth during a compensatory growth period that sometimes follows a return to ad libitum feeding.

Egg Production

Thirty percent feed restriction delayed onset of egg production by approximately 2 d (52.4 ± 4.5 d) as compared with controls (50.3 ± 4.4 d) and 15% restricted quail (50.8 ± 5.2 d). However, the differences among treatments were not significant (Table 3). Body weight at first egg was significantly higher in 30% restricted quail as compared with 15% restricted quail and ad libitum fed control quail. These results agree with observations in turkeys (McCartney et al., 1977; Voitle and Harms, 1978; Meyer et al., 1980) and quail (Sabine et al., 1995). However, these results disagree with observations of turkeys by others (Mitchell et al., 1962; Touchburn et al., 1968; Voitle et al., 1973; Borron et al., 1974; Krueger et al., 1978; Potter et al., 1978; Nestor et al., 1981), Lee (1981) in laying hens, and Wilson et al. (1971) in broiler breeder hens.

Early feed restriction did not significantly affect first egg weight, mean egg weight, or number of eggs produced from 6 to 13 wk of age (Table 3). These results agree with research in turkeys (Balloun, 1974; Cherms et al., 1976; Voitle and Harms, 1978; Potter et al., 1978; Owings and Sell, 1980; Ferket and Moran, 1986), and laying hens (Combs et al., 1961; Lee, 1981). However, Miles and Lesson (1990) in turkeys and Sabine et al. (1995) in quail report that early feed restriction reduces egg production. Other researchers of turkeys (Meyer et al., 1980; Owings and Sell, 1980; Nestor et al., 1981; Ferket and Moran, 1986), laying hens (Lee, 1981), and quail (Sabine et al., 1995) have shown that first egg weight is not reduced by early feed restriction. Egg specific gravity was improved by early 30% feed restriction. Egg specific gravity increased ($P < 0.05$) as compared to control (Table 3). These results disagree with the observations of Fattori et al. (1991) for broiler breeders and Renema et al. (1995) for turkeys.

Reproduction and Embryonic Mortality

Feed restriction at 70 and 85% of ad libitum intake did not significantly decrease fertility between 6 and 13 wk of age (Table 3). Other researchers report similar lack of effect of early feed restriction on fertility in turkeys (Touchburn et al., 1968; Owings and Sell, 1980; Miles and Leeson, 1990) and in broiler breeders (Wilson et al., 1971; McCartney and Brown, 1980). However, others (Mitchell et al., 1962; Anderson et al., 1963; Balloun, 1974; Borron et al., 1974; Jones et al., 1976; McCartney et al., 1977; Krueger et al., 1978; Potter et al., 1978; Voitle and Harms, 1978; Nestor et al., 1981; Ferket and Moran, 1986) report depressed fertility of early feed restricted turkeys and broiler breeders (Lilburn et al., 1990). Brown and McCartney (1986) working with broiler breeder males found no significant differences in testes weight as a percentage of BW for males fed 85 or 70% of full-fed controls. Males restricted to 85% of the ad libitum feed intake and ad libitum fed controls had greater average semen volumes than volumes produced by 70% restricted males. They also reported no effect of dietary treatment on luteinizing hormone level.

Hatchability of fertile eggs from control and restricted quail did not differ significantly (Table 3). These results

TABLE 4. Leukocyte population distribution from Japanese quail at 5 wk of age after feed restriction from 3 to 5 wk of age[1]

		Feed restriction (%)		
Leukocyte type	Sex[2]	0	15	30
Heterophils (H)	F	20.7 ± 0.3[b]	23.2 ± 0.5[a]	24.0 ± 0.6[a]
	M	19.2 ± 1.0[b]	23.7 ± 0.4[a]	22.8 ± 0.6[a]
Lymphocytes (L)	F	66.8 ± 0.5[a]	60.0 ± 1.0[b]	59.5 ± 0.8[b]
	M	63.2 ± 1.2[a]	61.7 ± 0.7[b]	61.5 ± 0.8[b]
H/L	F	0.3 ± 0.2[b]	0.4 ± 0.1[a]	0.4 ± 0.1[a]
	M	0.3 ± 0.1[b]	0.4 ± 0.1[a]	0.4 ± 0.1[a]
Eosinophils	F	3.3 ± 0.2[a]	2.5 ± 0.3[b]	2.8 ± 0.4[b]
	M	3.8 ± 0.3[a]	2.7 ± 0.2[b]	2.2 ± 0.3[b]
Basophils	F	0.7 ± 0.2[b]	3.2 ± 0.2[a]	2.8 ± 0.3[a]
	M	1.0 ± 1.3[b]	2.5 ± 0.2[a]	2.5 ± 0.4[a]
Monocytes	F	8.5 ± 0.3	11.0 ± 1.1	10.8 ± 0.8
	M	12.8 ± 1.3	9.5 ± 0.6	11.0 ± 1.0

[a,b]Means ± SE within a row that do not share a common superscript are significantly different ($P \leq 0.05$).

[1]No significant interaction was found among treatments and sex at any age.

[2]M = male; F = female.

agree with observations in broiler breeders (Wilson et al., 1971; McCartney and Brown, 1980; Fattori et al., 1991), turkeys (Mitchell et al., 1962; Potter and Leighton, 1973; Balloun, 1974; Borron et al., 1974; Jones et al., 1976; McCartney et al., 1977; Krueger et al., 1978; Voitle and Harms, 1978; Owing and Sell, 1980; Nestor et al., 1981; Miles and Leeson, 1990), and quail (Sabine et al., 1995). However, Cherms et al. (1976) and Ferket and Moran (1986) found that feed restriction decreases hatchability in turkeys. This finding agrees with Narahari et al. (1988) who stated that hatchability increases with a proportionate reduction in embryonic mortality. Hatchability maintained in feed restricted quail could result from lower embryonic mortality (Table 3).

Total embryonic mortality to 17 d of incubation was reduced ($P < 0.05$) by early feed restriction. Mortality for the fed control group fed ad libitum (16.1 ± 2.4%) was 56% more than mortalities from 15 or 30% feed restricted quail (9.1 ± 2.0 and 9.4 ± 1.9%, respectively) (Table 3). Differences in embryonic mortality were due to differences in late dead embryos because both early dead and pipped dead embryos were not significantly different among treatments (Table 3). Peebles and Marks (1991) found that increased eggshell permeability increases early and late embryonic mortality in quail. Peebles and Brake (1985) found that low pore number increases shell thickness (pore length). Japanese quail eggs that hatch or pip exhibit less weight loss through 15 d of incubation than eggs that die late (Soliman et al., 1994). Eggs containing early dead embryos exhibited the greatest weight loss. The functional component of the egg such as the shell membrane or albumen may contribute to this excessive weight loss. Therefore, early feed restriction that affected embryo mortality might also suggest that egg specific gravity would be affected, as observed in this study (Table 3).

Leukocyte Population Distribution

Feed restriction from 2 to 5 wk of age affected leukocyte population distribution in females and males (Table 4). Feed-restricted quail at 15 and 30% levels of ad libitum intake increased ($P < 0.05$) the percentage of heterophils as compared with heterophils in ad libitum fed control quail. Hocking et al. (1993) noted that feed restricted broiler breeders are stressed. This observation agrees with others (Glick, 1967; Gross et al., 1980; Maxwell et al., 1992) who reported increased heterophil populations when ducks received 50% of feed required to achieve their ad libitum fed BW at 21 wk of age. However, Maxwell et al. (1992) found no effect of feed restriction on heterophil populations when ducks received feed adequate to achieve only 25% of ad libitum fed BW at 21 wk of age. Eosinophils were lower ($P < 0.05$) in feed-restricted quail than ad libitum fed controls.

Basophils were significantly elevated in both restricted groups. The increase in basophils may reflect a stress response in quail, in agreement with the observations of Maxwell et al. (1990, 1992) who reported increased basophil frequency in feed-restricted broilers. They also observed that birds that received feed to achieve 25% of the growth of ad libitum fed birds produced a marked basophilia at 21 wk of age. Maxwell et al. (1992) also noted that feed-restricted broilers showed a decrease in the proportion of lymphocytes in the leucocyte population. These diet-related changes in heterophil and lymphocyte populations resulted in significantly higher heterophil/lymphocyte ratio in males and females of feed-restricted quail. Maxwell et al. (1990, 1992) noted significantly higher heterophil/lymphocyte ratios in broilers maintained on a prolonged program of feed restriction. In agreement with the observations of Maxwell et al. (1991), no significant differences in monocyte population were observed among feed-restricted and control quail.

Feed restriction in Japanese quail from 2 to 5 wk of age did not affect BW or egg production but increased egg specific gravity and reduced late dead embryo mortality between 6 and 13 wk of age. Leukocyte population distribution was significantly affected at 5 wk of age resulting in an increased heterophil-to-lymphocyte ratio, which is an indicator of stress in ducks and broiler breeders.

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