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Divergent Selection Effect on Reproductive Trait in Japanese Quails

[1]R. Sadeghi, [2]A. Pakdel, [2]M. Moradi Shahrbabak and [2]H. Moradi Shahrbabak
[1]Department of Animal Science, College of Agriculture and Natural Resources,
University of Tehran, P.O. Box 4111, Karaj, Alborz, Iran
[2]Department of Animal Science, Faculty of Agricultural Science and Engineering,
College of Agriculture and Natural Resources, University of Tehran, Karaj, Alborz, Iran

Abstract: This experiment was conducted to determine the effect of 9 generations of divergent selection for 4 weeks Body Weight (BW4) on growth and reproductive traits in Japanese quail. For this purpose, HW and LW lines were subjected to individual selection for high and low 4 weeks BW, respectively and were compared with control line (C). In compare to LW line and except for average daily gain from 4-6 weeks, average daily gain for other periods was significantly higher in HW. Age of sexual maturity was 7 and 4 days more than control line in HW and LW, respectively ($p \leq 0.05$). Body weight of sexual maturity in HW was significantly higher than those in control ($p \leq 0.05$). In compared to the C line, total egg weight increased 18.57 g in HW and decreased 112.56 (g) in LW ($p \leq 0.05$). Total egg number in HW was significantly lower than those in C line ($p \leq 0.05$).

Key words: Japanese quail, reproductive trait, productive trait, divergent selection, Iran

INTRODUCTION

The Japanese quail's small size, inexpensive rearing requirements, rapid maturation and adaptability to a wide range of husbandry conditions have made it popular as a laboratory animal for studies of behavior, development, genetics, growth, endocrinology, nutrition, physiology, pharmacology and toxicology (Landsdown *et al*., 1970; Padgett and Ivey, 1959; Wilson *et al*., 1959; Reese and Reese, 1962). Furthermore, Japanese quail have many characteristics and behavior patterns in common with the domestic chicken (*Gallus gallus domesticus*). They have been used to test the nutritive value of various feedstuffs for chickens (Kaya *et al*., 2003; Elangovan *et al*., 2003) and are increasingly being used as a model of that species for studies of applied animal ethology related to animal welfare (Gerken and Petersen, 1987; Gerken and Mills, 1993; Odeh *et al*., 2003). The Japanese quail is now a well-established animal model in biology and a bird used for intensive egg and meat production mainly in Asia and Europe but also in the Middle East and America (Minvielle, 2004).

The quail meat is preferred to the chicken meat because of its less fat content (low calorific value), taste and delicacy. It demands to produce more quail meat in the shorter period. This can be achieved by a specific selection program for higher body weight at specific age (Malarmathi *et al*., 2010). Genetic selection is a powerful means to increase body weight and rate of gain in Japanese quail (Devi *et al*., 2010). Genetic progress in body weight for Japanese quail is accomplished by continuous selection for the trait (Marks, 1971; Anthony *et al*., 1986).

Egg production in chicken is characterized by the number of eggs in a clutch and the period between clutches where oviposition fails to occur because of pause which results in missing egg between clutches. The cyclic laying process is described by some clutch traits such as the number of clutches, the average clutch size, the number of pauses and the pause size between clutches. Number of eggs in a clutch is determined by circadian cycle which consists of a daily rhythm and lag. Internal laying is a result of asynchrony in the development of the oviduct and the ovary. Pause consists of a circadian rhythm and a period called delay.

Genetic selection in various poultry species has resulted in higher body weight at various ages along the growth curve (Anthony *et al*., 1991). The selection scheme used to change an animal's pattern of growth resulted in both short-term and long-term effects on other traits such as tissue growth patterns, the onset of sexual maturity and overall reproductive efficiency. It has been shown that when selecting for traits besides reproductive fitness, a negative correlation between the selected trait

Corresponding Author: R. Sadeghi, Department of Animal Science, College of Agriculture and Natural Resources, University of Tehran, P.O. Box 4111, Karaj, Alborz, Iran

and reproductive fitness will resulted. This negative correlation has shown to be true between growth rate and reproductive traits such as female fertility and egg traits (Siegel, 1963; Falconer, 1981). The aim of present study was to determine the effect of nine generations of divergent selection for 4 weeks body weight in Japanese quail on productive and reproductive traits.

MATERIALS AND METHODS

Population structure and animal management: The base population of Japanese quail used in the current study was maintained at the animal research station in university of Tehran, Iran. Eight generations of divergent selection for 4 weeks BW has been done to establish the selection lines of high Body Weight (HW), Low body Weight (LW) and the Control line (C). The birds used from each line (HW, LW and C) in the current study were collected during 3 continues hatches. The collected eggs from each line incubated for 15 days separately. Then, eggs were transferred to the hatcher and 3 days later all chicks were removed from the hatcher. Immediately after the hatch, each bird was permanently identified by leg-banded. Sex identification was carried out according to the plumage and color pattern at 4 weeks of age. At this age, 300 female and 150 male (100 female and 50 male from each line) were selected. The statistical descriptions of 4 weeks body weight within each sex in the selected lines are presented in Table 1. According to the Table 1, means of 4 weeks body weight between male and female in HW line were very close but in LW line they were very different. Because of selected female's twofold number this different in HW line disappeared and in LW line became very obvious.

The adult female birds were housed in individual stainless steel wire mesh cages, exposed to 16 h of light. The feed and water were provided for them as *ad libitum*. The first diet containing 260 g kg^{-1} protein and 11.5 MJ metabolisable energy/kg was fed from the hatch to the 4 weeks of ages and changed to a ration contained 200 g kg^{-1} protein with 11.5 MJ metabolisable energy/kg during the laying period.

Table 1: Descriptive statistics for 4 weeks body weight (g) within sexes in the selected lines of Japaese quail

Lines[1]	No. of observations	Mean	SD	CV (%)	Selection Intensity (SI)
Female					
HW	100	228.13	0.86	3.76	0.46
LW	100	131.62	1.68	12.76	0.36
Male					
HW	50	225.12	0.85	2.66	1.11
LW	50	121.09	1.78	10.39	1.05

[1]HW = Selected line for high 4 weeks body weight; LW = Selected line for low 4 weeks body weight

Trait definitions

Growth related traits: Individual daily body weight gains during different growth periods from hatch to 2 (ADG0-2), 2-4 (ADG2-4), 4-6 (ADG4-6) and hatch to 6 weeks of age (ADG0-6) was obtained according to Brody as follows:

$$ADG = \frac{(w2\text{-}w1)}{(t2\text{-}t1)}$$

is the weight increment in the time interval (t2-t1).

Egg production parameters: A clutch was described as an uninterrupted laying period during the egg yield term. Each non-laying period between two clutches was defined as a pause. The clutch length is the number of eggs laid on consecutive days which is one of the components of the total number of eggs laid during a production cycle. The average clutch length was the arithmetic means of all clutches recorded. Age at sexual maturity was determined as the first egg laying-day of females.

The individual egg yield of all females during the first 90 days of production (TEN), Total Egg Weight (TEW) (g), Total Egg Number (TEN), Total Egg Weight (TEW), Age at Sexual Maturity (ASM), Body Weight at Sexual Maturity (BWSM), Clutch Number (CN) and Pause Number (PN) for each female bird in all 3 lines were recorded.

The fertility (%) and hatchability (%) were calculated for each line by the following equation:

$$\text{Fertility (\%)} = \left(\frac{\text{Number of fertile eggs}}{\text{Total number of eggs set}}\right)\times 100$$

$$\text{Hatchability (\%)} = \left(\frac{\text{Number of chicken hatched}}{\text{Number of fertile eggs}}\right)\times 100$$

Statistical analysis: Data were analyzed using the General Linear Model (GLM) procedure of SAS. Least Square Means (LSM) were calculated and the Least Square Differences (LSD) between means was evaluated. The means were calculated within sex in each line for all traits and the correlations between traits within lines were estimated by using Pearson correlation coefficients. The statistical model used for growth traits was:

$$Y_{ij} = \mu+L_i+S_j+S_j(L_i)+e_{ij}$$

Where:

Y_{ij} = Observations for a trait

i = The ith line

j = The jth sex

L = The fixed effect of the ith line
S = The fixed effect of the jth sex
$S_j (L_i)$ = The effect of sex within line
e_{ij} = The random error term

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RESULTS AND DISCUSSION

Growth related trait

Average Daily Gain (ADG): Least-squares means for ADG during different periods of age within sexes in the selected and control lines are presented in Table 2. The overall means of ADG in all periods were heavier in females that this results were nearly equal with finding by Shamma, Sefton and Siegel who indicated that ADG for females quail being heavier than males. Also, except for ADG4-6 that in LW line was more than HW for all periods ADG in HW was higher than LW. Also, the differences among all sources of variance studied were significant ($p \leq 0.05$). These results are in agreement with finding by Shamma, Darden, Marks , Sefton and Siegel.

Productive traits

Age of Sexual Maturity (ASM) and Body Weight of Sexual Maturity (BWSM): The average ASM was 48.88, 41.09 and 45.33 days for HW, C and LW, respectively (Table 3). The results reported that control line reached firstly sexual maturity followed by LW and HW reached finally sexual maturity. These results may be due to the correlation coefficient between age at sexual maturity and body weight. The results are in agreement with that reported by Oguz *et al.* (2001) and Dobalova *et al.* (1983) they reported delay in selected lines for HW to reach ASM than control lines. Also, the difference between selected lines (HW and LW) wasn't significant but they were significant with control ($p \leq 0.05$). The phenotypic correlation between ASM and BW4 showed in Table 4 it was positive for all lines and it was 0.31 in pooled population.

Means of BWSM in HW, C and LW were 237.81, 173.44 and 137.76 g, respectively (Table 3). The differences among lines for BWSM were statistically significant ($p \leq 0.05$) with the increase of BWSM and ASM. Generally, the results revealed that BWSM of Japanese quail of HW was heavier than the other lines. This result is in agreement with Bahie El-Deen (1999), Shalan (1998) and Kosba *et al.* (2003) who indicated that improving BW at 6 weeks of age had positive effect on

Table 2: Least squares means and Standard Errors (mean±SE) for average daily gain during different periods for three lines of Japanese quail females and males

Traits[1]	Lines	Females LSM±SE	Males LSM±SE	Pooled population
ADG0-2 (g/day)	HW	3.75 ± 0.18^a	3.57 ± 0.35^b	3.66 ± 0.17^A
	C	3.18 ± 0.19^c	3.05 ± 0.17^d	3.11 ± 0.18^B
	LW	2.47 ± 0.15^e	2.32 ± 0.14^f	2.79 ± 0.16^C
	Overall mean	3.13 ± 0.17^A	2.98 ± 0.18^B	3.09 ± 0.12
ADG2-4 (g/day)	HW	9.89 ± 0.25^a	9.42 ± 0.90^b	9.65 ± 0.24^A
	C	8.02 ± 0.30^c	7.99 ± 0.26^d	7.81 ± 0.25^B
	LW	7.13 ± 0.26^e	6.45 ± 0.24^f	6.79 ± 0.21^C
	Overall mean	8.35 ± 0.29^A	7.82 ± 0.23^B	8.18 ± 0.22
ADG4-6 (g/day)	HW	2.94 ± 0.21^e	2.83 ± 0.19^f	2.88 ± 0.14^C
	C	3.48 ± 0.23^a	3.32 ± 0.19^b	3.40 ± 0.17^A
	LW	3.33 ± 0.16^c	3.17 ± 0.14^d	3.25 ± 0.15^B
	Overall mean	3.26 ± 0.16^A	3.11 ± 0.20^B	3.17 ± 0.16
ADG0-6 (g/day)	HW	5.52 ± 0.28^a	5.25 ± 0.36^b	5.41 ± 0.29^A
	C	4.89 ± 3.70^c	4.58 ± 3.40^d	4.79 ± 0.31^B
	LW	4.31 ± 0.25^e	4.01 ± 0.29^f	4.19 ± 0.24^C
	Overall mean	4.91 ± 0.27^A	4.69 ± 0.30^B	4.85 ± 0.28

[1]ADG0-2 = Average Daily Gain from hatch to 2 weeks ages; ADG2-4 = Average Daily Gain from 2-4 weeks ages; ADG4-6 = Average Daily Gain from 4-6 weeks ages; ADG0-6 = Average Daily Gain from hatch to 6 weeks ages; HW = Selected line for high 4 weeks body weight; LW = Selected line for low 4 weeks body weight; C = Control line; Means of each trait with different small letters are significantly different ($p \leq 0.05$). Means having the different small or capital letters are significantly different ($p \leq 0.05$)

Table 3: Least squares means and Standard Errors (mean±SE) for different reproductive traits for three lines of Japanese quail females

Traits[1]	HW	C	LW	Pooled population
ASM (days)	48.88 ± 3.500^a	41.09 ± 2.520^b	45.33 ± 3.680^a	45.10 ± 2.190
BWSM (g)	237.81 ± 35.68^a	173.44 ± 9.550^b	137.76 ± 13.46^c	182.99 ± 8.890
TEN	72.76 ± 4.540^b	76.20 ± 1.850^a	76.40 ± 2.190^a	75.11 ± 1.540
TEW (g)	946.30 ± 86.26^a	927.73 ± 65.57^b	815.17 ± 44.01^c	896.49 ± 52.11
F (%)	81.85 ± 0.070^b	88.11 ± 0.080^a	71.30 ± 0.080^c	80.42 ± 0.050
H (%)	55.42 ± 0.090^c	65.93 ± 0.090^a	58.12 ± 0.080^b	59.82 ± 1.100

[1]ASM (days) = Age of Sexual Maturity; BWSM (g) = Body Weight of Sexual Maturity; TEN = Total Egg Number during 90 days after sexual maturity; TEW = Total Egg Weight during 90 days after sexual maturity; F (%) = Fertility percentage; H (%) = Hatchability percentage; HW = Selected line for high weight in 4 weeks body weight; LW = Selected line for low weight in four week body weight; C = Control line; different letters shows significant different between lines ($p \leq 0.05$)

Table 4: Least squares means and Standard Errors (mean±SE) for clutch and pause traits in three lines of Japanese quail females

Traits[1]	HW	C	LW	Pooled population
CL (day)	72.76 ± 4.540^b	76.20 ± 1.85^a	76.40 ± 2.190^a	75.11 ± 1.54
CN	5.96 ± 3.010^a	5.61 ± 1.58^a	4.45 ± 1.690^b	5.36 ± 1.49
PL (day)	17.65 ± 10.71^a	13.92 ± 2.32^b	13.67 ± 12.37^b	15.08 ± 2.28
PN	6.13 ± 2.070^a	5.91 ± 1.72^b	4.83 ± 1.680^c	5.62 ± 1.66

[1]CL = Clutch Length until 90 days of egg production; CN = Clutch Number until 90 days of egg production; PL = Pause Length until 90 days of egg production; PN = Pause Number until 90 days of egg production; HW = Selected line for high 4 weeks body weight; LW = Selected line for low 4 weeks body weight; C = Control line; different letters shows significant different between lines ($p \leq 0.05$)

increasing BWSM. The phenotypic correlation between BWSM and BW4 showed in Table 5 it was positive for three lines and it was 0.89 in pooled population.

TEN and TEW: Means of Total Egg Number (TEN) during the first 90 days of laying for the three lines are presented in Table 3. The results showed an increase in TEN for LW line than HW and C lines (76.40 vs. 72.76 and 76.20) with significant differences ($p \leq 0.05$) between LW and HW line. May be that is due to the effect of earlier maturity on increase the length of laying cycle and/or the increase in clutch size (Table 5). The phenotypic correlation between TEN and BW4 showed in Table 4 that was negative for three lines and it was 0.42 in pooled population.

Means for Total Egg Weight (TEW) during the first 90 days of laying by lines are shown in Table 3. The mean of TEW during the 90 days of laying for HW and C was heavier than LW and the differences among the three lines were significant ($p \leq 0.05$). Similar results were reported by Nestor *et al.* (1996), Kosba *et al.* (2002, 2003) and Marks (1979) showed that EW increased but not in proportion to the increase in BW. The phenotypic correlation between TEW and BW4 showed in Table 4 that was positive for three lines and it was 0.84 in pooled population.

Clutch Number (CN) and Pause Number (PN): Means of Clutch Number (CN) and Pause Number (PN) are shown in Table 5. The mean of CN was 5.96, 5.61 and 4.45 for HW, C and LW, respectively and the difference among the HW and LW was significant ($p \leq 0.05$). The mean of PN was 6.13, 5.91 and 4.83 for HW, C and LW, respectively and the difference among the three lines was significant ($p \leq 0.05$). Similar result was reported by Kemal.

Clutch Length (CL) and Pause Length (PL): The clutch length is the number of eggs laid on consecutive days which is one of the components of the total number of the eggs laid during a production cycle. CL in the HW was found lower than the LW and C while CN, PL and PN were higher. Therefore, CL was higher in LW than C and HW (Table 5). It was concluded that egg yields decreased

Table 5: Estimates of phenotypic correlations (±SE in subscript) between 4 weeks Body Weight (BW4) and other traits in three lines of Japanese quail females

Traits	ASM	BWSM	TEN	TEW	F (%)	H (%)
BW4	$0.20_{(0.04)}^{**}$	$0.20_{(0.04)}^{**}$	$-0.27_{(0.09)}^{*}$	$0.22_{(0.10)}^{**}$	$-0.13_{(0.05)}^{*}$	$-0.27_{(0.08)}^{*}$
	$0.20_{(0.04)}^{**}$	$0.34_{(0.06)}^{**}$	$-0.22_{(0.09)}^{*}$	$0.34_{(0.11)}^{**}$	$-0.10_{(0.05)}^{*}$	$-0.17_{(0.04)}^{*}$
	$0.22_{(0.06)}^{**}$	$0.30_{(0.05)}^{**}$	$-0.28_{(0.10)}^{*}$	$0.30_{(0.11)}^{**}$	$-0.12_{(0.06)}^{*}$	$-0.24_{(0.07)}^{*}$
	$0.31_{(0.10)}^{**}$	$0.89_{(0.12)}^{**}$	$-0.42_{(0.11)}^{*}$	$0.84_{(0.13)}^{**}$	$-0.11_{(0.05)}^{*}$	$-0.25_{(0.09)}^{*}$

ASM = Age of Sexual Maturity (day); BWSM = Body Weight of Sexual Maturity; TEN = Total Egg Number; TEW = Total Egg Weight (g); F % = Fertility; H % = Hatchability; Values of HW, C and LW lines and total population were shown one under the other at rows in each traits, respectively; *$p<0.05$; **$p<0.01$

when clutch numbers increased. The mean of PL was 17.65, 13.92 and 13.67 (day) for HW, C and LW, respectively and the differences among the three lines were significant ($p \leq 0.05$). Similar result was reported by Kemal.

Reproductive traits

Fertility: Data presented in Table 3 showed fertility averages of this trait were 81.85, 88.11 and 71.30 in lines HW, C and LW, respectively that there was a significant difference between lines ($p \leq 0.05$). It was clear that divergent selection affect fertility in quail eggs and LW line had the lowest fertility and C line had the highest one. The results are in close agreement with Marks (1996) and Harfoush (2004) that reported selection for high body weight at 4 weeks of age had a significant negative effect on fertility percentage. Researchers found that phenotypic correlation was negative in all lines and it was -0.11 in pooled population (Table 4).

Hatchability: The percentages of hatchability (Table 3) were 55.42, 65.93 and 62.13% in HW, C and LW, respectively. Hatchability was lower in the selected lines comparing with control line. Differences between the selected and control lines were significant ($p \leq 0.05$). The results are in close agreement with Peebles and Marks (1991) and Marks (1996), they reported that hatchability (%) in selected lines were significantly lower than control lines. Phenotypic correlation was negative in all lines and it was -0.25 in pooled population (Table 4).

CONCLUSION

In contrast to LW, clutch number, pause number and pause length increased but clutch length decreased for HW. Fertility was higher in HW than LW while hatchability was higher in LW ($p \leq 0.05$). Only total egg number, fertility and hatchability had negative phenotypic correlation with BW4 ($p \leq 0.05$) in three lines.

REFERENCES

Anthony, N.B., D.A. Emmerson, K.E. Nestor, W.L. Bacon, P.B. Siegel and E.A. Dunnington, 1991. Comparison of growth curves of weight selected populations of Turkeys, quails and chickens. Poult. Sci., 70: 13-19.

Anthony, N.B., K.E. Nestor and W.L. Bacon, 1986. Growth curves of Japanese quail as modified by divergent selection for 4 week body weight. Poult. Sci., 65: 1825-1833.

Bahie El-Deen, M., 1999. Inheritance of sexual dimorphism in body weight and its relationship with growth and egg production traits in Japanese quail. Egypt. Poult. Sci., 19: 657-669.

Devi, K.S., B.R. Gupta, M.G. Prakash, S. Qudratullah and A.R. Reddy, 2010. Genetic studies on growth and production traits in two strains of Japanese quails. Anim. Sci., 6: 223-230.

Dobalova, M., J. Bulla and J. Granat, 1983. The effect of light on the growth and egg yield in three lines of Japanese quails. Proceedings of the 5th International Symposium Actual Problems of Avian Genetics, Piestany, Czechoslovakia, March 21-24, 1983, Research Institute of Animal Production, Nitra, Czechoslovakia, pp: 131-137.

Elangovan, A.V., S.V.S. Verma and V.R.B. Sastry, 2003. Laying performance of Japanese quail fed on different seed meals in diet. Anim. Nutr., 19: 244-250.

Falconer, D.S., 1981. Introduction to Quantitative Genetics. 2nd Edn., John Wiley and Sons, Inc., New York, UK.

Gerken, M. and A.D. Mills, 1993. Welfare of domestic quail. Proceedings of the 4th European Symposium on Poultry Welfare, September 18-21, 1993, Edinburgh, USA., pp: 158-176.

Gerken, M. and J. Petersen, 1987. Bidirectional selection for dust bathing activity in Japanese quail (*Coturnix coturnix japonica*). Poult. Sci., 28: 23-31.

Harfoush, M.M.K., 2004. Genetic improvement of some productive traits in quails. Ph. D. Thesis, University of Egypt, Egypt.

Kaya, S., Z. Erdogan and S. Erdogan, 2003. Effect of different dietary levels of *Yucca schidigera* powder on the performance, blood parameters and egg yolk cholesterol of laying quails. J. Vet. Med., 50: 14-17.

Kosba, M.A., Bahie El-Deen and H.M. Shalan, 2002. Selection by independent culling levels for some egg production traits in Japanese quail. Agric. Res., 80: 1777-1788.

Kosba, M.A., Bahie El-Deen and H.M. Shalan, 2003. Long-Term selection for body weight in Japanese quail under Egyption conditions 3-correlated response of some egg production traits. Poult. Sci., 23: 961-975.

Landsdown, A.B.G., S.J. Crees and R.G. Wilder, 1970. The Japanese quail: Its suitability for embryonic and reproductive investigations. Anim. Technol., 21: 71-77.

Malarmathi, M., B.R. Gupta, M.G. Prakash and A.R. Reddy, 2010. Selection indices for the improvement of production traits in Japanese quails. Vet. Anim. Sci., 6: 170-173.

Marks, H.L., 1971. Selection for four-week body weight in Japanese quail under two nutritional environments. Poult. Sci., 50: 931-937.

Marks, H.L., 1979. Changes in unselected traits accompanying long–term selection for 4 weeks body weight in Japanese quail. Poult. Sci., 58: 269-274.

Marks, H.L., 1996. Long-term selection for body weight in Japanese quail under different environments. Poult. Sci., 75: 1198-1203.

Minvielle, F., 2004. The future of Japanese quail for research and production. Poult. Sci., 60: 500-507.

Nestor, K.E., W.L. Bacon, N.B. Anthony and D.O. Noble, 1996. Divergent selection for body weight and yolk precursor in *Coturnix coturnix* japonica 10. Response to selection over thirty generations. Poult. Sci., 75: 303-310.

Odeh, F.M., G.G. Cadd and D.G. Satterlee, 2003. Genetic characterization of stress responsiveness in Japanese quail. 1. Analyses of line effects and combining abilities by diallel crosses. Poult. Sci., 82: 25-30.

Oguz, I., Y. Akbas and O. Altan, 2001. Relationship of body weight at sexual maturity with body weights at various ages in lines of Japanese quail (*Coturnix coturnix japonica*) unselected and selected for four-week body weight. Applied Anim. Res., 19: 219-223.

Padgett, C.A. and W.D. Ivey, 1959. Coturnix quail as a laboratory research. Science, 129: 267-268.

Peebles, E.D. and H.L. Marks, 1991. Effects of selection on plasma thyroxine concentrations in Japanese quail under thiouracil and protein stress. Poult. Sci., 70: 641-650.

Reese, E.P. and T.W. Reese, 1962. The quail *Coturnix coturnix* as a laboratory animal. J. Exp. Anal. Behav., 5: 265-270.

Shalan, H.M., 1998. Independent culling levels selection and crossing for improving meat and egg production in Japanese quail. Ph.D. Thesis, University of Egypt, Egypt.

Siegel, P.B., 1963. Selection for breast angle at eight weeks of age: 2. correlated responses for feathering, body weighs and reproductive characteristics. Poult. Sci., 42: 437-449.

Wilson, W.O., U.K. Abbott and H. Abplanalp, 1959. Developmental and physiological studies with a new pilot animal for poultry-coturnix quail. Poult. Sci., 38: 1260-1261.