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Productive performance, egg quality, and hatching traits of Japanese quail lines selected for higher body weight and egg number

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Abstract: The present study evaluated the effect of selection for higher body weight (weight based selection = WBS) and egg numbers (egg based selection = EBS) on productivity, egg quality, and hatching traits of Japanese quail for three generations. From a base population of 1125 day-old chicks of Japanese quail, best performing families were allowed to propagate for getting next generation. WBS in G3 presented higher values of feed intake, egg weight, hatching weight. However, egg production and feed conversion ratio were better in EBS during G3. The incidence of embryonic mortality was also lower in the WBS line. In the 8th week egg quality traits differed in the EBS line, however, at the age of the 16th week, the WBS line during G3 revealed the better egg characteristic. Despite the lower egg production, the quails selected for higher 4th-week body weight had better egg quality than those selected for egg type line; hence, the selection for body weight is more beneficial and effective than the egg based selection.

Key words: Egg quality, hatching traits, Japanese quail, productivity, selection

1. Introduction

Poultry production is one of the rapidly growing subsectors of agriculture producing a range of commodities for the global population. Poultry meat and eggs are commodities being consumed in millions of numbers on daily basis [1]. Broiler chickens, commercial layers, turkeys, ducks and quails are generally used for meat and egg production [2]. These fast-yielding birds are genetically selected for a specific purpose and have higher growth and egg-laying rates [1,2]. The aim of developing such strains was to fulfil the dietary needs, especially, of proteins of the global population [3]. Among these, quail production is the most advantageous enterprise because of the short production cycle, early maturity and healthier meat and eggs [4,5]. Due to short generation intervals, the Japanese quail is the best model species in the breeding and selection experiments. Japanese quails are small birds and can gain more than 170 grams of weight in just 28 days [5]. On the other hand, it can lay more or less 300 eggs per year [6]. In past, this species was extensively used to improve meat yield and egg production in various parts of the world.

Pakistan is an underdeveloped country where nutritional deficiencies are common among the public. According to an estimate, 45% of children are suffering from malnutrition and stunted growth. There is immense potential for meat and egg production from Japanese quail. But for this, the existing potential of Japanese quail is low for meat and egg production than those from imported flocks [7,8] and there is a need to enhance the growth of these birds by selection programs. Pedigree selection, mass selection and family selection are generally used to enhance the traits of economic importance. Egg production, egg quality and hatching traits are the characters that are considered to get the maximum number of chicks. In past, efforts were made to enhance egg production and to improve egg quality and hatching traits. The aim of study was to evaluate the effects of selection for higher body weight and egg numbers on productivity, egg quality, and hatching traits of Japanese quail for three generations.

2. Materials and methods

2.1. Experimental site

The study was conducted at Avian Research and Training Centre (ARTC), the University of Veterinary and Animal Sciences (UVAS), Lahore, Pakistan and involved three genetic groups of Japanese quails. The first group consisted

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of the birds selected for body weight. The second group had quails selected for egg number. The third group consisted of nonselected random-bred Japanese quails. Each group of selection strategies had 75 families with a 1:4 male to female ratio.

2.2. Ethics

The care and use of bird were in accordance with the institutional guidelines and the laws and regulations of Pakistan and was approved by Ethical Review Committee (No. DR/495), University of Veterinary and Animal Sciences (UVAS).

2.3. Selection protocol

Initially, 3000 day-old chicks (DOC) of Japanese quail were procured from the hatchery of ARTC and were subjected to rearing for 4 weeks. From the 5th week, 900 females and 225 male birds were randomly selected as base population (G0) and divided into three groups based on different selection procedures i.e. weight-based selected (WBS), egg number-base selected (EBS) and random-bred control (RBC). Base population (G0) of each group comprised of 75 families containing 300 females and 75 males where each family consisted of one male and four females.

In WBS, total, 2050 chicks were obtained from the G0 population and their growth performance was assessed until the 4th week of age. Only those families fulfilling the criteria (average body weight + 0.5 standard deviation) were selected to be the parents in the next generation. Similar to WBS, 2050 chicks from the G0 population of the EBS line were obtained and grown until egg production started. All the female quails were equally divided into 225 families with a ratio of 1 male:4 females. Egg production records of these families were maintained till the end of the 12th week of age. At the end of the 12th week, out of 225 families, only those families were selected who fulfil the criteria (average egg number + 0.5 standard deviation) to be the parents of the next generation. RBC was maintained without practising any selection. Among selected families, the same selection process was repeated in the second (G2) and third (G3) generations.

2.4. Housing and management

Experimental birds were placed in cages specially made for quail rearing and breeding. Eggs were tagged and collected according to the particular family identification numbers. For hatching, eggs were placed in an automatic multistage incubator (Victoria Italy). After hatching, the chicks were placed in customized Ventury Welders battery cages already placed in well ventilated octagonal shape quail sheds with 33 × 12 × 9 ft dimensions. An uninterrupted supply of water was ensured with the help of nipple drinkers. A broiler starter ration (CP = 24% and ME = 2900 kcal/kg) was provided to broiler quails up to 5 weeks and a breeder ration (CP = 19.5% and ME = 2900 kcal/kg) was offered from 6th to 12th week of age. A photoperiod of 16 h was provided on daily basis throughout the experimental period.

2.5. Production performance (6 to 16 weeks)

A measured amount of feed (g) was offered to each family for 24 h. After that, feed refusal was weighed from each experimental unit and was divided by the total number of the birds. An average of the daily intake of the feed was derived at the end of each week. The average egg weight from each family was calculated by totalling the weights of all eggs from a specific family and then dividing it by the total number of eggs. The data were further converted into weekly data and an overall average was obtained similarly at the end of 16 weeks. Hen day egg production (HDEP) and hen house egg production (HHEP) was calculated on a weekly and overall basis (average of 1–16 weeks) by using following formula:

Hen day egg production (%) = (Number of egg produced / Number of females present at that day) × 100

Hen house egg production (%) = (Number of egg Produced / Number of females placed at the start of experiment) × 100

Feed per dozen eggs (FCRdz): It was calculated by using following formula.

FCRdz = (Total feed consumed (kg) / Number of eggs produced) × 12

FCR/kg egg mass (FCRem): It was determined by dividing the total feed consumed by the total egg mass-produced during the experimental period. The formula used for calculating the amount of feed per/egg mass is given below.

FCRem = Total feed consumed (kg) / Total egg mass produced (kg)

2.6. Egg geometry and quality traits (8th and 16th week)

In total, 1440 eggs were subjected to egg quality and geometry analysis during all four generations, 720 eggs at the 8th and 16th week of the age both. Of these 720 eggs, each genetic line shared 120 eggs in each generation where three eggs from each family were picked.

For egg geometry, the egg length and breadth were measured to calculate the shape index (SI), surface area (SA) and volume (EV). Shape index was calculated by the following formula as adopted by Lohani and Ahmad [9]:

Shape index = (Egg width / Egg length) × 100.

The surface area and volume of each egg were derived from the equations adopted by Lohani and Ahmad [9]:

Surface area (cm^2) = K × $W^{0.67}$; Volume of egg (cm^3) = 0.913 × W,

where K (constant) = 4.558 and W is the egg weight in grams.

Each egg was weighed on a weighing scale having the least count of 0.01 g and later these egg weights (g) were used to calculate the Haugh unit scores. Before calculating the Haugh unit, the individual egg was broken in a Petri dish and the height of the albumen (mm) was measured using a specific tripod micrometre stand specially designed for measuring albumen height. Albumen height was taken from three places and the average value was used in calculating the Haugh unit. Haugh unit of the individual egg was determined using and egg weight and albumen height [10] following the formula:

$HU = 100 \log (H - 1.7W^{0.37} + 7.6)$,

where HU = Haugh unit, H is the albumen height and W is the egg weight. Eggshell thickness (mm) was measured with the help of screw gauge (Mitutoyo/Insize Outside Micrometers, USA) on three points i.e. air cell, equator and the sharp end of each egg and an average thickness of these three points were considered as shell thickness of the respective egg. Yolk quality was also assessed by calculating the yolk index. Yolk index was calculated by dividing the yolk height (mm) with the width (mm) and multiplying the answer with 100 [11].

2.7. Hatching traits (14th week)

At 14 weeks of age, eggs of each family were collected for seven days and settable numbers of the eggs were subjected to incubation in a multistage stage incubator (Victoria Inc., Italy). The eggs were kept inside the setter portion under standard incubation protocols for 14 days (27.5 °C temperature; 55% relative humidity with 8 times turning a day). At 15 days of incubation, eggs were shifted to the hatcher section until 17 days (36.5 °C temperature; 65% relative humidity). After 17 days of incubation, total chicks and unhatched eggs were counted to derive the total hatched eggs. The unhatched eggs were subjected to breakout analysis to determine the numbers of infertile eggs and embryonic mortalities with naked-eye observations. Following parameters were evaluated by the method adapted by Rehman and Qaisrani [12]:

Fertile eggs (FE%): It was calculated as

Fertile eggs % = (Number of fertile eggs / Number of eggs set) × 100.

Infertile eggs (IFE%): it was observed by destructive method and calculate by using following formula.

Infertile eggs % = (Number of clear eggs / Number of eggs set) × 100

Hatchability (%): To calculate hatchability % following formula was used.

Hatchability % = (Number of chicks hatched / Number of fertile eggs) × 100

Embryonic mortality (%): It was categorized as early (1–7 days), mid (8–14 days), and late (15–17 days) embryonic mortality and calculated as

Embryonic mortality % = (Number of dead embryos (early, mid or late) / Number of eggs set) × 100.

Hatchling weight (HW, g): Weight of chick was recorded on electrical weighing balance capable of measuring up to 0.01 g.

2.8. Statistical analysis

Collected data were analysed under the factorial ANOVA technique using the general linear model procedure with the help of the Statistical Analysis System (SAS, version 9.1). Significant means were separated through Duncan's multiple range test.

3. Results and discussion

3.1. Production performance

In the present study, significant variations were observed for feed intake per bird per day (FI/B/D) of Japanese quails ($p < 0.0001$) among the groups of genetic lines and within generations. WBS quails consumed the highest FI/B/D as compared to RBC and EBS lines. G3 had the highest FI/B/D followed by G2, G1 while birds of G0 had minimum feed intake (Table 1). A significant interaction was also noted among the genetic lines and generations ($p < 0.0001$). FI/B/D was increased gradually during selection in consecutive generations where WBS birds during G3 presented increased FI/B/D while the lowest was in EBS during G0 (Table 2). This increase in FI/B/D might be attributed to the selection of both growth performance and production performance that resulted in increased feed intake [13]. Nazligul et al. [14] also reported the difference in feed consumption of Japanese quails affected by variation in body weight. Similarly, in Japanese quails, higher feed intake was noted in pedigree birds as compared to mass-selected birds and RBC groups [7]. In higher egg-producing selected lines significant variations for feed intake were already been reported by El-Deen et al. [15] as compared to the RBC group. Khaldari et al. [16] also observed increased feed intake in higher body weight selected lines as compared to nonselected birds. Similarly, increased feed intake in broiler breeders in response to increased body weight was also reported [17]. Considerable differences in feed intake were observed in different breeds of chicken due to the differences in the genetic background of the breeds [18].

In terms of different genetic lines, a significant difference ($p < 0.0001$) was observed regarding HDEP and EN/B. Higher HDEP and EN/B were recorded in EBS lines than those of WBS and RBC lines (Table 1). However, HDEP and EN/B were comparable among the birds of different generations ($p = 0.8996$). The overall results of the interaction between lines and generations were significant ($p < 0.0001$) with the highest HDEP and EN/B of EBSG3 while lowest in RBCG2 (Table 2). This differential response to different lines might be due to the selection accuracy resulted in higher HDEP and EN/B in EBS. Similarly, a higher egg number was reported in Japanese quail selected for higher egg production in two generations [19]. El-Deen et al. [15] also observed higher egg production in selected birds than the control group.

Table 1. Effect of family-based selection for improved body weight and egg production on breeder production performance (7 to 16 weeks).[1]

Item	Lines			p - value	Generation				p-value
	WBS	EBS	RBC		G0	G1	G2	G3	
FI/B/D	37.04 ± 0.17[a]	36.04 ± 0.17[b]	36.36 ± 0.17[b]	< 0.0001	35.71 ± 0.21[c]	36.34 ± 0.18[b]	36.73 ± 0.18[ab]	37.14 ± 0.19[a]	< 0.0001
HDEP	68.01 ± 0.37[b]	70.96 ± 0.46[a]	67.44 ± 0.35[b]	< 0.0001	68.82 ± 0.41	68.77 ± 0.50	68.58 ± 0.53	69.05 ± 0.55	0.8996
EN/B	47.61 ± 0.26[b]	49.67 ± 0.32[a]	47.21 ± 0.25[b]	< 0.0001	48.17 ± 0.29	48.14 ± 0.35	48.01 ± 0.37	48.33 ± 0.38	0.8996
HHEP	65.54 ± 0.29[b]	68.53 ± 0.32[a]	66.06 ± 0.34[b]	< 0.0001	65.98 ± 0.27[b]	66.66 ± 0.32[ab]	66.67 ± 0.45[ab]	67.54 ± 0.51[a]	0.0098
EW	12.46 ± 0.11[a]	12.18 ± 0.08[b]	11.39 ± 0.02[c]	< 0.0001	11.40 ± 0.17[d]	11.82 ± 0.07[c]	12.22 ± 0.10[b]	12.60 ± 0.13[a]	< 0.0001
FCRdz	0.66 ± 0.00[a]	0.61 ± 0.00[b]	0.65 ± 0.00[a]	< 0.0001	0.62 ± 0.00[b]	0.64 ± 0.01[ab]	0.64 ± 0.01[a]	0.65 ± 0.01[a]	0.0018
FCRem	4.40 ± 0.04[b]	4.20 ± 0.05[c]	4.74 ± 0.03[a]	< 0.0001	4.57 ± 0.05[a]	4.49 ± 0.05[ab]	4.42 ± 0.06[bc]	4.31 ± 0.06[c]	0.0001

[a-c] Means in a row with no common superscript differ significantly at $p \leq 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; FI/B/D = Feed Intake per bird per day (g); HDEP = Hen Day Production Percentage; EN/B = Egg number per bird; HHEP= Hen House Production Percentage; EW= Egg Weight (g); FCRdz = Feed Conversion Ratio per dozen eggs; FCRem = Feed Conversion Ratio per kg egg mass.

In the present study, the WBS line showed a continuous decrease in EN/B through generations which are in agreement with Kaye et al. [20] who observed lower egg numbers during G2 than G1 and baseline population in HW selected groups.

HHEP was significantly affected by different genetic lines ($p < 0.0001$) and generations ($p = 0.0098$). HHEP was higher in EBS as compared to RBC and WBS lines. Similarly, regarding generation's higher HHEP was noted in G3 followed by G2, G1, and G0 (Table 1). Interaction between lines and generations also differs significantly ($p < 0.0001$) with the highest HHEP in birds of EBS line during G3 while the lowest HHEP was observed in the WBS line in G3 (Table 2). Similar findings were observed by Okuda et al. [19] who reported an increase in egg numbers of selected lines of Japanese quails for egg production. Akram et al. [21] also describe the difference in production % among close-breed stocks of Japanese quails. Some other scientists also reported considerable differences in production % in Japanese quails due to the variation in their body weight [22].

In terms of different genetic lines and generations, significant differences ($p < 0.0001$) were observed regarding EW. Japanese quails of the WBS line showed higher EW followed by EBS and RBC lines. EW was the highest during G3 as compared to G2 and G1 while the lowest EW was recorded in G0 (Table 1). Genetic lines and generations interacted well for EW ($p < 0.0001$). Higher values of EW were observed in WBSG3 while the lowest value was noted in G0 of the RBC line (Table 2). It might be attributed to the positive relation between EW and selection for increased body weight and egg numbers. So, this change in gene frequency controlling egg weight also results in increased ova size and albumen secretions [7,23]. The present study is in line with the findings of Alkan et al. [24] who observed a significant change in egg weight for both lines selected for higher BW and egg production in Japanese quails. El-Deen et al. [15] also reported increased EW through consecutive two generations of selection for higher egg production when compared to the control line. Similarly, another study on Japanese quails noted improved EW in birds selected for higher egg production [19].

There was a significant difference in feed per dozen eggs (FCRdz) of genetic lines ($p < 0.0001$) and generations ($p = 0.0018$) as well as their interaction ($p < 0.0001$). Significantly better FCRdz was noted in EBS line as compared to RBC and WBS lines. Higher FCRdz was presented in G3 followed by G2, G1 while birds of G0 had minimum and better FCRdz (Table 1). As far as interaction of genetic lines × generation is concerned improved FCRdz was observed in EBSG3 and EBSG2 while the poorest was in WBSG3 (Table 2). Improved FCRdz might be due to the better and increased feed efficiency in selected birds. The present study is in agreement with Kosba et al. [25] who reported the improved FCR in selected lines of Japanese quail as compared to the control group. Similarly, another study indicated better feed efficiency in birds selected for higher four-week body weight in Japanese quail [16]. However, in another experiment, no difference in FCRdz was noted between groups of local and imported Japanese quail [26].

Feed per kg egg mass (FCRem) was significantly affected by genetic lines ($p < 0.0001$) and generations ($p =$

Table 2. Interaction effects (lines × generation) on breeder production performance (7 to 16 weeks).[1]

Item	WBS				EBS				RBC				p-value
	G0	G1	G2	G3	G0	G1	G2	G3	G0	G1	G2	G3	
FI/B/D	35.82 ± 0.39^{cd}	36.61 ± 0.30^{bc}	37.46 ± 0.16^{ab}	38.26 ± 0.19^{a}	35.48 ± 0.34^{d}	35.92 ± 0.30^{cd}	36.12 ± 0.38^{cd}	36.65 ± 0.32^{bc}	35.82 ± 0.39^{cd}	36.48 ± 0.35^{a}	36.62 ± 0.30^{bc}	36.51 ± 0.34^{bc}	< 0.0001
HDEP	69.42 ± 0.66^{cd}	68.44 ± 0.87^{cdef}	67.75 ± 0.67^{cdef}	66.43 ± 0.57^{ef}	68.72 ± 0.71^{cde}	69.93 ± 0.96^{bc}	71.87 ± 0.92^{ab}	73.32 ± 0.76^{a}	68.33 ± 0.78^{cdef}	67.93 ± 0.73^{cdef}	66.13 ± 0.60^{f}	67.39 ± 0.65^{def}	< 0.0001
EN/B	48.59 ± 0.46^{cd}	47.91 ± 0.61^{cdef}	47.42 ± 0.47^{cdef}	46.50 ± 0.40^{ef}	48.10 ± 0.49^{cde}	48.95 ± 0.67^{bc}	50.31 ± 0.65^{ab}	51.32 ± 0.53^{a}	47.83 ± 0.54^{cdef}	47.55 ± 0.51^{cdef}	46.29 ± 0.42^{f}	47.17 ± 0.45^{def}	< 0.0001
HHEP	66.32 ± 0.38^{cd}	66.26 ± 0.55^{cd}	65.22 ± 0.77^{de}	64.38 ± 0.52^{e}	65.64 ± 0.30^{cde}	67.20 ± 0.56^{c}	69.79 ± 0.35^{b}	71.50 ± 0.34^{a}	65.99 ± 0.64^{cde}	66.51 ± 0.56^{cd}	65.01 ± 0.65^{de}	66.73 ± 0.82^{cd}	< 0.0001
EW	11.41 ± 0.14^{d}	12.11 ± 0.14^{c}	12.71 ± 0.14^{b}	13.60 ± 0.14^{a}	11.44 ± 0.14^{d}	11.96 ± 0.12^{c}	12.51 ± 0.13^{b}	12.82 ± 0.10^{b}	11.36 ± 0.05^{d}	11.39 ± 0.04^{d}	11.43 ± 0.04^{d}	11.38 ± 0.03^{d}	< 0.0001
FCRdz	0.62 ± 0.01^{def}	0.64 ± 0.01^{bcde}	0.66 ± 0.01^{b}	0.69 ± 0.01^{a}	0.62 ± 0.01^{def}	0.62 ± 0.01^{ef}	0.60 ± 0.01^{f}	0.60 ± 0.01^{f}	0.63 ± 0.01^{cde}	0.65 ± 0.01^{bcd}	0.67 ± 0.01^{b}	0.65 ± 0.01^{bc}	< 0.0001
FCRem	4.54 ± 0.09^{cde}	4.44 ± 0.09^{def}	4.37 ± 0.06^{ef}	4.25 ± 0.06^{f}	4.54 ± 0.09^{cde}	4.32 ± 0.08^{f}	4.03 ± 0.06^{g}	3.91 ± 0.06^{g}	4.63 ± 0.07^{bcd}	4.72 ± 0.06^{abc}	4.85 ± 0.07^{a}	4.77 ± 0.06^{ab}	< 0.0001

$^{a\text{-}c}$ Means in a row with no common superscript differ significantly at $p \leq 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; FI/B/D = Feed Intake per bird per day (g); HDEP = Hen Day Production Percentage; EN/B = Egg number per bird; HHEP= Hen House Production Percentage; EW= Egg Weight (g); FCRdz = Feed Conversion Ratio per dozen eggs; FCRem = Feed Conversion Ratio per kg egg mass.

0.0001). EBS line showed improved FCRem as compared to WBS and RBC lines. Better FCRem was observed in G3 as compared to G2, G1 while the poorest FCRem was recorded during G0 (Table 1). Significant variations ($p < 0.0001$) were observed among selection lines and generations interactions. Quail birds of the EBS line during G3 showed better FCRem while birds of the RBC line during G2 had the poorest (Table 2). The improvement of FCRem in selected lines is attributed to the ability to use feed efficiently. Similarly, FCRem differs significantly among the close-bred stock of Japanese quails [27]. However, Rehman [26] reported no effect of different strains on FCRem.

3.2. Egg geometry and quality traits

Egg geometrical parameters such as shape index, surface area and volume are important to study as they play a critical role in embryonic development and hence can influence the day-old chick yield. In the current study, generations did not affect the egg geometry except the shape index ($p = 0.0035$) but selection strategies significantly affected the egg surface area ($p < 0.0001$) and volume ($p < 0.0001$) but generations had comparable values (Table 3–6). At both ages i.e. the 8th and 16th weeks, surface area and volume of the egg were significantly highest in WBS3 and the lowest values were found in WBS0. The birds in the WBS0 group were nonselected random bred quails. Our findings are in accordance with the findings of Nasr et al. [28] who reported a significantly higher egg surface area in quails selected for higher body weight than those selected for lower body weight. Egg surface area and volume are highly dependent on the length and breadth of the egg [11]. The length and breadth of the egg have been reported to be a positive correlation with the hen's body weight and egg weight [29]. Most probably, the higher egg surface area in WBS3 is due to continuous selection for body weight of those birds. This is in agreement with findings of earlier studies where body weight selected quails presented higher values of egg length and breadth [30]. Hence, the higher egg surface area in WBS3 favours the selection for higher body weight up to four consecutive generations.

Egg shape index differed significantly among the genetic lines and generations at the 8th week (Table 3). However, at the 16th week of age, generations had no impact on it (Table 5). Significantly highest shape index values were found in random bred quails of first generation (at the 8th week) and third generation (at the 16th week) than egg number based selected quails (Tables 4 and 6). Among the genetic lines, WBS quails and RBC quails had significantly higher egg shape index values than EBS quails (Table 5). Similarly, Hrnčár et al. [31] found a significantly higher value of egg shape index in WBS compared to EBS line in 20-weeks-old quails. In another study, two genetic lines of Japanese quail differed significantly in egg shape index at the 25th week of age [32]. Higher shape index in random bred population and weight base selected quails illustrated more rounded eggs in those lines compared to the eggs from egg number base selected quails. Contrary to our findings, Alkan et al. [24] observed that the quails selected for higher egg number produced eggs with higher egg shape index than those selected for higher body weight. Bagh et al. [33] found no difference in the egg volume and shape index of the eggs from the Grey, White and Brown varieties of quail.

In the 16th week, the albumen index was no affected by generations ($p = 0.9989$) and their interaction ($p = 0.4646$)

Table 3. Effect of family-based selection for improved body weight and egg production on egg geometry and quality traits at the 8th week.[1]

Item	Lines (n = 240)			p-value	Generation (n = 180)				p-value
	WBS	EBS	RBC		G0	G1	G2	G3	
SI	78.88 ± 0.34^{a}	77.68 ± 0.37^{b}	79.31 ± 0.39^{a}	0.0044	77.62 ± 0.40^{c}	79.09 ± 0.43^{ab}	78.17 ± 0.41^{bc}	79.61 ± 0.44^{a}	0.0035
SA	22.24 ± 0.11^{b}	22.54 ± 0.09^{a}	21.15 ± 0.08^{c}	< 0.0001	21.87 ± 0.12	21.90 ± 0.10	22.06 ± 0.10	22.07 ± 0.13	0.4125
EV	9.74 ± 0.07^{b}	9.94 ± 0.06^{a}	9.03 ± 0.05^{c}	< 0.0001	9.51 ± 0.08	9.52 ± 0.07	9.62 ± 0.07	9.63 ± 0.08	0.4099
AI	8.37 ± 0.10	8.59 ± 0.10	8.29 ± 0.11	0.1109	8.40 ± 0.12	8.39 ± 0.12	8.41 ± 0.12	8.46 ± 0.12	0.9797
YI	43.20 ± 0.18^{b}	43.76 ± 0.19^{a}	44.20 ± 0.18^{a}	0.0007	43.80 ± 0.21	43.75 ± 0.21	43.74 ± 0.21	43.58 ± 0.22	0.8976
HU	74.69 ± 0.06^{b}	74.62 ± 0.05^{b}	75.14 ± 0.05^{a}	< 0.0001	74.88 ± 0.06	74.86 ± 0.06	74.78 ± 0.06	74.76 ± 0.07	0.4320
ST	0.194 ± 0.001^{c}	0.205 ± 0.001^{a}	0.202 ± 0.001^{b}	< 0.0001	0.200 ± 0.001	0.201 ± 0.001	0.200 ± 0.001	0.202 ± 0.001	0.1772

[a-c] Means in a row with no common superscript differ significantly at $p \leq 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; SI = Shape Index; SA = Surface Area (cm^2); EV = Volume (cm^3); AI = Albumen Index; YI = Yolk Index; HU = Haugh Unit; ST = Shell Thickness (mm).

Table 4. Interaction effects (lines × generation) on egg geometry and quality traits at the 8th week.[1]

Item	WBS (n = 60)				EBS (n = 60)				RBC (n = 60)				p-value
	G0	G1	G2	G3	G0	G1	G2	G3	G0	G1	G2	G3	
SI	78.40 ± 0.69^{abc}	78.85 ± 0.68^{ab}	79.05 ± 0.68^{ab}	79.23 ± 0.67^{ab}	76.38 ± 0.69^{c}	77.83 ± 0.72^{bc}	77.45 ± 0.74^{bc}	79.05 ± 0.77^{ab}	78.09 ± 0.69^{bc}	80.59 ± 0.80^{a}	78.01 ± 0.72^{bc}	80.55 ± 0.81^{a}	< 0.0001
SA	20.98 ± 0.16^{d}	21.55 ± 0.16^{c}	22.53 ± 0.16^{b}	23.90 ± 0.15^{a}	23.51 ± 0.14^{a}	22.97 ± 0.14^{b}	22.55 ± 0.14^{b}	21.14 ± 0.15^{cd}	21.13 ± 0.16^{cd}	21.19 ± 0.15^{cd}	21.11 ± 0.16^{cd}	21.16 ± 0.14^{cd}	< 0.0001
EV	8.92 ± 0.10^{d}	9.29 ± 0.10^{c}	9.93 ± 0.10^{b}	10.84 ± 0.10^{a}	10.58 ± 0.09^{a}	10.21 ± 0.09^{b}	9.94 ± 0.09^{b}	9.02 ± 0.09^{cd}	9.02 ± 0.10^{cd}	9.06 ± 0.10^{cd}	9.01 ± 0.10^{cd}	9.04 ± 0.09^{cd}	< 0.0001
AI	8.27 ± 0.21	8.34 ± 0.21	8.40 ± 0.21	8.46 ± 0.21	8.63 ± 0.21	8.60 ± 0.21	8.58 ± 0.21	8.53 ± 0.21	8.29 ± 0.21	8.23 ± 0.21	8.24 ± 0.21	8.39 ± 0.22	0.9161
YI	44.38 ± 0.37^{ab}	43.61 ± 0.36^{bc}	42.76 ± 0.35^{cd}	42.06 ± 0.34^{d}	42.75 ± 0.35^{cd}	43.31 ± 0.36^{bc}	44.19 ± 0.37^{ab}	44.79 ± 0.37^{a}	44.28 ± 0.37^{ab}	44.34 ± 0.37^{ab}	44.27 ± 0.37^{ab}	43.90 ± 0.35^{ab}	< 0.0001
HU	75.24 ± 0.10^{a}	75.00 ± 0.10^{a}	74.57 ± 0.10^{b}	73.96 ± 0.09^{d}	74.22 ± 0.09^{cd}	74.45 ± 0.09^{bc}	74.59 ± 0.09^{b}	75.23 ± 0.09^{a}	75.17 ± 0.10^{a}	75.13 ± 0.09^{a}	75.17 ± 0.10^{a}	75.10 ± 0.10^{a}	< 0.0001
ST	0.189 ± 0.001^{f}	0.192 ± 0.001^{ef}	0.196 ± 0.001^{de}	0.199 ± 0.001^{cd}	0.209 ± 0.001^{a}	0.2006 ± 0.001^{ab}	0.202 ± 0.001^{bc}	0.203 ± 0.001^{bc}	0.200 ± 0.002^{cd}	0.203 ± 0.002^{bc}	0.202 ± 0.002^{bc}	0.204 ± 0.001^{bc}	< 0.0001

[a-c] Means in a row with no common superscript differ significantly at $p \leq 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; SI = Shape Index; SA = Surface Area (cm^2); EV = Volume (cm^3); AI = Albumen Index; YI = Yolk Index; HU = Haugh Unit; ST = Shell Thickness (mm).

Table 5. Effect of family-based selection for improved body weight and egg production on egg geometry and quality traits at the16th week.[1]

Item	Lines (n = 80)			p-value	Generation (n = 60)				p-value
	WBS	EBS	RBC		G0	G1	G2	G3	
SI	80.17 ± 0.30[a]	77.92 ± 0.36[b]	80.96 ± 0.38[a]	< 0.0001	79.45 ± 0.44	79.73 ± 0.43	79.74 ± 0.38	79.81 ± 0.40	0.9234
SA	24.73 ± 0.10[a]	23.00 ± 0.08[c]	23.53 ± 0.08[b]	< 0.0001	23.51 ± 0.08[c]	23.64 ± 0.08[bc]	23.84 ± 0.12[ab]	24.03 ± 0.16[a]	0.0014
EV	11.41 ± 0.07[a]	10.24 ± 0.05[c]	10.59 ± 0.05[b]	< 0.0001	10.57 ± 0.06[c]	10.66 ± 0.06[bc]	10.81 ± 0.08[ab]	10.94 ± 0.11[a]	0.0006
AI	8.47 ± 0.10[b]	8.75 ± 0.11[ab]	8.96 ± 0.11[a]	0.0054	8.72 ± 0.12	8.71 ± 0.12	8.72 ± 0.12	8.74 ± 0.12	0.9989
YI	43.87 ± 0.18[b]	44.94 ± 0.19[a]	44.03 ± 0.18[b]	< 0.0001	44.39 ± 0.21	44.26 ± 0.21	44.33 ± 0.21	44.15 ± 0.23	0.8714
HU	73.67 ± 0.06[c]	74.35 ± 0.05[a]	74.11 ± 0.05[b]	< 0.0001	74.15 ± 0.06[a]	74.10 ± 0.06[a]	74.00 ± 0.07[ab]	73.90 ± 0.08[b]	0.0356
ST	0.185 ± 0.001[c]	0.196 ± 0.001[a]	0.193 ± 0.001[b]	< 0.0001	0.191 ± 0.001	0.192 ± 0.001	0.191 ± 0.001	0.193 ± 0.001	0.1612

[a-c] Means in a row with no common superscript differ significantly at $p \leq 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; SI = Shape Index; SA = Surface Area (cm^2); EV = Volume (cm^3); AI = Albumen Index; YI = Yolk Index; HU = Haugh Unit; ST = Shell Thickness (mm).

(Tables 5 and 6). At the 16th weeks of age, RBC quails had a significantly higher (p = 0.0054) albumen index than WBS while the EBS line presented comparable value to RBC and WBS (Table 5). Similarly, Alkan et al. [24] showed a nonsignificant difference in the albumen index in egg type quails and random bred control quails. Albumen index is the ratio of height and width of the albumen. The higher the height, the higher will be the value of the albumen index and the better will the egg quality. A higher albumen index value in WBS quails at the 16th week is in agreement with the findings of Nasr et al. [28] who presented a higher value of albumen height in weight base selected quails than those selected for lower body weight and random bred control groups. This implied that the selection for body weight may result in improvement in the albumen index and hence in egg quality. Contrarily, Hanusová et al. [32] reported no difference in the albumen index of weight base selected and random bred control Japanese quails.

At both ages, egg yolk index was significantly (8th week p = 0.0007; 16th week p < 0.0001) better in EBS lines compared to WBS quails and generations did not affect (8th week p = 0.8976; 16th week p = 0.8714) the yolk index of the quails (Tables 3 and 5). In interaction, significant differences were observed among the different treatment groups. The quails from the EBS3 group produced eggs with the highest yolk index whereas the lowest yolk index was found in the WBS3 group at the 8th and 16th weeks of age (Tables 4 and 6). The higher yolk index value indicates that the eggs from EBS3 were less prone to evaporation losses during the storage, whereas the eggs from WBS3 may encounter higher losses [34]. It might be due to higher egg weight and less eggshell thickness in the WBS3 group. Earlier to this, Alkan et al. [24] showed a significantly higher yolk index in the low body weight line compared to the high body weight line of Japanese quail. However, Taskin et al. [30] reported a significantly higher value of yolk index in high body weight selected quails than those selected for low body weight and random bred control groups.

Haugh unit score is considered the best mathematical term for measuring the internal egg quality as it describes the egg protein quality [35]. In the present study, genetic lines differed significantly in their Haugh unit scores of eggs. At the 8th week of age, Haugh unit score was significantly better (p < 0.0001) in RBC quails than WBS and EBS (Table 3). In the 16th week, EBS had the highest Haugh unit score (p < 0.0001) followed by RBC while the lowest Haugh unit was found in WBS quails (Table 5). There was no effect (p = 0.4320) of generations on Haugh unit score of the eggs at the 8th week but the mean Haugh score of eggs at the 16th week of age was significantly higher (p = 0.0356) in base population than that of third generation quails. Haugh unit depends on the egg weight and albumen measurements. Earlier to this, Kaye et al. [20] showed a significant effect of generations and age on the egg weight and albumen length. It is possible that the increase in the egg weight and albumen measurements might have resulted in a higher Haugh unit score in different generations. Concerning interaction between genetic lines and generations, the highest value (p < 0.0001) of the Haugh unit was noted in EBS3 while the lowest value was found in WBS3 at both ages (Tables 4 and 6). Previously, it has been reported that the albumen height increased with an increase in egg size [36]. Possibly,

Table 6. Interaction effects (lines × generation) on egg geometry and quality traits at the 16th week.[1]

Item	WBS (n = 20)				EBS (n = 20)				RBC (n = 20)				p-value
	G0	G1	G2	G3	G0	G1	G2	G3	G0	G1	G2	G3	
SI	80.28 ± 0.73^{abc}	80.40 ± 0.73^{abc}	79.85 ± 0.46^{abcd}	80.15 ± 0.43^{abc}	77.07 ± 0.69^{e}	78.23 ± 0.72^{cde}	78.41 ± 0.72^{bcde}	77.96 ± 0.73^{de}	81.00 ± 0.77^{a}	80.57 ± 0.75^{b}	80.95 ± 0.74^{a}	81.33 ± 0.79^{a}	< 0.0001
SA	23.36 ± 0.14^{d}	23.90 ± 0.14^{c}	25.24 ± 0.13^{b}	26.40 ± 0.12^{a}	23.90 ± 0.14^{c}	23.36 ± 0.14^{d}	22.67 ± 0.14^{e}	22.06 ± 0.13^{f}	23.25 ± 0.15^{d}	23.64 ± 0.15^{cd}	23.62 ± 0.16^{cd}	23.61 ± 0.15^{cd}	< 0.0001
EV	10.47 ± 0.09^{d}	10.84 ± 0.09^{c}	11.75 ± 0.09^{b}	12.57 ± 0.09^{a}	10.84 ± 0.09^{c}	10.47 ± 0.09^{d}	10.02 ± 0.09^{e}	9.61 ± 0.08^{f}	10.40 ± 0.10^{d}	10.66 ± 0.10^{cd}	10.65 ± 0.11^{cd}	10.64 ± 0.10^{cd}	< 0.0001
AI	8.47 ± 0.21	8.50 ± 0.21	8.40 ± 0.20	8.51 ± 0.20	8.74 ± 0.21	8.71 ± 0.21	8.81 ± 0.22	8.73 ± 0.22	8.97 ± 0.22	8.94 ± 0.22	8.94 ± 0.22	8.99 ± 0.22	0.4646
YI	44.64 ± 0.36^{bc}	44.19 ± 0.36^{bc}	43.85 ± 0.35^{bcd}	42.81 ± 0.34^{d}	44.16 ± 0.37^{bc}	44.61 ± 0.37^{bc}	44.98 ± 0.38^{b}	46.01 ± 0.39^{a}	44.38 ± 0.37^{bc}	43.97 ± 0.37^{bc}	44.15 ± 0.36^{bc}	43.63 ± 0.37^{cd}	< 0.0001
HU	74.23 ± 0.10^{bc}	74.00 ± 0.10^{c}	73.47 ± 0.10^{d}	72.97 ± 0.10^{e}	73.99 ± 0.10^{c}	74.22 ± 0.10^{bc}	74.46 ± 0.10^{ab}	74.72 ± 0.10^{a}	74.24 ± 0.10^{bc}	74.07 ± 0.10^{c}	74.08 ± 0.11^{c}	74.03 ± 0.12^{c}	< 0.0001
ST	0.180 ± 0.001^{f}	0.183 ± 0.001^{ef}	0.187 ± 0.001^{de}	0.190 ± 0.001^{cd}	0.200 ± 0.001^{a}	0.197 ± 0.001^{ab}	0.193 ± 0.001^{bc}	0.194 ± 0.001^{bc}	0.191 ± 0.002^{cd}	0.194 ± 0.002^{bc}	0.193 ± 0.002^{bc}	0.195 ± 0.001^{bc}	< 0.0001

$^{a-c}$ Means in a row with no common superscript differ significantly at $p \leq 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; SI = Shape Index; SA = Surface Area (cm^2); EV = Volume (cm^3); AI = Albumen Index; YI = Yolk Index; HU = Haugh Unit; ST = Shell Thickness (mm).

Table 7. Effect of family-based selection for improved body weight and egg production on hatching traits.[1]

Item	Lines			p-value	Generation				p-value
	WBS	EBS	RBC		G0	G1	G2	G3	
FE	83.47 ± 0.40^{b}	84.72 ± 0.33^{a}	85.28 ± 0.30^{a}	0.0005	85.54 ± 0.40^{a}	84.17 ± 0.38^{b}	83.75 ± 0.44^{b}	84.50 ± 0.39^{ab}	0.0076
IFE	16.53 ± 0.40^{a}	15.28 ± 0.33^{b}	14.72 ± 0.30^{b}	0.0005	14.46 ± 0.40^{b}	15.83 ± 0.38^{a}	16.25 ± 0.44^{a}	15.50 ± 0.39^{ab}	0.0076
Hatch	71.00 ± 0.56^{c}	74.53 ± 0.25^{a}	72.19 ± 0.31^{b}	< 0.0001	73.39 ± 0.55	72.46 ± 0.38	72.24 ± 0.55	72.20 ± 0.47	0.2088
EEM	4.05 ± 0.24^{a}	2.61 ± 0.22^{b}	3.60 ± 0.23^{a}	< 0.0001	3.53 ± 0.30	3.26 ± 0.28	3.43 ± 0.28	3.46 ± 0.25	0.9056
MEM	3.72 ± 0.23	3.87 ± 0.20	3.62 ± 0.24	0.7417	3.72 ± 0.27	3.94 ± 0.30	3.74 ± 0.22	3.54 ± 0.25	0.7663
LEM	3.72 ± 0.23^{b}	3.77 ± 0.24^{c}	5.87 ± 0.33^{a}	< 0.0001	4.96 ± 0.39	4.51 ± 0.37	4.37 ± 0.33	5.29 ± 0.32	0.2009
HW	8.86 ± 0.06^{a}	8.67 ± 0.05^{b}	8.27 ± 0.04^{c}	< 0.0001	8.27 ± 0.04^{c}	8.61 ± 0.05^{b}	8.74 ± 0.07^{a}	8.79 ± 0.07^{a}	< 0.0001

[a-c] Means in a row with no common superscript differ significantly at $p \leq 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; FE= Fertile Eggs (%); IFE= Infertile Eggs (%); Hatch= Hatchability (%); EEM= Early Embryonic Mortality (%); MEM = Mid Embryonic Mortality (%); LEM= Late Embryonic Mortality (%); HW= Hatching Weight (g).

the greater egg weight in the WBS line of the current experiment had resulted in higher values of albumen height that led to the higher Haugh unit score. Contrary to our results, Alkan et al. [24] reported a significantly higher Haugh unit score in the high body weight line than egg type line of Japanese quails. Hrnčár et al. [31] were unable to find a significant difference in Haugh unit scores of eggs and meat type quails.

Eggshell thickness is generally used to describe shell strength. Higher the eggshell thickness less would be the chances egg breakage. In the current study, the eggshell thickness was significantly higher ($p < 0.0001$) in the eggs (both ages) of the EBS line followed by RBC and the lowest was noted in the eggs of WBS quails (Tables 3 and 5). Eggshell thickness shows the shell strength of the egg. The current study showed that the eggshell thickness was significantly higher in egg type quail i.e. EBS than WBS. However, Hrnčár et al. [31] found no difference in the shell thickness values meat type and egg type lines but the strength of the egg shell was significantly higher in egg type quails than meat type one. In interactions, EBS showed the highest values in EBS0. Although, the birds in EBS0 were random bred control or base population, yet the quails in the EBS line presented higher values in G1 and G2 than WBS quails of G1 and G2. However, in later generations i.e. G3, the shell thickness was comparable in both genetic groups (Tables 4 and 6). It was interesting to note that all of the EBS treatments were comparable to those of RBCs groups except the EBS0. This is in line with the findings of Fathi et al. [37] who found no difference in the eggshell thickness of egg type quails and nonselected quails. The higher thickness of eggshell in egg type line than weight base selected quails could be associated with the higher production potential of these birds [37,38]. In commercial layer chickens, it is a general belief of the researchers that the high producing laying hens store the calcium carbonate during the prelay period in the medullary bone to compensate for the calcium loss in eggshell formation [39]. The same phenomenon can be expected in Japanese quails of a current experiment that might have led to more deposition of calcium and thicker eggshell in egg type line than weight base selected line. Moreover, WBS quails produced heavier eggs than EBS which might also be responsible to utilize more calcium on eggs with bigger sizes than EBS quails and hence might have led to the thinner eggshell.

3.3. Hatching traits

In terms of different genetic lines ($p = 0.0005$) and generations ($p = 0.0076$) as well as their interaction ($p < 0.0001$), significant differences were observed regarding fertile egg (FE%) and infertile eggs (IFE%). RBC group showed higher FE% than those of EBS and WBS lines. However, IFE% was lower in birds of RBC than those of EBS and WBS lines (Table 7). Regarding generation, with subsequent generations decrease FE%, and an increase in IFE% was observed. Where, G0 showed better FE% as compared to G3, G1, and G2 (Table 7). Similarly, higher values of FE% were observed in WBSG0 while the lowest FE% was in WBSG2. However, Highest IFE% was observed in G1 as compared to G2, G3, and the least value was observed in G0. WBS × G2 had a higher number of infertile eggs whereas the lowest values were observed in WBSG0 in terms of IFE% (Table 8). Continuous selection for higher weight had a negative impact on fertility [20]. This decrease in FE% and an increase in IFE% might be attributed to the change in body weight due to selection

Table 8. Interaction effects (lines × generation) on hatching traits.[1]

Item	WBS				EBS				RBC				p-value
	G0	G1	G2	G3	G0	G1	G2	G3	G0	G1	G2	G3	
FE	86.58 ± 0.76^{a}	82.80 ± 0.61^{de}	81.65 ± 0.67^{e}	82.86 ± 0.73^{cde}	84.27 ± 0.64^{bcd}	84.35 ± 0.67^{bcd}	84.49 ± 0.79^{abcd}	85.76 ± 0.49^{ab}	85.77 ± 0.61^{ab}	85.36 ± 0.60^{ab}	85.11 ± 0.60^{ab}	84.87 ± 0.64^{abc}	< 0.0001
IFE	13.42 ± 0.76^{e}	17.20 ± 0.61^{ab}	18.35 ± 0.67^{a}	17.14 ± 0.73^{abc}	15.73 ± 0.64^{bcd}	15.65 ± 0.67^{bcd}	15.51 ± 0.79^{bcde}	14.24 ± 0.49^{de}	14.23 ± 0.61^{de}	14.64 ± 0.60^{de}	14.89 ± 0.60^{de}	15.13 ± 0.64^{cde}	< 0.0001
Hatch	72.94 ± 1.38^{abcd}	70.99 ± 0.62^{de}	70.19 ± 1.35^{e}	69.88 ± 0.85^{e}	74.08 ± 0.55^{abc}	74.58 ± 0.46^{ab}	74.38 ± 0.49^{ab}	75.10 ± 0.54^{a}	73.16 ± 0.72^{abcd}	71.82 ± 0.61^{cde}	72.15 ± 0.52^{bcde}	71.63 ± 0.57^{cde}	< 0.0001
EEM	4.78 ± 0.49^{a}	3.37 ± 0.38^{abc}	3.92 ± 0.59^{abc}	4.12 ± 0.43^{ab}	2.54 ± 0.48^{c}	2.92 ± 0.46^{bc}	2.59 ± 0.37^{c}	2.41 ± 0.44^{c}	3.29 ± 0.46^{abc}	3.49 ± 0.60^{abc}	3.78 ± 0.44^{abc}	3.84 ± 0.36^{abc}	0.0083
MEM	4.02 ± 0.49	4.01 ± 0.55	3.37 ± 0.32	3.48 ± 0.49	3.75 ± 0.46	3.63 ± 0.42	4.34 ± 0.35	3.76 ± 0.41	3.38 ± 0.47	4.19 ± 0.62	3.53 ± 0.42	3.38 ± 0.40	0.8801
LEM	4.84 ± 0.59^{ab}	4.43 ± 0.59^{ab}	4.17 ± 0.56^{ab}	5.38 ± 0.61^{a}	4.10 ± 0.54^{ab}	3.23 ± 0.43^{b}	3.26 ± 0.41^{b}	4.48 ± 0.54^{ab}	5.93 ± 0.84^{a}	5.87 ± 0.74^{a}	5.66 ± 0.60^{a}	6.01 ± 0.48^{a}	0.0015
HW	8.27 ± 0.08^{c}	8.82 ± 0.05^{b}	9.13 ± 0.09^{a}	9.25 ± 0.09^{a}	8.28 ± 0.08^{c}	8.76 ± 0.08^{b}	8.84 ± 0.08^{b}	8.79 ± 0.08^{b}	8.27 ± 0.08^{c}	8.25 ± 0.08^{c}	8.25 ± 0.10^{c}	8.33 ± 0.09^{c}	< 0.0001

$^{a\text{-}c}$ Means in a row with no common superscript differ significantly at $p \le 0.05$.
[1]Values are the least-square mean ± standard error.
WBS = Weight Based Selection; EBS = Egg Based Selection; RBC = Random-Bred Control; G0 = Generation Zero; G1 = Generation 1; G2 = Generation 2; G3 = Generation 3; FE= Fertile Eggs (%); IFE= Infertile Eggs (%); Hatch= Hatchability (%); EEM= Early Embryonic Mortality (%); MEM = Mid Embryonic Mortality (%); LEM= Late Embryonic Mortality (%); HW= Hatching Weight (g).

because higher weight results in a decline of fertility in consecutive 3 generations have already been reported [40]. It can also be referred to as the difficulty in mating because of the large size or body frame [41,42]. Similarly, another study on Japanese quail pedigree birds had lower fertility as compared to the RBC group [7]. Rehman and Qaisrani [12] had also reported different variations among close-bred stocks for IFE in Japanese quails. However, some scientists suggest low weight selection for prolonged duration could result in decreased EF [43].

There was a significant difference ($p < 0.0001$) in hatchability % of genetic lines. However, hatchability % was comparable among the birds of different generations ($p = 0.2088$). Significantly better hatchability % was noted in EBS as compared to RBC and WBS (Table 7). Genetic lines and generations interacted very well for hatchability %. The birds from the EBS line during G3 presented better hatchability % as compared to birds of WBS × G3 (Table 8). This increase in hatch% might be due to the better water-retaining capacity of EBS eggs during incubation [44,45]. However, comparable hatch% through generations attributed to the lower heritability estimates [46]. Similarly, a decrease in hatch% among birds selected for higher body weight till 65 generations has already been reported [43]. This is contradicted with the findings of Ahmad et al. [7] who reported better hatch% in pedigreed quails selected for higher body weight as compared to the RBC group. However, in another study, no effect was observed on hatch% due to selection [47].

Early embryonic mortality (EEM) was affected significantly ($p < 0.0001$) among genetic lines of quails. However, generations were comparable for EEM% ($p = 0.9056$). EEM% was higher in WBS followed by RBC and EBS (Table 7). Genetic lines and generations interact significantly ($p = 0.0083$) with higher EEM% in RBC during G0 and the lowest during G3 of WBS birds (Table 8). Higher EEM % in the WBS group might be due to chromosomal abnormalities. Similarly, higher EEM % during the initial days of incubation had already been reported in selected lines of Japanese quails [48]. However, this is contraindicated with Ahmad et al. [7] who observed lower EEM in the mass-selected group than those of pedigreed and RBC groups of Japanese quails. However, Hussain et al. [46] reported no effect of selection on EEM%.

Mid embryonic mortality (MEM%) was nonsignificant among the birds of genetic lines ($p = 0.7417$) as well as generations ($p = 0.7663$) and no interaction ($p = 0.8801$) between lines and generations was noted. LEM% was significantly affected by genetic lines ($p < 0.0001$). Higher late embryonic mortality (LEM%) was noted in RBC than those of WBS and EBS lines. However, LEM% was comparable ($p = 0.2009$) among the birds of different generations (Table 7). The interaction between lines and generations ($p = 0.0015$) showed significant variations regarding LEM% with higher LEM% in RBCG3 and lowest in EBSG1 groups (Table 8). Similarly, Ahmad et al. [7] observed lower LEM in the mass-selected group while a high incidence of LEM was noted in RBC birds. However, other researchers suggested lower LEM% in eggs from RBC birds than those of selected lines [49]. Kaye et al. [20] also reported higher dead in shell % during incubation of eggs produced by higher weight selected birds than the control group.

In the present study, hatchling weight (HW) differs significantly ($p < 0.0001$) through generations among genetic lines as well as their interaction. HW was better in WBS as compared to EBS and RBC. Similarly, higher HW was observed in G3 than those in G2, G1, and G0 (Table 7). HW improved gradually during consecutive generations with the highest HW in WBSG3 and the lowest HW was noted in RBCG0 and WBSG0 (Table 8). This increase in HW of selected groups through generations might be attributed to the excessive selection of birds for both growth and production because heavyweight line birds produce heavy eggs and HW [50]. Hussain et al. [13] also observed maximum potential utilization of selection in pedigreed birds as compared to mass-selected and RBC groups regarding body weight. Similarly, higher HW was observed in pedigree selected Japanese quails than those of mass-selected and RBC groups [7]. Chick weight was also higher in heavyweight lines as compared to low weight lines compared at the time of hatching [47].

Despite the lower egg production, the quails selected for higher 4th-week body weight had better egg quality than those selected for egg type line; hence, the selection for body weight is more beneficial and effective than the egg based selection.

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References

1. Hussain J, Javed K, Hussnain F, Musarrat S, Mahmud A et al. Quality and sensory attributes of eggs from different chicken genotypes in Pakistan. Journal of Animal and Plant Sciences 2018; 28: 1609-1614.
2. Ghayas A, Hussain J, Mahmud A, Jaspal MH. Evaluation of three fast-and slow-growing chicken strains reared in two production environments. South African Journal of Animal Science 2020; 50: 378-388. doi: 10.4314/sajas.v50i3.4

3. Hussain J, Rabbani I, Aslam S, Ahmad HA. An overview of poultry industry in Pakistan. World's Poultry Science Journal 2015; 71 (4): 689-700. doi: 10.1017/S0043933915002366

4. Ghayas A, Hussain J, Mahmud A, Javed K, Rehman A et al. Productive performance, egg quality, and hatching traits of Japanese quail reared under different levels of glycerin. Poultry Science 2017; 96: 2226-2232. doi: 10.3382/ps/pex007

5. Ahmad S, Mehmood S, Javed K, Mahmud A, Usman M et al. Different selection strategies for the improvement of the growth performance and carcass traits of Japanese quails. Brazilian Journal of Poultry Science 2018; 20: 497-506. doi: 10.1590/1806-9061-2018-0733

6. Hussain J, Mehmood S, Ullah I, Mahmud A, Ghayas A et al. Post hatch performance of meat type Japanese quail influenced by time of offering feed and ambient environment. Journal of Animal and Plant Sciences 2019; 29 (2): 365-369.

7. Ahmad S, Hussain J, Mahmud A, Ishaq HM, Rehman A et al. Different selection strategies for improvement of egg quality and hatching traits of Japanese quail. European Poultry Science 2019; 83: 1-15. doi: 10.1399/eps.2019.289

8. Jatoi AS, Bughio E, Sahota AW, Akram M, Jaspal MH et al. Progeny growth performance as influenced by different parental body weights in four close-bred flocks of Japanese quails (coturnix coturnix japonica). Journal of Animal and Plant Sciences 2021; 31 (2): 358-368. doi: 10.36899/JAPS.2021.2.0223

9. Lohani F, Ahmad S. A comparison of some egg geometry parameters in four close-bred stocks of Japanese quail. Scientific Journal of Zoology 2013; 2(9): 99-101. doi: 10.14196/sjas.v2i9.996

10. Batool T, Farooq S, Roohi N, Mahmud A, Usman M et al. Effect of different dietary lysine regimens on meat quality attributes in varieties of indigenous Aseel chicken. Kafkas Universitesi Veteriner Fakultesi Dergisi 2018; 24: 639-645. doi: 10.9775/kvfd.2018.19523

11. Doyon G, Cardou MB, Hamiliton RMG, Castaigne F, Randall CJ. Egg quality. 2. Albumen quality of eggs from five commercial strains of White Leghorn hens during one year of lay. Poultry Science 1986; 65 (1): 63-66. doi: 10.3382/ps.0650063

12. Rehman A, Qaisrani IA. Comparative study on some hatching traits among four closebred stocks of Japanese quail. Agriculture Advances 2013; 2: 288-291. doi: 10.14196/aa.v2i11.1084

13. Hussain J, Akram M, Sahota AW, Javed K, Ahmad HA et al. Selection for higher three week body weight in Japanese quail. 1: Effect on growth performance. Journal of Animal and Plant Sciences 2013; 23 (6): 1496-1500.

14. Nazligul A, Turkyilmaz K, Bardalciodlu HE. A study on some production traits and egg quality characteristics of Japanese quail. Turkish Journal of Veterinary and Animal Sciences 2001; 25: 1007-1013.

15. El-Deen MB, Nour AA, El-Tahawy WS, Fouad HA. Effect of selection for weight of early eggs on egg production traits in Japanese quail. Asian Journal of Poultry Science 2015; 9 (4): 179-190. doi: 10.3923/ajpsaj.2016.64.71

16. Khaldari M, Pakdel A, Mehrabani Yegane H, Nejati Javaremi A, Berg P. Response to selection and genetic parameters of body and carcass weights in Japanese quail selected for 4-week body weight. Poultry Science 2010; 89: 1834-1841. doi: 10.3382/ps.2010-00725

17. Hassan MM, Haq E, Ahmad F. Effect of age and body weight at molting on the performance of broiler breeder hens under environmental control houses in Pakistan. Pakistan Veterinary Journal 2008; 28 (4): 189-193.

18. Akhtar N, Mahmood S, Hassan M, Yasmeen F. Comparative study of production potential and egg characteristics of Lyallpur Silver Black, Fayoumi and Rhode Island Red breeds of poultry. Pakistan Veterinary Journal 2007; 27 (4): 184-188.

19. Okuda EU, Orunmoyi M, Adeyinka IA, Eze ED, Shoyombo AJ et al. Estimation of genetic parameters of egg production and reproductive traits in Japanese quails. Agriculture Advances 2014; 3 (1): 19-27. doi: 10.14196/aa.v3i1.1157

20. Kaye J, Akpa GN, Alphonsus C, Kabir M, Zahraddeen D et al. Response to genetic improvement and heritability of egg production and egg quality traits in Japanese quail (Coturnix coturnix japonica). American Scientific Research Journal for Engineering, Technology, and Sciences 2016. 16 (1): 277-292.

21. Akram M, Hussain J, Ahmad S, Rehamn A, Lohani F et al. Comparative study on production performance, egg geometry, quality and hatching traits in four Closebredstocks of Japanese quail. Agriculture Advances 2014; 3 (1): 13-18. doi: 10.14196/aa.v3i1.1155

22. Hanan AH. Variations in egg performance and plasma constituents at different ages of female Japanese quail. Egyptian Poultry Science 2010; 30 (2): 565-581.

23. Altinel A, Gunep H, Kirmizibayrak T, Corekci SG, Bilal T. The studies on egg quality characteristics of Japanese quails. Journal of Faculty of Veterinary University Istanbul, Turkey 1996; 22 (1): 203-213.

24. Alkan S, Karabag K, Galic A, Karsli T, Balcioglu MS. Effect of selection for body weight and egg production on egg quality traits in Japanese quail (Coturnix coturnix Japonica) of different lines and relationship between these traits. Kafkas Universitesi Veteriner Fakultesi Dergisi 2010; 16 (2): 277-280.

25. Kosba MA, El-Deen MB, Shalan MH. Long-term selection for body weight in Japanese quail under Egyptian conditions. 3-Correlated response of some egg production traits. Egyptian Poultry Science Journal 2003; 23: 961-975.

26. Rehman ZU. Comparative productive performance of Japanese quail from different local and imported stocks. M. Phil Thesis. Department of Poultry Production, Faculty of Animal Production and Technology. University of Veterinary and Animal Sciences Lahore, Pakistan, 2006.

27. Usman M, Ahmad S. A comparison of some production performance traits in parent Japanese quail among four Closebredstocks. Scientific Journal of Veterinary Advances 2013; 2 (11): 169-171. doi: 10.14196/sjvs.v2i11.1081

28. Nasr MA, Ali ES, Hussein MA. Performance, carcass traits, meat quality and amino acid profile of different Japanese quail strains. Journal of Food Science and Technology 2017; 54: 4189-4196. doi: 10.1007/s13197-017-2881-4

29. Abbaya HY, Akpa GN, Adedibu II, Attah EO. Relationships among egg quality traits in Japanese quails over three generations of selection for egg production. Nigerian Journal of Animal Science 2018; 20 (1): 26-33.

30. Taskin A, Karadavut U, Tunca RI, Genc S, Cayan H. Effect of selection for body weight in Japanese quails (Coturnix coturnix Japonica) on some production traits. Indian Journal of Animal Research 2017; 51 (2): 358-364. doi: 10.18805/ijar.11466

31. Hrnčár C, Hanusová E, Hanus A, Bujko J. Effect of genotype on egg quality characteristics of Japanese quail (Coturnix japonica). Slovak Journal of Animal Science 2014; 47: 6-11.

32. Hanusová E, Hrnčár C, Hanus A, Oravcova M. Egg traits in Japanese quails. Acta Fytotechn Zootechn 2016; 19: 62-67. doi: 10.15414/afz.2016.19.si.62-67

33. Bagh J, Panigrahi B, Panda N, Pradhan CR, Mallik BK et al. Body weight, egg production, and egg quality traits of gray, brown, and white varieties of Japanese quail (*Coturnix coturnix japonica*) in coastal climatic condition of Odisha. Veterinary World 2016; 9 (8): 832-836. doi: 10.14202/vetworld.2016.832-836

34. Ondrušíková S, Nedomová Š, Pytel R, Cwiková O, Kumbár V. Effect of different storage times on Japanese quail egg quality characteristics. Potravinarstvo 2018; 12 (1): 560-565. doi: doi.org/10.5219/949

35. Kondaiah N, Panda B, Singhal RA. Internal egg-quality measure for quail eggs. Indian Journal of Animal Science 1983; 53: 1261-1264.

36. Şekeroğlu A, Altuntaş E. Effects of egg weight on egg quality characteristics. Journal of the Science of Food and Agriculture 2009; 89 (3): 379-383. doi: 10.1002/jsfa.3454

37. Fathi MM, El-Dlebshany AE, El-Deen MB, Radwan LM, Rayan GN. Effect of long-term selection for egg production on eggshell quality of Japanese quail (*Coturnix japonica*). Poultry Science 2016; 95 (11): 2570-2575. doi: 10.3382/ps/pew233

38. Bahie El-Deen M, Shalan H. Response to selection for egg number in Japanese quail. 3rd World's Poultry Conference, Hurghada, Egypt, 2005.

39. Leeson S, Summers JD. Commercial poultry nutricion. 2.ed. Ontario: Book University, 1997. 350p.

40. Aboul-Seoud DIM. Divergent selection for growth and egg production traits in Japanese quail. Ph.D Thesis. Department of Animal Production, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt, 2008.

41. Ipek A, Sahan U. Effect of breeder age and breeding season on egg production and incubation in farmed Ostriches. British Poultry Science 2004; 45: 643-647. doi: 10.1080/00071660400006339

42. Ahmad M, Balvir S, Chauhan SS, Singh KS. Effect of breed, egg size and shape on fertility, late embryonic mortality and hatchability. Indian Journal of Poultry Science 2000; 35 (2): 207-210.

43. Suda Y, Okamoto S. Long-term selection for small body weight in Japanese quail. 2: changes in reproductive traits from 60 to 65th generations. Journal of Poultry Science 2003; 40: 30-38. doi: 10.2141/jpsa.40.30

44. Wilson HR. Effects of maternal nutrition on hatchability. Poultry Science 1997; 76:134-143. doi: 10.1093/ps/76.1.134

45. Liao B, Qiao HG, Zhao XY, Bao M, Liu L et al. Influence of eggshell ultrastructural organization on hatchability. Poultry Science 2013; 92 (8): 2236-2239. doi: 10.3382/ps.2012-02728

46. Hussain J, Akram M, Sahota AW, Javed K, Ahmad HA et al. Selection for higher three week body weight in Japanese quail. 2: Estimation of genetic parameters. Journal of Animal and Plant Sciences 2014; 24 (3): 869-873.

47. Sadeghi R, Pakdel A, Shahrbabak MM. Effects of divergent selection and egg status in artificial incubator on reproductive trait in Japanese quail. World Applied Sciences Journal 2013; 24 (4): 463-466. doi: 10.5829/idosi.wasj.2013.24.04.2914

48. Saini Brah GS, Chaudhary ML. Evaluation of fertility, hatchability and embryonic mortality of divergent lines of Japanese quails. Journal of Research 2005; 42: 87-92.

49. Abdel-Mounsef NAF. Non genetic factors affecting some productive traits in Japanese quail. M.Sc. Thesis. Faculty of Agriculture, Al-Azhar University, Cairo, Egypt, 2005.

50. Anthony NB, Nestor KE, Bacon WL. Growth curve of Japanese quail as modified by divergent selection for 4-week body weight. Poultry Science 1986; 65: 1825-1833. doi: 10.3382/ps.0651825