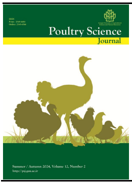

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Genetic and Environmental Parameters Analysis of Weekly Egg Weights in Wild and White Japanese Quails

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Abstract
The aim of the current study was to estimate the genetic and environmental parameters for weekly egg weights using a random regression model in wild and white Japanese quails. The base population included 300 wild and white Japanese quails, with a mating ratio of 1:2 (one male with two females). Four mating groups including pure and cross-breeding methods, were considered to produce the next generation. Eggs were collected and numbered based on their sire and dam. At the fifth week of age, 508 female quails were transferred to the laying cages. The data on egg weight was recorded from the seventh to fifteenth week of age. Nine random regression models were analyzed to determine the best orders of Legendre polynomials. The model with first and second-order Legendre polynomials for additive genetic and permanent environmental effects, respectively, indicated the lowest AIC value and was chosen as the appropriate model. The heritability estimates and the ratios of the permanent environment to the phenotypic variance of weekly egg weights ranged from 0.09 to 0.35 and from 0.08 to 0.51, respectively. The effect of permanent environmental factors on the average weight of laid eggs decreased with increasing laying weeks, followed by an increase in the additive genetic effect on the occurrence of this trait. The estimates of genetic and phenotypic correlations between weekly egg weights varied from 0.59 to 0.98 and from 0.21 to 0.51, respectively. As a result, because of higher heritability estimates for later ages, selection to improve weekly egg weight is better performed based on at least the fifth week of the laying period onward. In conclusion, due to high positive genetic correlations among weekly egg weights, the selection basis of each weekly part record can lead to improving the consecutive weekly egg weights.

Introduction
Egg is considered a highly nutritive and balanced food for human consumption (Kaye *et al*., 2016). Quails and domestic chickens are the only two domestic fowl species producing stocking eggs at a global scale (Lukanov *et al*., 2018). For egg-type quails, the intention has been focused on increasing total egg mass, optimizing egg weight and earlier sexual maturity to increase laying performance (Camci *et al*., 2002). Egg size can significantly affect egg quality traits. It is suggested that larger eggs are more suitable to obtain better hatchability, lower rates of embryonic mortality, and heavier hatchlings compared with smaller eggs in Japanese quails (Petek *et al*., 2005; Hegab and Hanafy, 2019; Kostaman and Sopiyana, 2021).

Egg size and weight in quails can be affected by various factors, such as genotype, breed, age and environmental conditions. There are significant differences in external and internal egg quality traits between laying and meat types of Japanese quails (Hrnčár *et al*., 2014). The most significant differences in benefit of the meat type were recorded for weights of egg, shell, albumen and yolk. A study to determine the effect of different body weight groups on the egg traits was carried out in Japanese quails, and the birds in the heavyweight group showed higher egg weights followed by those in the medium and small body

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weight groups (Jatoi *et al*., 2013). In accordance with these results, lower weights of albumen and eggs in pure white quails than in pure wild quails have been found (Shahraki *et al*., 2023). Furthermore, it has been reported that advanced age is associated with increasing egg weight (Nhan *et al*., 2018).

Egg weight is a longitudinal trait that is recorded during the continuous weeks of the laying period. Random regression models have been used to estimate genetic parameters for weekly and monthly egg numbers in laying hens (Anang *et al*., 2002), in a commercial female broiler line (Farzin *et al*., 2013), in turkeys (Emamgholi Begli *et al*., 2021) and, in quails (Farzin & Seraj, 2022; Karami *et al*., 2017; Abou Khadiga *et al*., 2017). In a study to estimate the genetic parameters of partial egg production, random regression was suggested as a functional model to analyze the traits related to egg production in Japanese quail (Karami *et al*., 2017).

The estimation of genetic parameters for different productive and reproductive traits is necessary to design selection programs. The breeding relies on the estimates of genetic variances among individuals. The breeders work towards exploiting these genetic variances by taking into account additive and non-additive effects (Okenyi *et al*., 2013). Heritability estimates of egg weight have been reported to be low to moderate in Japanese quails (Saatci *et al*., 2006; Sezer, 2007; Silva *et al*., 2013; Momoh *et al*., 2014; Kaye *et al*., 2016; Sari *et al*., 2016), which indicates that direct selection for this trait might lead to genetic improvement in Japanese quail. There are some studies that have been conducted to investigate the environmental factors affecting the egg weight of Japanese quails, but few studies have existed to estimate the genetic effects of this trait. Therefore, the main aim of the current study was to estimate the genetic and environmental effects on weekly egg weights in wild and white Japanese quails. Furthermore, this study presents the effect of the mating method on weekly egg weight in two strains of Japanese quails, and weekly egg weight during the laying period was compared in four groups (pure groups and the crosses of wild and white Japanese quails). Moreover, the goodness of fit for different random regression models was examined to estimate the variance and covariance components and their related parameters for weekly egg weight.

Material and Methods

The current study was carried out using the pedigreed quails obtained from pure and crossed mating groups of wild and white Japanese quails. The base population included 150 wild (50 males and 100 females) and 150 white (50 males and 100 females) Japanese quails, with a mating ratio of 1:2 (one male with two females). Four mating groups were considered to produce the next generation: 1 (the progenies of wild males and females), 2 (the progenies of white males and wild females), 3 (the progenies of wild males and white females), and 4 (the progenies of white males and females). Eggs were collected in the boxes (based on the number of parents to determine the pedigree of quails), and after placing in the setter, transferred to the hatchery. Four hatches were performed in total. The leg bands were used to number the hatched quails, and then the chicks were transferred to a rearing room. The temperature of the rearing period was 35º C in the first week and then decreased weekly to 24º C in the fifth week. Chicks were fed a diet including 24% crude protein (CP) and 2900 kcal/kg metabolizable energy (ME). At the fifth week of age, female quails were transferred to laying cages. The means of age at sexual maturity (ASM) and body weight at sexual maturity (BWSM) were 48.47 ± 4.99 days and 233.90 ± 22.74 gr, respectively. A diet containing 20% CP and 3000 ME was used during the laying period. The data collection started at the seventh week of age and lasted for eight weeks. The eggs obtained from the first week of the laying period were not considered in the analysis because of a high standard deviation among the laying quails. The average weekly egg weight for each female quail was recorded and used for analysis.

Statistical Analysis

To investigate the effects of hatch and mating group on weekly egg weights, a general linear model (GLM) of the SAS procedure was used based on the following model:

$$y_{ijk}= \mu+ H_i+G_j +b_1(ASM)+b_2(BWSM)+e_{ijk}$$

Where y_{ijk} is the weekly egg weight of each quail; μ is the overall mean; H_i is the fixed effect of hatching time (i=1, 2, 3, and 4); Gj is the fixed effect of mating group (j=1, 2, 3, and 4); b_1 is the coefficient of regression of ASM (age at sexual maturity) covariate; b_2 is the coefficient of regression of BWSM (body weight at sexual maturity) covariate; and e_{ijk} is the random residual effect. The Duncan's test was used to compare the means of traits.

The following random regression model (using Legendre polynomials as covariates) was used to analyze the weekly egg weights:

$$y_{ijlm} = H_i + M_j + b_{k_1}(ASM) + b_{k_2}(BWSM) + \sum_{t=0}^{q_1} b_n z_{lmt} + \sum_{t=0}^{q_2} a_{lt} z_{lmt} + \sum_{t=0}^{q3} p_{lt} z_{lmt} + e_{ijlm}$$

Where y_{ijkl} is the weekly egg weight of each female quail; H_i is the fixed effect of the hatch; M_j is the fixed effect of the mating group; b_{k_1} is the regression coefficient of ASM covariate; b_{k_2} is the regression coefficient of BWSM covariate; b_n is the fixed regression coefficient of laying week; a_{lt} is the random regression coefficient for additive genetic effect; p_{lt} is the random regression coefficient for permanent environmental effect; z_{lmt} is the covariate of the Legendre polynomial; q_1 is the order of Legendre polynomial for fixed effect; q_2 is the order of Legendre polynomial for additive genetic effect; q_3 is the order of Legendre polynomial for permanent environmental effect, and e_{ijlm} is the random residual effect. In the present study, heterogeneous residual variances were considered throughout the laying period. The residual variances ranged from 0.83 to 0.98. The assumption of heterogeneous residual variance can lead to improvement in the accuracy of estimation, followed by an increase in computing time per iteration and convergence.

Estimates of variance and covariance components and related parameters were carried out by the restricted maximum likelihood method (REML) using the WOMBAT program (Meyer, 2007).

Model comparison

The detection of an adequate model to fit the data were carried out using the AIC (Akaike, 1974) as follows:

$$AIC_k = -2\,log(ML_k) + 2p_k$$

Where, AIC_k is the Akaike information criterion of model k, $\log(ML_k)$ is the log of the maximum likelihood value of model k and p_k is the number of free parameters in model k.

The model with the highest maximum likelihood value and the smallest AIC value was considered the optimal model. In the case of comparing two models with an equal log of maximum likelihood values and AIC criteria, the simpler model is selected as the appropriate model.

Results and Discussion

Descriptive statistics for the average weight of eggs in different weeks of egg production are presented in Table 1. The average egg weight increased from the second (11.73 gr) to the eighth (13.02 gr) week of the laying period. A similar pattern of changing in egg weight from 9 to 12 weeks of age was previously reported by Lotfi *et al*., (2012), who found an obvious increasing trend for mean values of egg weight in Japanese quail. An increase in egg weight with increasing age of laying quail has been observed in some studies (Kaye *et al*., 2016; Ghayas *et al*., 2017; Baylan, 2017; Lukanov *et al*., 2018). In a study on four lines of Japanese quails, the average weekly egg weight increased until the fourth week of the laying period and then remained constant with minor changes in continuous weeks of egg production (Arunrao *et al*., 2023). In contrast to these results, decreases in weekly egg weight have been reported in the 6th week of egg production (Alshaheen, 2017), and as well in the final stages of egg production in quails (Santos *et al*., 2015; Nhan *et al*., 2018).

Table 1. Descriptive statistics for the average weight of eggs in different weeks of laying period

Trait[1]	Number [2]	Mean	Standard Deviation	Minimum	Maximum	Coefficient of Variation
AEW2	508	11.73	1.53	8.26	17.75	13
AEW3	494	11.98	1.49	8.65	18.56	12
AEW4	493	12.08	1.42	8.07	17.44	12
AEW5	485	12.34	1.32	7.91	16.18	11
AEW6	486	12.62	1.43	8.77	17.23	11
AEW7	482	12.87	1.57	8.89	19.10	12
AEW8	482	13.02	1.48	9.01	18.17	11
AEW2-8	482	12.39	1.35	9.15	18.09	11

[1] AEW2 to AEW8: Average of egg weight in 2 to 8 weeks of the laying period; AEW2-8: Overall mean of egg weights from 2 to 8 weeks of the laying period.

[2] Number of laying quails which their eggs are recorded

Table 2. The least-square means (± standard errors) for weekly egg weights in different hatches

Trait [1]	Hatch [2]			
	1	2	3	4
AEW2	11.13 ± 0.28	11.65 ± 0.14	11.68 ± 0.16	11.69 ± 0.12
AEW3	11.65 ± 0.21	11.86 ± 0.14	11.90 ± 0.14	11.90 ± 0.12
AEW4	11.68 ± 0.25	11.80 ± 0.13	11.85 ± 0.14	11.98 ± 0.11
AEW5	12.27 ± 0.23	12.21 ± 0.11	12.27 ± 0.12	12.29 ± 0.10
AEW6	12.58 ± 0.19	12.63 ± 0.25	12.65 ± 0.21	12.69 ± 0.17
AEW7	12.81 ± 0.21	12.85 ± 0.16	12.86 ± 0.17	12.88 ± 0.18
AEW8	12.99 ± 0.17	13.02 ± 0.16	13.06 ± 0.17	13.06 ± 0.16
AEW2-8	12.14 ± 0.19	12.29 ± 0.13	12.31 ± 0.14	12.35 ± 0.14

[1] AEW2 to AEW8: Average of egg weight in 2 to 8 weeks of the laying period; AEW2-8: Overall mean of egg weights from 2 to 8 weeks of the laying period.

[2] Hatches 1 to 4 included 41, 141, 119 and 207 observations, respectively. Due to missing data, the number of observations in different weeks varied slightly.

The least-square means (± standard errors) for weekly egg weights in different hatches are shown in Table 2. No significant differences regarding weekly egg weights were observed between different hatches. However, the first hatch showed lower egg weights than the other hatches ($P > 0.05$). Similarly, higher egg weights for the fourth and fifth hatches compared with the first two hatches ($P < 0.05$) were reported (Raoufi *et al*., 2013). Higher egg weights at later hatches might be a result of a positive correlation between egg weight and quail age (Camci *et al*., 2002); thus, egg weight can be associated with the advance of maternal age.

The least-square means (± standard errors) for weekly egg weights in different mating groups are presented in Table 3. The mating group had a significant effect on weekly egg weights ($P < 0.05$). Group 1 (progenies of wild males and females) showed higher egg weights than the crossed groups, as well as group 4 (progenies of white males and females). There was a significant difference between the two crossed mating groups. The laying quails of group 2 (progenies of wild female quails) showed heavier eggs during their egg production periods than the laying quails of group 3 (progenies of white female quails). There were no significant differences in weekly egg weights between laying quails of groups 3 (progenies of wild males and white females) and group 4 (progenies of white males and females). These results could be because of different body weights at sexual maturity in various mating groups. The means of body weights at sexual maturity for groups 1 to 4 were 239.19 ± 23.70, 233.07 ± 20.20, 227.17 ± 22.71 and 228.01 ± 22.54 gr, respectively. In other words, the groups with higher body weights at sexual maturity showed heavier eggs during the laying period. The positive correlations between laying quail body weight and egg weight have been reported previously (Mielenz *et al*., 2006; Lotfi *et al*., 2012; Silva *et al*., 2013). In earlier studies on Japanese quails, wild quails showed heavier body weight at the same age compared to white quails (Shokoohmand *et al*., 2007; Pourtorabi *et al*., 2017). White Japanese quail with lower body weight is known as a laying strain, whereas wild Japanese quail is known as a meat strain. According to the previous finding, egg-type quails lay smaller eggs exhibiting higher laying intensity and vice versa; meat-type quails lay heavier eggs with lower laying intensity (Lukanov *et al*., 2018). However, in a study that was conducted to compare egg production traits in white and wild Japanese quails, the pure white strain showed a higher egg number only in the second week of the laying period compared to the pure wild strain, as well as the white and wild crossed mating groups, and the differences between the mating groups for the next continuous weeks of egg production were not significant (Farzin and Seraj, 2022).

Table 3. The least-square means (± standard errors) for weekly egg weights in different mating groups

Trait [1]	Mating groups [2, 3]			
	1	2	3	4
AEW2	11.84 [a] ± 0.12	11.59 [b] ± 0.16	11.14 [c] ± 0.23	11.07 [c] ± 0.15
AEW3	12.21 [a] ± 0.11	11.88 [b] ± 0.15	11.57 [c] ± 0.23	11.34 [d] ± 0.15
AEW4	12.33 [a] ± 0.11	12.09 [b] ± 0.14	11.79 [c] ± 0.21	11.78 [c] ± 0.14
AEW5	12.56 [a] ± 0.09	12.29 [b] ± 0.13	12.03 [c] ± 0.19	11.97 [c] ± 0.13
AEW6	12.89 [a] ± 0.10	12.59 [b] ± 0.12	12.31 [c] ± 0.21	12.29 [c] ± 0.15
AEW7	13.19 [a] ± 0.09	12.89 [b] ± 0.14	12.67 [c] ± 0.19	12.58 [c] ± 0.14
AEW8	13.42 [a] ± 0.11	13.19 [b] ± 0.15	12.94 [c] ± 0.18	12.91 [c] ± 0.14
AEW2-8	12.61 [a] ± 0.10	12.34 [b] ± 0.14	12.01 [c] ± 0.20	11.95 [c] ± 0.14

[1] AEW2 to AEW8: Average of egg weight in 2 to 8 weeks of the laying period; AEW2-8: Overall mean of egg weights from 2 to 8 weeks of the laying period.

[2] Mating groups 1 to 4 included 146, 127, 125 and 110 observations, respectively. Due to missing data, the number of observations in different weeks varied slightly. Group 1: wild male * wild female; group 2: white male * wild female; group 3: wild male * white female; group 4: white male * white female

[3] Different lowercase letters indicate significant differences among the means ($P < 0.05$)

Some studies have been conducted to investigate the effect of selection for body weight on traits related to egg quality in Japanese quail. For example, in a study to compare egg production traits in three Japanese quail populations, the average egg weight was higher in the populations that had higher body weights (Lukanov *et al*., 2018). A similar finding was reported by Jatoi *et al*., (2013), who investigated the effect of grouping based on body weight on the production performance of Japanese quail. In all studied populations, the highest to lowest average egg weight belonged to heavy, medium and low-weight groups, respectively. In contrast with these results, a study was conducted by Baylan (2017) to determine the effect of different selection methods based on body weight on egg quality traits in Japanese quail. Egg weight in the first week of the laying period in the lines resulting from cross mating was greater than the line with individual selection, but no difference was observed for egg weight in the 15th week of the laying period or average egg weight. In another study, Arunrao *et al*., (2023) investigated the production traits of four distinct lines of Japanese quail kept in a tropical climate. The lines were genetically selected based on different traits in several generations. As a result, the lines which had been selected for higher body weight and egg production showed significantly heavier egg weights.

The values of the logarithm of maximum likelihood (Log ML) and Akaike information criterion (AIC) are shown in Table 4 for the models with different orders of fit. Model 2, with a Legendre polynomial of order 1 for the additive genetic effect and a Legendre polynomial of order 2 for the permanent environmental effect, indicated the lowest AIC value and, therefore, was chosen as the appropriate model. In similar research to analyze weekly egg production using a random regression model in Japanese quails, the model with the orders 1 and 3 of Legendre polynomial for additive genetic and permanent environmental effects, respectively, showed the lowest value of the Bayesian information criterion (BIC) and consequently was mentioned as an appropriate model (Farzin and Seraj, 2022). In another study to analyze average egg weight and egg number in Japanese quail, a multi-trait random regression model was used, and as a conclusion, a model with second and third orders of Legendre polynomial for additive genetic and permanent environmental effects, respectively, was presented as the optimal model (Karami *et al.*, 2017).

Table 4. Order of fit for additive genetic (q_2) and permanent environmental (q_3) effects, number of parameters (p_k), log of maximum likelihood values (Log(ML)), and Akaike information criterion (AIC)

Model	Order of fit		p_k	Log(ML)	AIC
	q_2	q_3			
1	1	1	10	-1336.14	2692.28
2	1	2	13	-1330.36	2686.73
3	1	3	17	-1338.91	2711.82
4	2	1	13	-1333.87	2693.74
5	2	2	16	-1330.27	2692.54
6	2	3	20	-1334.15	2742.27
7	3	1	17	-1332.14	2698.28
8	3	2	20	-1330.59	2785.45
9	3	3	24	-1336.44	2761.84

The use of a random regression model to estimate the genetic parameters of traits related to egg production in Japanese quail has been limited to a few studies (Farzin & Seraj, 2022; Karami *et al*., 2017; Abou Khadiga *et al*., 2017). A random regression model has been used to describe longitudinal traits because of its flexibility and potential to account for time-dependent effects (Swalve, 2000). In the random regression model, unlike the fixed regression model and repeatability model, genetic and environmental variances for egg-related traits are not considered to be constant during the laying cycle. Therefore, it can lead to obtaining more accurate estimates of variance components, which consequently improves the accuracy of genetic parameters. It was recommended that the random regression model was more practical for estimating the genetic parameters of egg production compared with the multiple-trait model in laying chickens (Anang *et al*., 2002). Additionally, the same findings were presented in turkeys (Kranis *et al*., 2007).

The variance components, heritability and ratio of permanent environment to phenotypic variance for weekly egg weights are presented in Table 5. Heritability of weekly egg weight ranged from 0.09 (second week) to 0.35 (eighth week). The ratio of permanent environment to phenotypic variance varied from 0.08 (eighth week) to 0.51 (second week). These estimates show that the effect of permanent environmental factors on the average weight of laid eggs decreases with the increase in laying weeks, followed by an increase in the additive genetic effect on the phenotype variation of this trait. In accordance with these results, Karami *et al*., (2017) found an increase in direct heritability for egg weight from the second (0.27) to the sixth (0.54) week of the laying period due to an increase in the rate of genetic variance over the egg production cycle. Similar results for cumulative egg production were found by Luo *et al*., (2007) on broiler lines. It was discussed that the low heritability estimates at the beginning of the laying period could be a result of the physiological changes in hens starting egg production. As the laying period progresses, the physiological conditions of hens become relatively stable, and therefore, the ratio of the permanent environment to phenotypic variance decreases at older ages. In agreement with the mentioned studies, it has been suggested that selection based on egg weight might be more accurate at older ages (Zamani *et al*., 2015). However, it has to be noted that in order to determine the best selection time, various factors such as the generation interval and the recording costs should also be considered.

Table 5. Estimates of genetic (σ_a^2), permanent environmental (σ_{pe}^2), residual (σ_e^2), and phenotypic (σ_p^2) variances, heritability (h^2) and the ratio of the permanent environment to phenotypic variance (pe^2) for weekly egg weights

Trait [1]	σ_a^2	σ_{pe}^2	σ_p^2	$h^2 \pm SE$	$pe^2 \pm SE$
AEW2	0.19 ± 0.18	1.16 ±0.24	2.27 ± 0.17	0.09 ± 0.08	0.51 ± 0.09
AEW3	0.27 ± 0.13	0.74 ± 0.15	1.93 ± 0.11	0.14 ± 0.07	0.38 ± 0.07
AEW4	0.37 ± 0.13	0.53 ± 0.13	1.81 ± 0.11	0.20 ± 0.07	0.29 ± 0.07
AEW5	0.48 ± 0.16	0.16 ± 0.17	1.55 ± 0.11	0.31 ± 0.10	0.10 ± 0.11
AEW6	0.49 ± 0.15	0.17 ± 0.14	1.64 ± 0.10	0.30 ± 0.09	0.10 ± 0.09
AEW7	0.53 ± 0.14	0.15 ± 0.12	1.54 ± 0.11	0.34 ± 0.08	0.09 ± 0.08
AEW8	0.51 ± 0.15	0.11 ± 0.11	1.45 ± 0.12	0.35 ± 0.09	0.08 ± 0.07

[1] AEW2 to AEW8: Average egg weight in 2 to 8 weeks of the laying period

In various studies on Japanese quail, the heritability of egg weight has been reported in the range of 0.04 to 0.59 (Khaldari *et al*., 2010; Momoh *et al*., 2014; Sari *et al*., 2016; Karami *et al*., 2017; Saghi *et al*., 2022). This variation in heritability values in different studies can be due to the difference in the time of data collection, the use of individual or repeated records, the model used to estimate the parameters, and the studied population (Farzin *et al*., 2013). Furthermore, the method to form the basic population and the mating method can also lead to different heritability estimates for traits related to egg quality in different studies (Abbasi *et al*., 2017). In a study on a population of native chickens in China, the value of heritability for egg weight was different in individual females in comparison to sire families (0.43 and 0.35, respectively) (Chen *et al*., 2019). Despite the variation in the magnitude of the heritability estimates for egg weight in different studies, it seems that the additive genetic effect on this trait is noteworthy.

Genetic and phenotypic correlations between weekly egg weights are shown in Table 6. These estimates varied from 0.59 to 0.98 and from 0.21 to 0.51 for genetic and phenotypic correlations, respectively. In general, the genetic correlation estimates between consecutive weeks were high, and decreased to medium as the time interval increased. These results showed that the selection based on the part records of egg weights can lead to improve the consecutive weekly egg weights. The estimated phenotypic correlations were lower than the related genetic correlations between two different weekly egg weights. Similar results were reported in Japanese quail previously. For example, Lotfi *et al*. (2012) reported the ranges of 0.91-0.99 and 0.39 to 0.67 for the genetic and phenotypic correlations between weekly egg weights. In another study by Karami *et al*. (2017), the estimates of genetic and phenotypic correlations between weekly egg weights ranged from 0.88 to 0.99 and from 0.44 to 0.62, respectively. Lower phenotypic correlations compared to the genetic correlations were also reported for weekly egg weights in native laying hens (Zamani *et al*., 2015). Furthermore, similar patterns of genetic and phenotypic correlations were found for weekly egg production in Japanese quail (Farzin and Seraj, 2022), and for monthly egg production in a commercial female broiler line (Farzin *et al*., 2013). The phenotypic correlation between different traits is influenced by additive genetic and environmental factors that are affecting these traits. Therefore, differences in the estimates of phenotypic and genetic correlations could be described by the relationship between genetic and environmental effects. It is important to consider that environmental factors are assumed as any factors that are not additive genetic (Sodini *et al*., 2018). In addition to this disjunction between patterns of genetic and environmental factors on the formation of phenotype, the differences between the genetic and phenotypic correlations may be a result of random sampling error that occurs in estimating true population values (Cheverud, 1988). It is suggested that the high standard error of the genetic correlation coefficient can lead to an increase in the range of real genetic correlation between two traits (Raoufi *et al*., 2013). In the current study, the standard errors of the genetic correlations were not high (ranged from 0.05 to 0.14). It seems that the lower estimates of phenotypic correlations between weekly egg weight traits, compared to the genetic correlations, could be a result of the permanent environmental correlations between these traits. This means that genetic correlation between traits may not be allowed to develop completely due to environmental limitations.

Table 6. Estimates of genetic (upper triangle) and phenotypic (lower triangle) correlations (± standard errors) between weekly egg weights

	AEW2 [1]	AEW3	AEW4	AEW5	AEW6	AEW7	AEW8
AEW2		0.92 ± 0.10	0.80 ± 0.12	0.71 ± 0.14	0.65 ± 0.11	0.61 ± 0.10	0.59 ± 0.11
AEW3	0.51 ± 0.04		0.97 ± 0.05	0.92 ± 0.09	0.88 ± 0.09	0.78 ± 0.10	0.68 ±0.09
AEW4	0.35 ± 0.04	0.48 ± 0.03		0.98 ± 0.09	0.89 ± 0.08	0.81 ± 0.09	0.73 ± 0.08
AEW5	0.29 ± 0.05	0.32 ± 0.04	0.46 ± 0.03		0.94 ± 0.10	0.82 ± 0.09	0.77 ± 0.09
AEW6	0. 24 ± 0.04	0.30 ± 0.04	0.39 ± 0.04	0.47 ± 0.04		0.95 ± 0.08	0.87 ± 0.09
AEW7	0.23 ± 0.04	0.27 ± 0.03	0.35 ± 0.04	0.41 ± 0.04	0.49 ± 0.04		0.96 ± 0.08
AEW8	0.21 ± 0.04	0.26 ± 0.04	0.29 ± 0.03	0.36 ± 0.03	0.44 ± 0.04	0.50 ± 0.04	

[1] AEW2 to AEW8: Average egg weight in 2 to 8 weeks of the laying period

Conclusion

In the present study, the estimates of heritability for weekly egg weights changed from low (second week) to medium (eighth week). The opposite pattern of changes was observed for the ratio of permanent environment variance to phenotypic variance. These results show that the additive genetic effect on the occurrence of weekly egg weight increases over the laying period. Therefore, it seems that selection to improve weekly egg weight could be done based on at least the fifth week of the laying period onward. Furthermore, because of high positive genetic correlations which were estimated among weekly egg weights, the selection basis of each weekly egg weight can lead to improve the consecutive weekly egg weights.

Conflicts of Interest

The authors declare no conflicts of interest.

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