J I T A A
Journal of the Indonesian Tropical Animal Agriculture
Accredited by Ditjen Riset, Teknologi dan Pengabdian kepada Masyarakat No. 164/E/KPT/2021

J. Indonesian Trop. Anim. Agric.
pISSN 2087-8273 eISSN 2460-6278
http://ejournal.undip.ac.id/index.php/jitaa
51(1):12-20, March 2026
DOI: 10.14710/jitaa.51.1. 12-20

Genetic parameters for egg production traits in KU-Phuphan black bone chicken population

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Received July 24, 2025; Accepted January 28, 2026

ABSTRACT

Genetic parameters for egg production traits in the KU-Phuphan black bone chicken, a native Thai breed, were analyzed to estimate heritability, investigate genetic correlations, and provide essential genetic data for developing effective breeding strategies to improve egg production performance. The study focused on traits age at first egg (AFE) and cumulative egg production at 180, 270, 300, and 365 days. Data were collected from 541 hens across three generations raised in an open-house system. Genetic parameters, including heritability and genetic correlations, were estimated using the AIREMLF90 software with the average information restricted maximum likelihood method. The results revealed moderate heritability for AFE (0.41) and higher heritability estimates for cumulative egg production traits (0.30–0.50). Genetic correlations among egg production traits were high (0.93–0.99), indicating that these traits were influenced by similar genetic factors. However, the genetic correlations between AFE and egg production traits were low (0.18 to -0.02), suggesting that these traits were influenced by different genetic factors. In conclusion, the potential was highlighted for genetic selection to improve egg production traits in this breed. Therefore, in designing breeding programs, breeders should consider the high heritability of egg production traits and the low genetic correlations between AFE and egg production.

Keywords: *Egg production traits, Genetic correlation, Heritability, KU-Phuphan black bone chicken.*

INTRODUCTION

The poultry sector is crucial in providing a sustainable source of protein and income for rural communities, especially in developing countries (Akinola and Essien, 2011). Among numerous poultry breeds, indigenous chickens are widely recognized for their adaptability to adverse environmental conditions (Dessie *et al.*, 2011), disease resistance (Mtambo, 2000), and unique meat and egg quality characteristics (Mtileni *et al.*, 2009). In Thailand, native chickens, such as the KU-Phuphan black bone chicken, are highly regarded for their distinct black bones that have been linked to medicinal properties and their flavorful meat (Khumpeerawat *et al.*, 2021). Native chicken meat is clearly a healthy food choice, due to its low fat, low cholesterol, and high protein content (Promwatee *et al.*, 2013).

However, with advances in genetic studies and genetic parameter estimation, there has been the development of genetically improved Thai native chickens that fulfill–the demands of the industry and poultry farmers. This has involved the simultaneous consideration of several selection characteristics by creating a selection index that is relevant to egg production by including age at first egg (AFE), weight at first egg (WFE), body weight at first egg (BWFE), and total egg number at day 365 (EN365) (Boonkum *et al.*, 2014). The egg production process must be consistent and continuous to improve the productivity of Thai native chickens. Several studies have estimated genetic parameters for egg production traits in various indigenous chicken breeds. For example, Niknafs *et al.* (2012) reported heritability estimates of 0.17 and 0.36 for egg number (EN) and age at first egg, respectively, in Mazandaran native chickens, indicating low-to-moderate genetic variability that could be exploited through selection. Similarly, Tongsiri *et al.* (2015) reported heritability range estimates of 0.18–0.38 for EN and 0.37–0.46 for AFE, indicating that these traits had low-to-moderate heritability and could respond to selection, which suggested that early sexual maturity could be improved through genetic selection.

Genetic evaluation is an internationally recognized method for studying the genetic aspects of various economically important traits in animals. In different countries, genetic evaluations of egg production traits in layer chickens have utilized monthly cumulative egg production data as the foundational information for analysis (Anang *et al.*, 2000; Luo *et al.*, 2007) instead of using total cumulative egg production data over the entire egg-laying period. The use of such monthly cumulative egg production data facilitates the genetic evaluation of individual chickens throughout the entire egg production cycle, obviating the need to wait until the end of production. Furthermore, it enables better adjustment for environmental influences affecting egg production, thereby enhancing the accuracy of selection and facilitating more rapid progress in breeding (Jensen, 2001). Among the statistical techniques and models used for genetic evaluation, the BLUP (best linear unbiased prediction) technique (Henderson, 1984) is noted for its accuracy and has been widely used (Luo *et al.*, 2007; Wolc and Szwaczkowski, 2009). Thus, this study aimed to analyze the impact of age at first egg and egg number on genetic parameters.

MATERIALS AND METHODS

Data Collection and Management

Data were obtained from the Animal Research Farm at the Kasetsart University, Chalermphrakiat Sakon Nakhon Province Campus. The study used hens from the first to third generations, with a total of 541 hens recorded across the three generations. Pedigree data were also collected, encompassing information from 871 hens. Daily data recording began at the time each hen laid its first egg and continued for 365 days thereafter.

The hens were housed in an open-house system, consisting of a two-story, gable-type building with a metal-sheet roof. The dimensions of the house were 9 m in width and 16 m in length. A standing single-cage system was used, with each cage measuring 30 cm × 41 cm × 38 cm (width × depth × height). The cages were located in the center of the building, divided into two sides (left and right) in an A-frame format. Each side consisted of two levels of cages, with a total of 352 cages installed in the building. Feed was provided at a restricted rate of 110 g/day for each hen, divided into two feedings. Feeding was carried out manually using a Plastic chicken feed trough system installed along the length of the cages. Water was provided *ad libitum* through a nipple drinking system, with one nipple drinker allocated per hen. All hens were vaccinated in accordance with the regulations set by the Thai Department of Livestock Development following the standard vaccination protocol for backyard poultry.

Traits Measured

The primary data used in this study were egg production records from KU-Phuphan chickens. The following variables were analyzed:

1. Cumulative egg production at 180, 270, 300, and 365 days.
2. Age at first egg.

Descriptive Statistical Analysis

All collected data were analyzed to calculate the mean and standard deviation using SAS® OnDemand for Academics: SAS® Studio (2014) with the PROC MEANS procedure.

Estimation of Variance Components and Genetic Parameters

The data were used to estimate the genetic variance components of the studied traits based on multivariate analysis using an animal model. The analysis was performed using the AIREMLF90 software (Misztal *et al.*, 2014) with the average information restricted maximum likelihood (AIREML) method. Then, the estimated variance components were used to calculate heritability, genetic correlations, and phenotypic correlations for each trait.

The multi-trait animal model was used for the simultaneous analysis of five traits: age at first egg (AFE) and cumulative egg production at 180, 270, 300, and 365 days (designate as EN180, EN270, EN300, and EN365, respectively). The model is defined as follows:

$$y = Xb + Za + e$$

In matrix notation for the five traits, the model is represented as:

$[y_1 y_2 y_3 y_4 y_5]$ = $[X_1 00000 X_2 00000\ X_3 00000\ X_4 00000\ X_5 00000][\beta_1 \beta_2 \beta_3 \beta_4 \beta_5]$ + $[Z_1 00000\ Z_2 00000\ Z_3 00000\ Z_4 00000\ Z_5 00000][\alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5]$ + $[e_1 e_2 e_3 e_4 e_5]$

Where:

y is the vector of observed values for the five traits.

β is the vector of fixed effects (generation and hatch group).

α is the vector of random additive genetic effects, $\alpha \sim N(0, G \otimes A)$

e is the vector of random residual effects, $e \sim N(0, R \otimes I)$

X and Z are the incidence matrices relating the observations to the fixed and random animal effects, respectively.

Expectations and Variance-Covariance Structures:

The random effects are assumed to follow a normal distribution with $E[y] = X\beta$. The variance-covariance structure is defined as:

Var $[\alpha\ \varepsilon] = [G \otimes A\ 0\ 0\ \ R \otimes I]$

Where:

A is the additive genetic relationship matrix

I is the identity matrix.

$\otimes$ denotes the Kronecker product.

G and R are the additive genetic and residual

$$G = [\sigma_{a_1}^2\ \sigma_{a_{12}}\ \sigma_{a_{13}}\ \sigma_{a_{14}}\ \sigma_{a_{15}}\ \sigma_{a_{21}}\ \sigma_{a_2}^2\ \sigma_{a_{23}}$$
$$\sigma_{a_{24}}\ \sigma_{a_{25}}\ \sigma_{a_{31}}\ \sigma_{a_{32}}\ \sigma_{a_3}^2\ \sigma_{a_{34}}\ \sigma_{a_{35}}\ \sigma_{a_{41}}$$
$$\sigma_{a_{42}}\ \sigma_{a_{43}}\ \sigma_{a_4}^2\ \sigma_{a_{45}}\ \sigma_{a_{51}}\ \sigma_{a_{52}}\ \sigma_{a_{53}}\ \sigma_{a_{54}}\ \sigma_{a_5}^2],$$
$$R = [\sigma_{e_1}^2\ \sigma_{e_{12}}\ \sigma_{e_{13}}\ \sigma_{e_{14}}\ \sigma_{e_{15}}\ \sigma_{e_{21}}\ \sigma_{e_2}^2\ \sigma_{e_{23}}$$
$$\sigma_{e_{24}}\ \sigma_{e_{25}}\ \sigma_{e_{31}}\ \sigma_{e_{32}}\ \sigma_{e_3}^2\ \sigma_{e_{34}}\ \sigma_{e_{35}}\ \sigma_{e_{41}}$$
$$\sigma_{e_{42}}\ \sigma_{e_{43}}\ \sigma_{e_4}^2\ \sigma_{e_{45}}\ \sigma_{e_{51}}\ \sigma_{e_{52}}\ \sigma_{e_{53}}\ \sigma_{e_{54}}\ \sigma_{e_5}^2]$$

variance-covariance matrices, respectively, structured as follows:

Heritability

Heritability refers to the proportion of genetic variance to the total phenotypic variance. Phenotypic variation, or differences among animals, arises from both genetic and environmental factors. However, the extent to which genetic potential is expressed in the phenotype can be measured in terms of heritability.

The estimation of heritability (h^2) is given by:

$$h^2 = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_e^2}$$

where:

σ_a^2 = additive genetic variance.

σ_e^2 = residual variance.

Genetic Correlations (r_g) and Phenotypic Correlations (r_p)

The relationships between different traits are highly beneficial for breeding programs, as they provide insights into how traits influence productivity. These relationships can be used as criteria for selection.

The genetic correlation (r_g) between traits was estimated as:

$$r_{gxy} = \frac{\sigma_{g(xy)}}{\sqrt{\sigma_{g(x)}^2 * \sigma_{g(y)}^2}}$$

The phenotypic correlation (r_p) between traits was estimated as:

$$r_{pxy} = \frac{\sigma_{p(xy)}}{\sqrt{\sigma_{p(x)}^2 * \sigma_{p(y)}^2}}$$

where:

$\sigma_g(xy)$= genetic covariance between traits X and Y,

$\sigma_{p(xy)}$ = phenotypic covariance between traits X and Y,

$\sigma^2_{g(x)}$ = genetic variance of trait X,

$\sigma^2_{g(y)}$ = genetic variance of trait Y,

$\sigma^2_{p(x)}$ = phenotypic variance of trait X,

$\sigma^2_{p(y)}$ = phenotypic variance of trait Y,

RESULTS AND DISCUSSION

The descriptive statistics for the KU-Phuphan black bone chickens are summarized in Table 1. The dataset consisted of 541 animals with records and 871 animals with pedigrees. The mean age at first egg (AFE) was 209.23 days with a range of 148–299 days. For the egg production traits, the mean number of eggs laid by 180, 270, 300 and 365 days (EN180, EN270, EN300 and EN365) was 117.85, 160.89, 171.40 and 186.44, respectively. The range and SD values suggested considerable variability in age at first egg and egg production. Based on these results, there was a consistent improvement in egg production over time combined with substantial individual variability across all traits. These findings indicated that while there was a consistent increase in egg production over time, the substantial variability among individuals could be influenced by genetic and environmental factors (Grossman and Koops, 2001).

However, the range of AFE in this study (148–299 days) was consistent with values reported by Sawasdee *et al.* (2015), where the mean AFE value in Thai native chickens was 198.32±24.61 days. This range was comparatively broader than research conducted in studies of some other breeds, such as the Rhode Island Red, where the mean AFE value was 136.79±1.52 days (Debnath *et al.*, 2015), while Chen *et al.* (2024) reported that the AFE values were 129.00 ± 10.10 days and 132.00 ± 21.10 days for White Leghorns and Rhode Island Reds, respectively. This broader range could be attributed to the unique genetic makeup of the KU-Phuphan black bone chickens, a local breed known for its distinct characteristics.

The gradual increase in egg production from EN180 to EN365 aligned with patterns observed in general breeds, where sustained laying performance is prioritized over early productivity. The mean value (186.44 eggs) of EN365 was lower than that of-commercial White Leghorns (264.84 eggs) (Al-Samarai *et al.*, 2008). This difference may be attributed to the fact that KU-Phuphan black bone chicken is a local breed, which typically has lower egg production compared to commercial breeds.

The estimated variance components and heritability for AFE and egg production traits in the KU-Phuphan Black Bone chickens are presented in Table 2. The heritability (h^2) of AFE was estimated at 0.41, indicating that 41% of the variation in AFE was due to genetic factors. For egg production traits, the h^2 estimates were 0.30

Table 1. Descriptive statistics of KU-Phuphan Black Bone chickens used in current analysis.

Category[1]	Number	Mean	SD	Min	Max	CV (%)
Animals with records	541					
Animals with pedigree data	871					
Number of records	541					
AFE (days)	541	209.23	32.30	148	299	15.44
EN180 (days)	541	117.85	21.97	47	175	18.64
EN270 (days)	541	160.89	31.07	72	252	19.31
EN300 (days)	541	171.40	33.37	78	270	19.47
EN365 (days)	541	186.44	35.69	88	298	19.14

[1] Number, number of records; Mean, average of age at first egg and egg production traits; SD, standard deviation; Min, minimum; Max, maximum; CV, coefficient of variation.

AFE = age at first egg, EN180 = total eggs at 180 days, EN270 = total eggs at 270 days, EN300 = total eggs at 300 days, EN365 = total eggs at 365 days.

for EN180, 0.50 for EN270, 0.49 for EN300, and 0.49 for EN365. These results suggested that egg production traits, particularly EN270, EN300, and EN365, had moderate-to-high heritability, indicating that genetic selection could be effective in improving these traits (Tongsiri *et al.*, 2015).

The h^2 estimates for AFE and egg production traits in the KU-Phuphan black bone chickens can provide valuable insights for breeding programs. The moderate heritability of AFE (0.41) suggests that genetic selection could be effective in reducing the age at which these chickens start laying. This finding was consistent with a study on other chicken breeds, such as the Rhode Island Red and the White Plymouth Rock that also showed moderate heritability (0.45 and 0.46, respectively) for AFE (Tongsiri *et al.*, 2015). However, the heritability estimate for AFE in the current study was slightly higher than those reported for certain commercial breeds, such as the White Leghorn, where typically, heritability estimates for AFE were in the range 0.12 -0.32 (Veeramani *et al.*, 2008). This difference may have been due to the unique genetic background of the KU-Phuphan black bone breed, which is local with distinct characteristics.

The high heritability estimates for egg production traits, particularly EN270, EN300, and EN365 (in the range 0.49-0.50), indicated that these traits were strongly influenced by genetic factors, making them good candidates for genetic improvement through selective breeding. These findings were consistent with research on other chicken breeds, which also had reported moderate-to-high heritability for egg production traits (Chomchuen *et al*., 2022; Lin *et al*., 2025). However, the heritability estimates for EN270, EN300, and EN365 in the current study were higher than those reported for some commercial breeds, such as the White Leghorn and Rhode Island Red, where typically, heritability estimates for egg production traits were around 0.11 and 0.24, respectively (Chen *et al*., 2024). The

Table 2. Estimated variance components and heritability (SE) of age at first egg and egg production traits in KU-Phuphan black bone chickens.

Trait[1]	AFE	EN180	EN270	EN300	EN365
σ_a^2	329.79	138.33	468.46	516.90	571.82
σ_e^2	465.13	320.03	461.44	538.68	601.58
σ_T^2	794.92	458.36	929.90	1055.58	1173.40
h^2	0.41 (0.03)	0.30 (0.03)	0.50 (0.02)	0.49 (0.04)	0.49 (0.03)

[1] σ_a^2 = additive genetic variance, σ_e^2 = residual variance. σ_T^2 = total variance, and h^2 = heritability.
AFE = age at first egg, EN180 = total eggs at 180 days, EN270 = total eggs at 270 days, EN300 = total eggs at 300 days, EN365 = total eggs at 365 days.

Table 3. Genetic correlations (above diagonal) and phenotypic correlations (below diagonal) estimated from multiple traits of KU-Phuphan black bone chickens.

Trait[1]	AFE	EN180	EN270	EN300	EN365
AFE	-	0.18	0.09	0.06	-0.02
EN180	0.02	-	0.99	0.93	0.95
EN270	-0.18	0.82	-	0.99	0.97
EN300	-0.21	0.79	0.98	-	0.99
EN365	-0.19	0.77	0.95	0.99	-

[1] AFE = age at first egg, EN180 = total eggs at 180 days, EN270 = total eggs at 270 days, EN300 = total eggs at 300 days, EN365 = total eggs at 365 days.

values suggested that genetic selection could be particularly effective in improving egg production traits in the KU-Phuphan black bone breed.

The current results suggested that genetic selection could be an effective strategy for improving both AFE and egg production traits in KU-Phuphan black bone chickens. However, when designing breeding programs breeders should consider the unique characteristics of this local breed, such as the higher heritability estimates for egg production traits. Future research should focus on identifying the specific genetic and environmental factors that contribute to the variability in these traits, as well as exploring the potential for crossbreeding with commercial breeds to improve egg production while maintaining the unique characteristics of the KU-Phuphan black bone chicken.

The genetic and phenotypic correlations among the traits of KU-Phuphan black bone chickens are presented in Table 3. The results of this study have provided important insights into the relationships between AFE and egg production traits. The low genetic correlations between AFE and egg production traits (ranging from 0.18 to -0.02) suggested that these traits were influenced by different genetic factors. This finding was consistent with another study on other chicken breeds, including the black-bone and blue eggshell chicken line, which also reported a low genetic correlation between AFE and EN300 of 0.19 (Wang *et al.*, 2022). Similarly, the White Leghorn breed showed low genetic correlations between AFE and egg production traits in the range -0.28 to -0.33 (Godara *et al.*, 2007; Tomar *et al.*, 2014). Thus, selection for one trait (such as AFE) may not greatly impact another (such as egg production) and vice versa.

The high genetic correlations among cumulative egg production traits (EN180, EN270, EN300, and EN365), ranging from 0.93 to 0.99, indicated that these traits were largely influenced by the same genetic factors. These strong positive relationships are primarily a result of the inherent nature of cumulative measures; later traits (e.g., EN365) inherently include the observations of earlier traits (e.g., EN180 and EN270). This finding aligns with other research on native chicken breeds, such as the Thai native chicken (Pradu), where high genetic correlations (above 0.88) were observed among monthly egg production traits throughout the year (Boonkum *et al.*, 2012).

The extremely high genetic correlations observed suggest a clear practical implication for breeding programs: early selection using EN270 (cumulative egg production at 270 days) can serve as an effective selection criterion. Since selection for EN270 would lead to proportional and highly correlated improvements in later traits like EN300 and EN365, breeders can optimize resources by culling non-productive hens earlier and accelerating the generation interval, thereby improving overall efficiency in KU-Phuphan black bone chicken breeding programs.

The phenotypic correlations, while generally lower than the genetic correlations, also provide valuable information. The phenotypic correlations ranged from -0.21 (negative) to 0.02 (positive), all of which were weak This finding was consistent with other studies on the White Leghorn breed which reported weak negative phenotypic correlations between AFE and egg production traits (ranging from -0.14 to -0.24) (Sreenivas *et al.*, 2012; Godara *et al.*, 2007; Laxmi *et al.*, 2010) . However, the strength of these correlations was not sufficient to suggest a strong phenotypic relationship between AFE and egg production.

The high phenotypic correlations among egg production traits (ranging from 0.77 to 0.99) further supported a conclusion that these traits were closely related at the phenotypic level. This was consistent with findings from another study by Yang *et al.* (2023) that also indicated strong phenotypic correlations among egg production traits in the indigenous Beijing-You chickens breed, where a high phenotypic correlation (0.71) was observed between EN43 (egg number until 43 weeks of age) and EN66 (egg number until 66 weeks of age). These high phenotypic correlations in this study suggested that improvements in one egg production trait (such as EN180) were likely to be associated with improvements in other related traits (such as EN270 and EN300).

The current findings were both similar to and different from other studies. For example, the low genetic correlations between AFE and egg production traits in the current study were consistent with findings from other breeds, such as the Black-bone and Blue eggshell chicken line and the White Leg horn chicken (Wang *et al.*, 2022; Godara *et al.*, 2007; Tomar *et al.*, 2014). However, the high genetic correlations among egg production traits in the current study were higher than those reported for some commercial breeds, such as the Thai native chicken (Pradu), where genetic correlations among egg monthly production traits were typically around 0.88 (Boonkum *et al.*, 2012), which suggested that genetic selection could be particularly effective in improving egg production traits in KU-Phuphan black bone chickens. Those researchers reported that the high correlation value may have been due to using the same type of total egg number but differing only in the number of days of total egg accumulation, which resulted in the high correlation value obtained. The genetic correlation was positive, as reported by Odegard *et al.* (2003), because of the influence of the same genes that regulate expression.

CONCLUSION

In conclusion, genetic selection can improve both age at first egg and egg production in KU-Phuphan black bone chickens. However, the low genetic correlations between these traits mean selection for one may not improve the other, requiring careful breeding program design. Future research should identify specific genetic and environmental factors influencing trait variability and explore crossbreeding with other black bone breeds to enhance egg production while preserving the KU-Phuphan unique traits.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Animal Research Facility at Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus for providing research facilities, resources, and essential datasets. We also extend our sincere gratitude to the staff and colleagues from Ubon Ratchathani University, Kasetsart University (Sakon Nakhon), and Bangladesh Agricultural University for their invaluable collaboration and support throughout this study.

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