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Effects of Body Condition, Anatomical Measurement, and Age on the Cumulative Number of Individual Egg Production and Laying Pattern in First Laying Hens

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ABSTRACT

The individual egg production capacity of laying hens plays an outstanding role in achieving total production within a flock, which is affected by several internal and external factors. This study aimed to evaluate the effect of body condition, anatomical measurement, and age at the first laying (AFL) on the cumulative number of individual egg production (CNIEP) and laying pattern. Therefore, 172 Isa Brown laying chickens were investigated. Data on body condition and anatomical measurement were collected at the age of 16 weeks, while data on production was collected during 21 weeks of production (18-39 weeks). The obtained data were analyzed by Partial Least Square- Structural Equation Modeling (PLS-SEM) using smartPLS. The findings revealed that CNIEP could be predicted by body condition, anatomical measurement, and AFL. Compared to body condition and anatomical measurements, AFL was the most prominent factor in CNIEP. Body condition, anatomical measurement, AFL, and CNIEP had weak effects on the Isa Brown laying chickens' patterns.

Keywords: Anatomical measurement, Individual egg production, Laying pattern

INTRODUCTION

External characteristic properties of laying hens, such as the width of pubic bone and depth of the body, have been used as indicators to identify and select superior laying hens (Borrell and Torres, 2021). This practice has roots in the experiential knowledge gained during the domestication of these birds. As science and technology have advanced, numerous studies have been conducted to explore the correlation between anatomical and behavioral characteristics of egg production. Considering the egg production capacity, the laying hen typically falls into three categories, namely low, moderate, and superior productivity (Ajaero and Ezekwe, 2007, Ogbu et al., 2015; Preisinger, 2018). Body measurements on laying hens usually involve assessing the span of pubic bones, depth of body, width of cranium, and length of keel (Isaac and Obike, 2020). According to Latshaw and Bishop (2001), physical characteristics have large correlation ranging from 0.431 to 0.93 and that of pelvis width and body weight are factors naturally related to egg production.

The egg production in a flock is determined by the individual performance of each laying hen. Individual egg production capability of laying hen varies among the population (Sharifi et al., 2022) due to differences in the genetic potential of each individual. Although as much as 56% of the population can reach the production target, there is still a significant number of hens producing less than 100 or 150 eggs at the same time (Preisinger, 2018). This underscores the significant genetic variation in individual production capabilities among chickens. Individual assessment of laying performance is very important for discerning variations within the population. This enables selective breeding or culling so that the chickens with low production (poor layer) are not included in the population. The presence of inferior animals (low production) within the population can decrease overall production performance during rearing. This condition leads to economic losses in laying hen's business due to inefficient conversion of consumed feed to egg production.

The laying pattern of the chickens can be expressed in the form of clutches and days off. Superior laying hens certainly have a small number of clutches (NCs) in one rearing period, leading to a large number of eggs. There are different laying patterns in each population of laying hens. Recent studies have indicated that laying patterns in laying hens are regulated by genes located on chromosome 6 (Chen and Tixier-Boichard, 2003). Therefore, laying patterns can be used as a parameter in selecting and culling (Wolc et al., 2019). At present, there are a few studies explaining the relationship between this laying pattern from physical condition, age at first laying eggs, and anatomical measurements of the laying hen. This study aimed to deeply examine some variables, focusing based on anatomical measurements, body condition, and age at first laying in relation to individual egg production and laying pattern of laying hens. The primary objective of this study was to determine the capability of individual laying hens to produce eggs with regard to their physical conditions. Additionally, the study aimed to explore whether the physical conditions of individual chicken along with the production capacity of individual chickens also responded differently to individual laying patterns or not.

MATERIALS AND METHODS

Ethical approval

This research was conducted under the regulations of Animal Science faculty, Brawijaya University (Indonesia), in accordance with the recommendations in the Guide for the Care and Use of Animals (register number KEP.31/07/2022).

Study location

This research was performed at Pojok Village, Wates Sub-district, Kediri Regency, East Java Province Indonesia from February to May 2022. This region is 77 meters above sea level (MASL), -7.781 of latitude and 112.071 of longitude with a rainfall rate of 1860 mm per year and an average daily temperature was 27^{o}C (Indonesia Statistical Bureau, 2023).

Experimental chickens and their management

This research was conducted on 172 pullets (Isa Brown laying chickens) aged 18 weeks which were randomly selected at 16 weeks of age from a population of 300 chickens in a litter floor housing system, using Slovin’s equation (Ryan, 2013). This research was conducted at an open house system in dimensions of 15 m x 4 m x 3.5 m (length x depth x height) with a battery aligned in six rows with 60 chickens per row (three rows face to face/V-shaped liked). The battery was arranged 1.5 m above the floor. This study was held from 16 to 39 weeks of age with lighting programs of 16L/8D (from 18 weeks of age until the age of 5% of laying [21 weeks]) and 14L/10D (from 5% of lay until the end of data collection/39 weeks of age). Laying hens had *ad libitum* access to water and their feeding regimen adhered to a feeding program prescribed from manual guidance of commercial laying hens for tropical countries (Hendrix Genetics, 2021). The commercial diet was from PT, Cargill Indonesia “Komplit Petelur Super” (Nutrient content is available in Table 1). During the rearing, the chickens were vaccinated against common diseases as a protocol from Medion company (Medion, 2018).

Table 1. Nutrient content of the prepared feed for the laying phase

Dry matter	88 %
Crude protein	16.5 – 18 %
Crude fat	7%
Metabolizable energy (ME)	2700-2970 Kcal/kg
Fiber	7%
Ash	14%
Calcium	3.25 -4.25 %
Phosphor	0.6 – 1 %
Aflatoxin (Max.)	50 ppb

ME: Metabolizable energy; Source of table: NRC, 1994

Body weight and anatomical measurement

Body weight and anatomical measurements (Width of pubic, size of the abdomen, Width of ischium, and depth of the body) were collected at the age of 16 weeks prior to the placement in battery cage. The body weight of the chicken was measured in grams (g) using a scale weight digital. Anatomical/body measurement was performed using a caliper in millimeters (mm).

Individual egg production parameters

Individual egg production parameters such as daily egg production and days off were recorded from the first laying until week 21 of the first production CYCLE (18 weeks to 39 weeks of rearing) using a Closed-Circuit Television (CCTV, China).

Statistical analysis

Data analysis on this research was performed using the Partial Least Square-Structural Equation Model (PLS-SEM) using SmartPLS (version 3.3.9). The assessment of model results was made as recommended by Hair et al. (2021) at a significant level of 0.05.

RESULTS AND DISCUSSION

The current study was performed to examine the relationship between the five latent variables, namely body condition at the age of 16 weeks, anatomical measurement at the age of 16 weeks, age at the first laying, cumulative number of individual egg production, and laying pattern to determine the effect of interaction between these variables. The summary result of the construct can be seen in Figure 1. Modeling from smartPLS comprising of body condition, anatomical measurement, age at the first laying, cumulative number or individual egg production, and laying pattern. On this five-structure model, it consists of one latent variable with a reflective measurement model (laying pattern) with two indicators and four latent variables with a formative measurement model (body condition, anatomical measurement, age on the first laying, and number of individual egg production) covering 8 indicators in total.

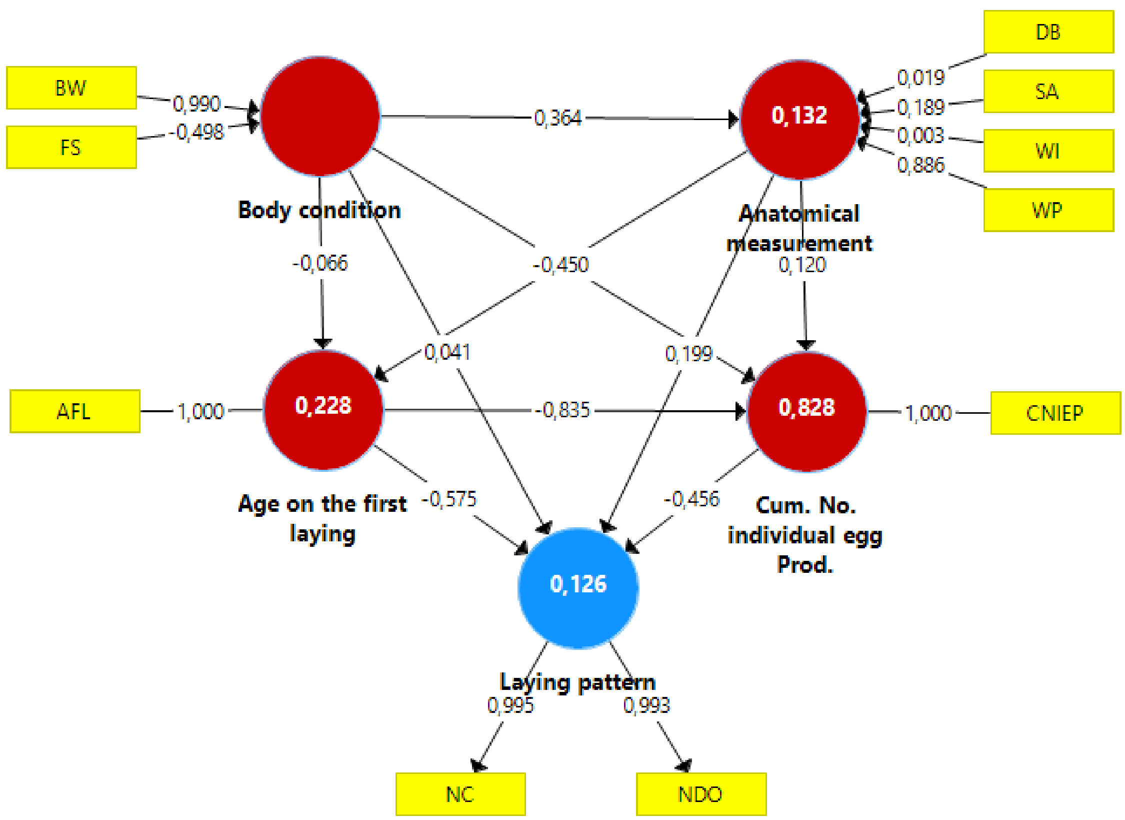

Figure 1. Modeling of the construct of body condition, anatomical measurement, age at the first laying, cumulative number or individual egg production, and laying pattern analyzed by SmartPLS model of laying hen. BW: Body weight, FS: Fleshing score, WP: Width of pubic, SA: Size of abdomen, WI: Width of ischium, DB: Depth of body, AFL: Age on the first laying, CNIEP: Cumulative number of individual egg production, NC: Number of clutches, NDO: Number of days off

Assessment of outer model (reflective and formative measurement models)

As a reflective measurement model, the laying pattern had two indicator variables, including NC and number of days off (NDO) for individual chickens throughout 148 days of production. The results indicated that NC and NDO had loading factors of 0.995 and 0.993, respectively (Table 2), meaning that NC and NDO had almost equal contributions to the construct. This finding aligns with Wolc et al.'s (2019) assertion that NC is a trait in egg-laying patterns controlled by the role of genes located on chromosome 6 from 28 to 29 Mb affecting parameters, such as NCs, maximum number of eggs in a clutch, and average clutch size (Bloom et al., 1993; Chen and Tixier-

Boichard, 2003; Roy et al., 2014). As reported by Ogbu et al. (2015), NCs are not the independent criterion and may not reveal much concerning individual laying performances. This is supported by studies indicating that better individual performance is associated with smaller NCs, longer clutch lengths, and fewer days open all indicative of high production and NCs were negatively correlated with a number of eggs (Gumulka et al., 2010; Ani and Nnamani, 2011; Wolc et al., 2019). The better individual performance is related to the smaller NCs with longer clutch lengths and fewer days open which indicate high production. However, Bednarczyk et al. (2000) mentioned that the NCs and NDO (Ogbu et al., 2015) could be used as one of the selection criteria describing the cyclic laying process. On the other hand, NDO indicates frequent NCs leading to less egg production (Ogbu et al., 2015).

In the assessment of formative measurement models, the fleshing score (FS) and width of the ischium (WI) were indicators that should be considered due to their very low loading weight (-0.498 and 0.003, respectively) with a non-significant p-value. The FS is a variable assessed subjectively using a predetermined score. It might be better to measure this variable using a measurement tool, to provide a measurement value that describes the size diversity of each individual in fleshing. On the other hand, WI is one of the variables with a low correlation with other variables in the latent variable. Based on the Variance Inflation Factor (VIF) value, there was no multicollinearity for all indicators. The width of the pubic was the best indicator to estimate the laying pattern (w = 0.886), compared to the size of the abdomen (w = 0.019), WI (w = 0.003), and the depth of the body (w = 0.189). The effects of the width of the pubic, size of the abdomen, and depth of the body with respect to the results of the bootstrap procedure were significant on the laying pattern variable ($p < 0.05$) but not the width of the ischium. Based on the result presented in Table 3, it was revealed that the construct of the laying pattern appeared to meet the criteria introduced by Hair et al. (2021). The values of average variance extracted (AVE), composite reliability (CR), Cronbach's alpha (CA), and Rho_A were full fill the requirements. Furthermore, NC and NDO indicators of the laying pattern were found to be significant based on the bootstrapping procedure ($p < 0.05$).

Table 2. Assessment of the laying pattern of laying hens for 21 weeks of observation (reflective measurement model) reared under tropical climate in Indonesia

	Reflective indicators	Convergent validity			Internal consistency reliability			Discriminant validity	t Value	p-value
		Loadings	Indicator reliability	AVE	Composite Reliability	Cronbach's Alpha	Rho_A			
		>0.5	>0.5	>0.5	0.70-0.95					
Laying pattern	NC	0.995	0.990	0.988	0.994	0.988	1.005	Yes	874	P < 0.05
	NDO	0.993	0.986						641	P < 0.05

NC: Number of clutches, NDO: Number of days off, AVE: Average variance extracted, Loading: Correlation value between physiological response, respiration rate, and rectal temperature, Cronbach's Alpha: A measure of internal consistency of a test, Rho_A: Measurement the strength of association between two variables, less than 0.05 show significant

Table 3. Assessments of body condition, and anatomical measurement of laying hen reared under tropical climate in Indonesia

	Formative indicator	Outer weight	T value	P value	95% bootstrap confidence interval	Outer VIF
Body condition	BW	0.990	2.621	P < 0.05	[-0.590,0,999]	1.056
	FS	-0.498	0.887	P > 0.05	[-0.603,0.643]	1.056
Anatomical measurement	WP	0.886	12.347	P < 0.05	[0.858,0.997]	1.343
	SA	0.019	5.514	P < 0.05	[0.376,0.820]	2.336
	WI	0.003	0.247	P > 0.05	[-0.241,0.315]	1.024
	DB	0.189	3.238	P < 0.05	[0.166,0.649]	1.914

BW: Body weight, FS: Fleshing score, WP: Width of pubic, SA: Size of the abdomen, WI: Width of ischium, DB: Depth of body, VIF: Variance inflation factor, ($p < 0.05$).

Table 4. Assessment of path coefficients of the structural model on all latent variables of laying hen reared under tropical climate in Indonesia

Constructs	Path coefficients	T value	p-value	95% bootstrap confidence interval	f^2 value (Effect size)
AFL → CNIEP	-0.835	27.164	p <0.05	[-0.889, -0.773]	3.119 (large)
AFL → LP	-0.195	3.080	p <0.05	[-0.363,-0.005]	0.071 (medium)
AM → AFL	-0.450	5.584	p <0.05	[-0.604,-0.280]	0.228 (medium)
AM → CNIEP	0.495	6.250	p <0.05	[0.326,0.634]	0.059 (medium)
AM → LP	0.232	2.450	p <0.05	[0.044,0.408]	0.030 (medium)
BC → AFL	-0.230	1.822	p <0.05	[-0.392, 0.197]	0.005 (small)
BC → AM	0.364	2.238	p <0.05	[-0.263, 0.543]	0.152 (medium)
BC → CNIEP	0.278	2.006	p <0.05	[-0.237, 0.430]	0.009 (small)
BC → LP	0.119	1.030	p <0.05	[-0.179, 0.305]	0.002 (small)
CNIEP → LP	-0.456	2.672	p <0.05	[-0.801, -0.152]	0.041 (medium)

AFL: Age on the first laying, CNIEP: Cumulative number of individual egg production, LP: Laying patter, AM: Anatomical measurement, BC: Body condition.

Assessment of structural model

From all the variables observed, the cumulative number of individual egg production (CNIEP) is one of the most important variables, indicating how well an individual chicken can produce eggs in the same timeframe. The expectation of raising laying hens is that all individuals can produce the same amount of each individual, but in reality, the ability of individuals in a population is very diverse. This diversity in individual abilities can be influenced by several factors, including the condition of the body at the pre-layer (Lacin et al., 2008), the anatomical size of each individual (Isaac and Obike, 2020), the age when they first laid eggs, lighting (Khalil et al., 2004), and other factors in terms of rearing management (Zaheer, 2015).

Based on the results presented in Table 4, the CNIEP is significantly influenced by body condition at 16 weeks, anatomical measurement, and age on the first egg, which is 82.2% (R^2). Of the three variables, age on the first laying (AFL) could play a significant role in withdrawing CNIEP, compared to body condition and anatomical measurements (γ = -0.835, $p < 0.01$). Alilo (2017) reported that the onset age of laying could affect the total egg production in its life cycle and selection of laying hen in the first part of the laying cycle could improve the production. Other researchers believe that age at the first egg is negatively correlated with the first three months of egg production and there is a positive and high correlation between egg production during the first three months and annual production (Khalil et al., 2004; Liu et al., 2018). Therefore, they suggest that selection can be performed at the beginning based on the first three months of production performance. Additionally, age at the first egg is an important trait in laying hens controlled hormonally and regulated by various genes and pathways (Xu et al., 2011; Tan et al., 2021).

According to the model, anatomical measurement (γ = 0.495, $p < 0.01$) showed up better contribution to CNIEP than body condition (γ = 0.278, $p < 0.05$). Present findings are in agreement with the study of Sherwood (1922) who found the correlation between external body characters and annual egg production in white leghorn fowls ranging from low to strong, both positive and negative. Sherwood (1992) found a correlation ranging from low to strong, both positive and negative between anatomical measurements and egg production. In the present study, the indicator of the width of the pubic had a very significant positive correlation as a bivariate correlation with CNIEP (r = 0.509, $p < 0.01$). In addition, the width of the pubic was the best indicator in representing the construct of anatomical measurement with the outer weight of 0.886 (Figure 1). This shows that the width of the public is the most dominant variable in explaining the construct in the latent variable (anatomical measurement). On the other hand, body condition had no effect on CNIEP and the effect size was 0.009. This means that body condition (body weight and fleshing score) does not have a real impact on the production ability of individual Isa Brown strain chickens. Consistent with the present study, Lacin et al. (2008) also investigated the impact of varying body weights in Lohman laying hens on egg production, finding no significant effect. These collective findings suggest that the performance of contemporary laying hen strains is no longer solely determined by differences in body weight. Instead, distinctions in egg production ability may be discerned based on other economic traits, such as anatomical size.

Body condition at 16 weeks and anatomical measurement accounted for 22.8 % of the total variability in AFL according to the model, and this was a weak effect (Figure 1). Anatomical measurement had a more key role in the age of the first laying (γ = -0.450, $p < 0.01$) since there was no effect of body condition on AFL egg (γ = -0.230, $p > 0.05$, $f^2 = 0.005$). Among the six indicators in body condition (two factors) and anatomical measurement (four indicators), only the width of the pubic bone and size of the abdomen demonstrated a significant negative correlation, with r values of -.443 and -.402, respectively ($p < 0.01$). On the other hand, body condition accounted for 13.2% of the total variability in anatomical measurement, showing the weakness of body condition in explaining the variance in anatomical measurement construct. Similarly, the findings indicated a weak correlation of body weight and fleshing score with all indicators in anatomical measurement (Table 4). Body condition, anatomical measurement, AFL, and CNIEP accounted for 12.6% of the total variability in laying pattern variables according to the model indicating a weak effect (Figure 1). This suggests that the laying pattern which includes the number of clutches and the number of days off is not much influenced by body condition (body weight and fleshing score), age at the first laying, and CNIEP. Among these three exogenous variables, CNIEP appeared to have more influence on laying pattern with a contribution of -0.456 (γ) than body condition (γ = -0.195), anatomical measurement (γ = 0.234), and AFL (γ = 0.119). Body condition did not affect the laying pattern, meanwhile, anatomical measurement and AFL had a positive and significant effect on the laying pattern which was very small ($p > 0.05$, $f^2 = 0.030$ for AM and $f^2 = 0.071$ for AFL).

CONCLUSION

Age on the first laying contributes significantly to the cumulative number of individual egg production and laying pattern of the laying hen. Anatomical measurement has a significant role in the first laying age, cumulative number of individual egg production, and laying pattern. Body condition at 16 weeks does not affect age on the first laying and the laying pattern but significantly contributes to anatomical measurement and cumulative number of individual egg production. It is suggested to manage the population to start producing eggs on time (18 weeks) by applying planned management practices. Since the result of current research indicated that the chickens whose production was late could reduce the total number of individual eggs production; therefore, it is highly recommended to take out the chicken that is late in production to maximize the profit.

DECLARATIONS

Availability of data and materials

The primary data of this study are authentic and available by request from the corresponding author via email.

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Authors' contributions

Heni Setyo Prayogi contributed to the conceptualization, investigation, data curation, writing, review, and editing of the manuscript. Suyadi, V.M. Ani Nugiartiningsih, and Osfar Sofjan were involved in every step of the research as well as manuscript revision based on reviewer feedback. All authors checked and approved the final version of the manuscript for publishing in the present journal.

Competing interests

The authors have declared that there are no competing interests in the results presented in this article

Ethical considerations

All the authors had checked and confirmed the article submission for ethical issues, such as plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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