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The Size and Shape of IPB Chickens and Kampong Chickens in Relation to Natural Selection

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ABSTRACT

IPB D1 chickens have been shown to exhibit superior growth and reproductive performance in comparison to kampong chickens, as demonstrated in previous studies. The selection of IPB D1 chickens resulted in the generation of IPB D2 and IPB D3 chickens. The objective of this study is to make a comparative analysis of the size and body shape of kampong chickens, IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens. This analysis will be based on crowd diagrams during the starter and grower periods. The present study employed Principal Component Analysis (PCA) based on measurements of eight linear body surface area variables, including femur length, tibia length, tarsometatarsus length, tarsometatarsus circumference, third toe length, wing length, maxilla length, and comb height. These variables are closely related to adaptive ability, resulting from natural selection. The selection of chickens based on eight linear body surface area, in conjunction with natural selection, has been demonstrated to enhance chicken productivity. The analysis results demonstrate that IPB D1 and IPB D2 cocks, and IPB D2 and IPB D3 hens, in the starter period exhibit comparable body shapes, suggesting a relatively uniform morphological pattern resulting from shared direction of selection. During the grower period, disparities in the direction of selection became evident between IPB D2 and IPB D3 cocks, as evidenced by the distribution of individual points in divergent directions in the cluster diagram. This phenomenon is indicative of disparities in selection pressure on body characteristics in the two strains. Significantly, during the starter period, a separate group of kampong hens formed at the top of the diagram, indicating the strong uniqueness of native chicken morphological characteristics and a body size pattern that is strikingly different from the IPB selection strain.

Keywords: Crowd diagram, linear body surface, natural selection, size, shapes

ABSTRAK

Ayam IPB D1 memiliki keunggulan pertumbuhan dan reproduksi lebih baik dibandingkan ayam kampung, berdasarkan studi sebelumnya. Seleksi yang dilakukan pada ayam IPB D1 menghasilkan ayam IPB D2 dan ayam IPB D3. Penelitian ini bertujuan untuk membandingkan ukuran dan bentuk tubuh ayam kampung, ayam IPB D1, ayam IPB D2, serta ayam IPB D3 berdasarkan diagram kerumunan pada periode *starter* dan *grower*. Penelitian ini menggunakan Analisis Komponen Utama (AKU) berdasarkan pengukuran delapan variabel ukuran permukaan tubuh linear meliputi panjang *femur*, panjang *tibia*, panjang *tarsometatarsus*, lingkar *tarsometatarsus*, panjang jari ketiga, panjang sayap, panjang *maxilla*, serta tinggi jengger yang berkaitan erat dengan kemampuan adaptasi sebagai hasil dari seleksi alam. Seleksi yang dilakukan berdasarkan delapan ukuran permukaan tubuh linear, bersama dengan seleksi alam dapat meningkatkan produktivitas ayam. Hasil analisis memperlihatkan bahwa ayam IPB D1 dan IPB D2 jantan dan ayam IPB D2 dan IPB D3 betina periode starter memiliki kemiripan bentuk tubuh, yang mengindikasikan adanya pola morfologi yang relatif seragam akibat arah seleksi yang sejalan. Pada periode grower, perbedaan arah seleksi mulai tampak jelas antara ayam IPB D2 dan IPB D3 jantan, yang tergambar melalui penyebaran titik individu ke arah yang saling berlawanan dalam diagram kerumunan. Fenomena ini mencerminkan adanya perbedaan tekanan seleksi terhadap karakter tubuh pada kedua galur tersebut. Menariknya, sebagian individu ayam kampung betina pada periode starter membentuk kelompok terpisah ke arah atas diagram, menandakan keunikan ciri morfologis khas ayam kampung yang masih kuat dan memiliki pola ukuran tubuh yang berbeda secara mencolok dibanding galur hasil seleksi IPB.

Kata kunci: Diagram kerumunan, ukuran permukaan tubuh linear, seleksi alam, ukuran tubuh, bentuk tubuh

INTRODUCTION

Poultry husbandry is of significant importance to national development, as it constitutes the primary source of animal protein for communities worldwide. According to the Central Statistics Agency, in 2023, the availability of chicken meat in Indonesia from superior broiler breeds reached 3,997,652 tons, while local chicken meat production was only 280,725 tons. Local chicken meat production remains considerably lower than that of broiler chickens. Local chickens possess the potential to be developed into superior breeds. The implementation of crossbreeding techniques has been identified as a strategy for enhancing the genetic quality and overall quality of local chicken populations.

The crossbreeding of F1 PS roosters (Pelung chickens crossed with Sentul chickens) and F1 KM hens (village chickens crossed with Cobb parent stock) produces offspring known as IPB D1 chickens. This assertion is supported by Decision No. 693/KPTS/PK.230/M/9/2019, the IPB D1 chicken is a newly developed composite local chicken breed that has been officially released by the Ministry of Agriculture of the Republic of Indonesia. As asserted by Sumantri and Darwati (2017), the IPB D1 chicken demonstrates superior growth and reproductive performance in comparison to the kampong chicken. The selection process applied to the IPB D1 chicken resulted in the IPB D2 and IPB D3 chickens. The IPB D2 chicken has been developed from the IPB D1 chicken through a selection process aimed at enhancing its resistance to Newcastle disease (ND) (Miraj *et al.* 2022). Conversely, IPB D3 chickens were obtained through a selection process aimed at promoting high body weight growth traits (Damarani 2022).

A comparative analysis was conducted to assess the size and body shape of kampong chickens, IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens. This analysis was performed using principal component analysis (PCA). This analysis was based on measurements of eight linear body surface area variables that are closely related to adaptive ability as a result of natural selection. According to Nishida *et al.* (1982), these linear body surface area variables include the length of long bones (i.e., femur length, tibia length, and tarsometatarsus length), tarsometatarsus circumference, third toe length, wing length, maxilla length, and comb height. Nishida *et al.* (1982) observed the size and shape of the local chicken, which is an indigenous Indonesian chicken breed. This local chicken has demonstrated a remarkable capacity for adaptation to the Indonesian environment. The eight linear body surface area variables are closely related to adaptive ability as a result of natural selection. The measurements employed in this study encompassed linear body surface measurements, including femur length, tibia length, and tarsometatarsus length. This variable is found to be significantly influenced by genetic factors as opposed to environmental factors. Everitt and Dunn (1999) asserted that the morphology of animal bodies is predominantly shaped by genetic factors, rather than by environmental influences. The integration of breeding selection based on linear body surface measurements, in conjunction with natural selection, has been demonstrated to enhance chicken performance.

The objective of this study is to make a comparison of the body size and shape of kampong chickens, IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens. This comparison will be made using a crowd diagram during the starter and grower periods. In this study, the size and shape of the chickens' bodies were analyzed through several parameters, including femur length, tibia length, tarsometatarsus length, tarsometatarsus circumference, third toe length, wing length, maxilla length, and comb height. These parameters are closely related to the adaptation process as a result of natural selection.

MATERIALS AND METHODS

Study Area

Research on kampong chicken and IPB chicken farming was conducted in several areas of West Java Province, Indonesia, including Bogor, Sukabumi, and Tasikmalaya Regencies. The highest altitude was recorded in Sukabumi Regency (800 m above sea level), and the lowest in Bogor Regency (192 m above sea level). The highest temperatures were recorded in Tasikmalaya Regency (24-28 °C) and the lowest in Sukabumi Regency (20-27 °C). The highest recorded rainfall was in Bogor Regency, with an annual precipitation of 4000-5000 mm. The highest levels of humidity were recorded in Bogor and the regencies, ranging from 60% to 95%. Kampong chicken farmers utilise a semi-intensive husbandry system, comprising traditional feed and ad libitum drinking water, in conjunction with an open colony-style coop system. IPB chicken farmers employ an alternative rearing system. The intensive rearing system employed by IPB chicken farmers is characterised by the provision of ad libitum access to drinking water. The feed utilised on IPB chicken farms in Bogor is commercial starter and grower feed, while in Sukabumi, a feed mixture with a ratio of 60% commercial feed and 40% bran is employed. The study spanned a period of three months, commencing in December 2023 and concluding in February 2024. This was followed by a phase of data processing that occurred from March to April 2024.

Sampling Materials and Equipment

A comparative analysis of linear body surface area was conducted on kampong chickens, IPB D1 chickens of the 11th generation, IPB D2 chickens of the 5th generation, and IPB D3 chickens of the 4th generation. For kampong chickens, observations were conducted on the 600–700 gram weight class, in accordance with the research by Aryanti *et al.* (2013) conducted at two months of age. Concurrently, for the 978–1,261 gram weight class, as indicated by the research of Irmaya *et al.* (2021), this was observed at 3–4 months of age. In this study, the terms "starter" and "grower" were employed to delineate this age range, and these terms were also applied to IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens. The starter period (0–2 months) constitutes the initial stage of chicken growth, during which intensive formation and development of organs occurs as a basis for further growth. The grower period (3–4 months),

constitutes a subsequent phase of growth characterised by an augmentation in body size, the formation of muscle tissue, and enhanced efficiency in nutrient utilization.

The instruments utilized in this study encompassed digital calipers, measuring tapes, digital scales, and writing instruments. The measurements were taken from live chickens. The materials utilized in this study encompassed 75 cocks and 96 hens kampong, 4 cocks and 17 hens IPB D1, 32 cocks and 52 hens IPB D2, and 30 cocks and 47 hens IPB D3 during the starter period. During the grower period, the following substances were utilized: 57 cocks and 83 hens kampong, 12 cocks and 55 hens IPB D1, 65 cocks and 148 hens IPB D2, and 67 cocks and 206 hens IPB D3.

Data Collection

The measurement process for each observed variable was carried out in a specific manner (Figure 1). The length of the femur (X_1) was measured along the femur bone using a caliper. The length of the tibia (X_2) was measured from the patella to the end of the tibia using a caliper. The length of the tarsometatarsus (X_3) is measured along the tarsometatarsus bone, also known as the shank, using a caliper. The circumference of the tarsometatarsus (X_4) is measured circumferentially at the midpoint of the tarsometatarsus bone using a measuring tape, and the result is then converted to the caliper scale. The length of the third toe (X_5) is measured from the base to the tip of the third toe using a caliper. The wing length (X_6) is measured along the wing bones, from the base of the humerus to the tip of the phalanges, using a caliper. The maxilla length (X_7) is measured from the base to the tip of the lower part of the beak using a caliper. The height of the comb (X_8) is measured from the point of attachment to the head to the highest point of the comb, without considering the shape of the comb due to technical constraints in the field. The measurement of the area of the comb in the field is a challenging task. However, the height of the comb is still measured using a vernier caliper.

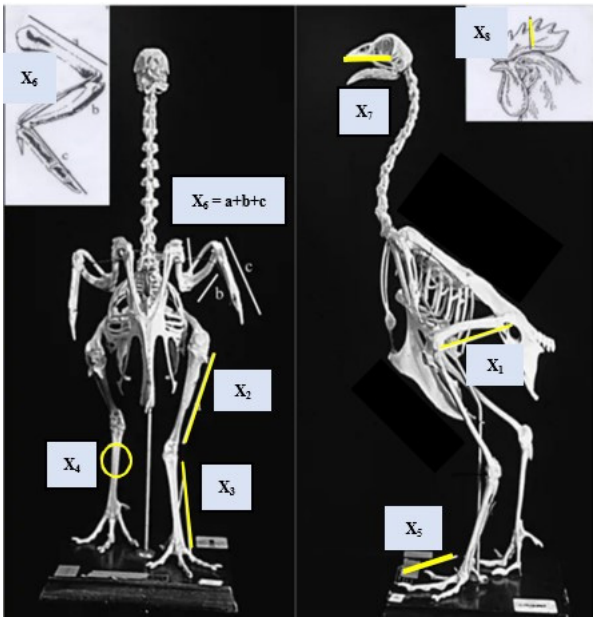

Figure 1. Linear body surface measurements of chickens observed based on their body frame (X_1 = femur length, X_2 = tibia length, X_3 = tarsometatarsus length, X_4 = tarsometatarsus circumference, X_5 = third toe length, X_6 = wing length, X_7 = maxilla length, and X_8 = comb height) Adapted from Waggoner & Hutchinson (2001).

Data Analysis

The data were processed using Minitab® 21.3.1 software. The descriptive statistical analyses employed in this study encompassed the mean, standard deviation, and coefficient of variation. The analysis was conducted based on two distinct chicken groups and gender. The calculation of the mean, standard deviation, and coefficient of variation performed using equations 1 to 3 in accordance with the method employed by Walpole (1992) before principal component analysis was developed.

$$mean\ (\bar{x}) = \frac{\sum_{i=1}^{n} x_i}{n} = \frac{x_1+x_2+x_3+\ldots x_{11}}{n} \quad (1)$$

$$standard\ deviation\ (s) = \left(\frac{\sum_{x=1}^{n}(x_i-\bar{x})^2}{n-1}\right)^{\frac{1}{2}} \quad (2)$$

$$coefficient\ of\ variation = \frac{s}{\bar{x}} \times 100\% \quad (3)$$

The descriptive data were subsequently analysed using principal component analysis (PCA) to obtain equations for size and shape derived from the covariance matrix (Gaspersz 1992), using equations 4 to 5. The purpose of this study was to apply PCA to determine the size and shape characteristics of each group of chickens that were observed. The first principal component score (Y_1) elucidates the body size equation as the chicken body size score calculated using equations 4, while the second principal component score (Y_2) elucidates the body shape equation as the chicken body shape score calculated using equations 5 (Nishida *et al.* 1982).

$$Y_1 = a_{11}X_1 + a_{21}X_2 + \cdots + a_{81}X_8 \quad (4)$$

$$Y_2 = a_{12}X_1 + a_{22}X_2 + \cdots + a_{82}X_8 \quad (5)$$

Where Y_1 is first principal component (size score), Y_2 is second principal component (shape score), $a_{11} - a_{81}$ is eigenvector for body size equation, $a_{12} - a_{82}$ is eigenvector for body shape equation, X_1-X_8 is variables 1,2,3,…,8.

The correlation between the source variables (eight linear body surface area variables) and the principal components can be estimated by analyzing the correlation coefficients between the source variables and the principal components. The correlation model utilized in this study calculated using equations 6 which is based on Gaspersz's (1992) formulation, can be expressed as follows.

$$r_{ziyj} = r_{ij} = \frac{\alpha_{ij}\sqrt{\lambda_{ij}}}{s_i} \quad (6)$$

Where r_{ziyj} is correlation coefficient of variable i of component j, αij is eigenvector of variable i with component j, λ_{ij} is eigenvalue (characteristic root) of principal component j, si is standard deviation of variable i.

The body size and shape scores of the chickens are then utilized to illustrate a crowd diagram. The chicken body size score is aligned with the X-axis, while the chicken body shape score is aligned with the Y-axis. Each data point is assigned a body size score and a body shape score, which are represented in the form of dots (plots) with different symbols according to group and gender.

RESULTS AND DISCUSSION

Linear Body Surface in the Starter Period

The mean linear body surface area observed in kampong chickens, IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens during the starter period is presented in Tables 1 and 2. The analysis revealed that kampong chickens exhibited the highest mean body surface area, followed by IPB D3 chickens, IPB D1 chickens, and IPB D2 chickens in both cocks and hen subjects. The mean body surface area of kampong chickens does not differ significantly from that of IPB D3 chickens. The mean body surface area of IPB D3 chickens was found to be greater than that of IPB D1 and IPB D2 chickens. This phenomenon can be attributed to the deliberate selection of IPB D3 chickens, which have been specifically bred for their rapid rate of body weight gain. This rapid increase in body mass leads to an enhancement in body surface area, thereby contributing to the observed outcomes.

Body surface area has a strong correlation with livestock growth (Hastuti *et al.* 2021). According to Permatasari *et al.* (2013), there is a high correlation between body size and chicken body weight, which makes body size a useful parameter for estimating body weight. The mean body surface area of IPB D2 chickens was found to be the smallest compared to other chickens. This outcome is attributable to the selection of IPB D2 chickens for their resistance to Newcastle disease (ND). The observed differences in body surface area may be attributed to variations among local chicken breeds and IPB D1 chickens, including IPB D2 and IPB D3 chickens, as well as differences in both external and internal environments.

Table 1. Mean, Standard Deviation, and Coefficient of Variation of Linear Body Surface Area Variables in Kampong Chicken, IPB D1 Chicken, IPB D2 Chicken, and IPB D3 Chicken Cockss during The Starter Period

Variables	Kampong	IPB D1	IPB D2	IPB D3
	♂ (n=75)	♂ (n=4)	♂ (n=32)	♂ (n=30)
	----------(mm)----------			
X_1	68.82 ± 10.58 (15.38%)	58.75 ± 2.13 (3.63%)	59.82 ± 4.42 (7.40%)	67.74 ± 6.24 (9.20%)
X_2	95.48 ± 15.71 (16.45%)	80.40 ± 5.10 (6.34%)	75.74 ± 5.10 (6.73%)	94.72 ± 6.36 (6.71%)
X_3	68.95 ± 11.69 (16.96%)	61.38 ± 4.21 (6.87%)	57.07 ± 4.66 (8.17%)	71.31 ± 5.86 (8.21%)
X_4	27.56 ± 3.56 (12.92%)	23.75 ± 2.75 (11.59%)	23.44 ± 2.27 (9.69%)	29.30 ± 1.93 (6.60%)
X_5	45.54 ± 6.53 (14.34%)	42.27 ± 3.73 (8.81%)	37.98 ± 3.93 (10.34%)	43.69 ± 3.94 (9.02%)
X_6	180.51±25.47 (14.11%)	165.88 ± 10.37 (6.25%)	150.29±11.69 (7.78%)	176.92±13.50 (7.63%)
X_7	27.20 ± 3.18 (11.70%)	25.60 ± 1.23 (4.81%)	22.88 ± 2.18 (9.52%)	25.81 ± 1.906 (7.39%)
X_8	12.43 ± 5.247 (42.22%)	11.58 ± 1.98 (17.10%)	6.40 ± 3.03 (47.27%)	11.69 ± 3.89 (33.26%)

% in parentheses indicates the coefficient of variation

Explanation: X_1 = Femur Length, X_2 = Tibia Length, X_3 = Tarsometatarsus Length, X_4 = Tarsometatarsus Circumference, X_5 = Third Toe Length, X_6 = Wing Length, X_7 = Maxilla Length, X_8 = Comb Height, n = Number (tails)

Table 2. Mean, Standard Deviation, and Coefficient of Variation of Linear Body Surface Area Variables in Kampong Chicken, IPB D1 Chicken, IPB D2 Chicken, and IPB D3 Chicken Henss during The Starter Period

Variables	Kampong	IPB D1	IPB D2	IPB D3
	♀ (n=96)	♀ (n=17)	♀ (n=52)	♀ (n=47)
	----------(mm)----------			
X_1	67.80 ± 9.55 (14.08%)	53.05 ± 6.25 (11.78%)	56.75 ± 5.85 (10.31%)	65.36 ± 8.76 (13.40%)
X_2	92.26 ± 14.05 (15.23%)	71.14 ± 10.98 (15.43%)	71.55 ± 6.51 (9.09%)	86.34 ± 11.38 (13.17%)
X_3	65.77 ± 9.47 (14.40%)	51.37 ± 7.85 (15.28%)	54.08 ± 5.09 (9.42%)	64.75 ± 8.40 (12.97%)
X_4	25.68 ± 2.86 (11.12%)	21.12 ± 2.93 (13.90%)	21.94 ± 2.49 (11.36%)	25.87 ± 3.19 (12.34%)
X_5	43.52 ± 5.35 (12.28%)	35.67 ± 4.68 (13.11%)	36.16 ± 3.49 (9.64%)	41.80 ± 4.20 (10.05%)
X_6	176.75 ± 22.65 (12.81%)	146.69 ± 18.34 (12.50%)	143.15 ± 12.12 (8.47%)	168.31 ± 15.56 (9.25%)
X_7	26.45 ± 2.50 (9.44%)	23.36 ± 2.42 (10.35%)	22.36 ± 1.83 (8.16%)	25.03 ± 1.78 (7.11%)
X_8	5.05 ± 1.871 (37.02%)	4.54 ± 2.28 (50.17%)	4.25 ± 1.95 (45.79%)	5.77 ± 1.99 (34.63%)

% in parentheses indicates the coefficient of variation

Explanation: X_1 = Femur Length, X_2 = Tibia Length, X_3 = Tarsometatarsus Length, X_4 = Tarsometatarsus Circumference, X_5 = Third Toe Length, X_6 = Wing Length, X_7 = Maxilla Length, X_8 = Comb Height, n = Number (tails)

As posited by Junaedi and Khaeruddin (2018), genetic and environmental factors have been identified as contributing elements to variations in body size. As stated in the study by Kusuma and Prijono (2007), variations in chicken body size are influenced by environmental conditions during rearing.

Linear Body Surface in the Grower Period

The mean linear body surface area observed in kampong chickens, IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens during the grower period is presented in Tables 3 and 4. The disparities in genetic lines between kampong chickens and IPB D1 chickens (including IPB D2 and IPB D3 chickens), along with both external and internal environmental factors, culminate in divergent body surface area measurements in chickens. The analysis revealed that kampong chickens exhibited the highest average body surface area, followed by IPB D1 chickens, IPB D3 chickens, and IPB D2 chickens, both in cockss and hens. Contrary to the observations made during the starter period, this study revealed that IPB D3 chickens in the grower period exhibited smaller body surface areas compared to IPB D1 chickens.

This phenomenon is likely attributable to augmented muscle adhesion in anatomical regions extending beyond the eight linear body surface variables that were observed. The 25% Cobb strain blood in IPB D3 chickens selected for rapid growth is likely the cause of increased muscle adhesion in the chest area, which is not included in the eight observed variables. According to Safitri and Plumerastuti (2023), Cobb broiler chickens exhibit several advantages over other broiler strains, including rapid growth, optimal breast formation, and enhanced bone and muscle structure. These advantages are particularly notable when compared to other popular broiler strains such as Lohman, Ross, Hybro, and Hubbard.

Body surface area measurements indicate that IPB D2 chickens are smaller than IPB D1 chickens during the grower period for both cockss and hens (Table 3 and Table 4). This is attributable to the fact that IPB D2 chickens are the result of a selection process from IPB D1 chickens, with

Table 3. Mean, Standard Deviation, and Coefficient of Variation of Linear Body Surface Area Variables in Kampong Chicken, IPB D1 Chicken, IPB D2 Chicken, and IPB D3 Chicken Cockss during The Grower Period

Variables	Kampong	IPB D1	IPB D2	IPB D3
	♂ (n=57)	♂ (n=12)	♂ (n=65)	♂ (n=67)
	----------(mm)----------			
X_1	91.96 ± 8.18 (8.90%)	77.98 ± 7.29 (9.35%)	76.32 ± 9.71 (12.73%)	76.08 ± 8.04 (10.57%)
X_2	131.58 ± 12.96 (9.85%)	108.27 ± 10.20 (9.42%)	106.54 ± 13.48 (12.65%)	104.38 ± 13.09 (12.55%)
X_3	96.36 ± 9.11 (9.46%)	82.33 ± 9.58 (11.63%)	81.31 ± 11.61 (14.28%)	81.52 ± 9.56 (11.72%)
X_4	35.81 ± 3.56 (9.94%)	32.00 ± 4.26 (13.33%)	31.45 ± 4.70 (14.94%)	31.48 ± 3.57 (11.35%)
X_5	57.68 ± 4.95 (8.58%)	53.89 ± 3.95 (7.32%)	51.56 ± 4.41 (8.55%)	51.05 ± 5.03 (9.85%)
X_6	232.09 ± 16.72 (7.20%)	210.73 ± 16.70 (7.93%)	205.78 ± 23.02 (11.19%)	205.10 ± 18.51 (9.02%)
X_7	33.22 ± 2.88 (8.67%)	30.00 ± 3.13 (10.43%)	30.07 ± 2.86 (9.52%)	29.63 ± 2.26 (7.64%)
X_8	22.56 ± 7.99 (35.43%)	18.72 ± 8.73 (46.62%)	15.04 ± 10.34 (68.79%)	13.62 ± 5.82 (42.77%)

% in parentheses indicates the coefficient of variation

Explanation: X_1 = Femur Length, X_2 = Tibia Length, X_3 = Tarsometatarsus Length, X_4 = Tarsometatarsus Circumference, X_5 = Third Toe Length, X_6 = Wing Length, X_7 = Maxilla Length, X_8 = Comb Height, n = Number (tails)

Table 4. Mean, Standard Deviation, and Coefficient of Variation of Linear Body Surface Area Variables in Kampong Chicken, IPB D1 Chicken, IPB D2 Chicken, and IPB D3 Chicken Henss during The Grower Period

Variables	Kampong	IPB D1	IPB D2	IPB D3
	♀ (n=83)	♀ (n=55)	♀ (n=148)	♀ (n=206)
	----------(mm)----------			
X_1	86.14 ± 6.30 (7.31%)	73.03 ± 7.71 (10.56%)	70.91 ± 7.63 (10.76%)	71.24 ± 7.75 (10.87%)
X_2	120.70 ± 9.32 (7.72%)	98.71 ± 10.07 (10.21%)	96.94 ± 12.04 (12.42%)	97.84 ± 11.14 (11.38%)
X_3	85.02 ± 7.58 (8.91%)	74.11 ± 8.52 (11.50%)	73.05 ± 8.76 (12.00%)	74.68 ± 8.42 (11.28%)
X_4	32.60 ± 2.29 (7.02%)	29.22 ± 3.21 (11.00%)	28.44 ± 3.54 (12.46%)	29.01 ± 3.08 (10.63%)
X_5	52.83 ± 4.52 (8.56%)	47.57 ± 4.64 (9.75%)	47.66 ± 4.48 (9.40%)	48.21 ± 4.67 (9.69%)
X_6	215.37 ± 13.20 (6.13%)	197.09 ± 17.34 (8.80%)	191.25 ± 17.10 (8.94%)	191.89 ± 17.03 (8.88%)
X_7	31.08 ± 2.38 (7.64%)	28.74 ± 2.26 (7.87%)	28.71 ± 2.21 (7.71%)	28.24 ± 2.15 (7.63%)
X_8	8.32 ± 3.42 (41.10%)	7.43 ± 2.85 (38.40%)	6.68 ± 3.50 (52.42%)	7.43 ± 3.68 (49.45%)

% in parentheses indicates the coefficient of variation

Explanation: X_1 = Femur Length, X_2 = Tibia Length, X_3 = Tarsometatarsus Length, X_4 = Tarsometatarsus Circumference, X_5 = Third Toe Length, X_6 = Wing Length, X_7 = Maxilla Length, X_8 = Comb Height, n = Number (tails)

a particular emphasis on the development of resistance to ND disease. The nutrients present in IPB D2 chicken feed are primarily utilized to sustain the body's defenses against ND disease. According to Lestari *et al.* (2022), IPB D2 chickens have higher Ig Y levels, at least 9.55 mg mL^{-1}, and a minimum ND titer of 3 log2 HI. Furthermore, the IPB D2 chicken was developed through a selection process aimed at enhancing its immunocompetence.

Body Size and Shape and Crowd Diagram Formation

The equations for body size and shape of kampong chickens, IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens are shown in Table 5. Regarding body size, wing length exhibits the strongest correlation with that variable when compared to others, as illustrated in Table 6. According to the findings presented in Table 6, comb height has been identified as the most significant correlate of body shape when compared to other variables. In all observed chicken types, wing length contributes the most to body size scores, while comb height contributes the most to body shape scores.

Table 5. The Equation in Size and Body Shape Between Kampong Chickens, IPB D1 Chickens, IPB D2 Chickens, and IPB D3 Chickens

		Equation	Proportion	Eigen value
Body size	=	0.29X1+0.46X2+0.34X3+0.11X4 +0.17X5+ 0.73X6+0.08X7+0.10X8	0.934	0.333
Body shape	=	0.22X1+0.37X2+0.17X3+0.09X4 –0.09X5–0.50X6–0.03 X7+0.72X8	0.022	33.4

Explanation: X_1 = Femur Length, X_2 = Tibia Length, X_3 = Tarsometatarsus Length, X_4 = Tarsometatarsus Circumference, X_5 = Third Toe Length, X_6 = Wing Length, X_7 = Maxilla Length, X_8 = Comb Height

Table 6. Correlation between Body Size and Shape and Each Variable of Linear Body Surface Area in Kampong Chickens. IPB D1 Chickens. IPB D2 Chickens. and IPB D3 Chickens

Variables	Size	Shape
Femur length (X_1)	0.945	0.111
Tibia length (X_2)	0.971	0.118
Tarsometatarsus length(X_3)	0.971	0.075
Tarsometatarsus circumference (X_4)	0.899	0.114
Third toe length (X_5)	0.918	−0.077
Wing length (X_6)	0.991	−0.104
Maxilla length (X_7)	0.885	−0.045
Comb height (X_8)	0.568	0.623

The length of the wings plays a pivotal role in facilitating flight and maintaining equilibrium in chickens. According to Winangun (2023), the wings of chickens function as a stabilizing mechanism during locomotion, descent, or jumping. Additionally, it is elucidated that the wings of the chicken undergo a rhythmic expansion and contraction, thereby contributing to the maintenance of its bodily equilibrium during movement. The correlation between wing length and body size in chickens is direct: increased wing length corresponds to increased body size. According to Nishida *et al.* (1982), the body size conformation of poultry can be effectively distinguished based on wing length.

The comb height is associated with the capacity to manage excessive heat in elevated ambient temperatures through the dilation of blood vessels in the comb, facilitating the transfer of heat from the chicken's body to the surrounding environment (Hester *et al.* 2015). The height of the comb serves as a distinguishing feature, indicating that each group of chickens possesses unique characteristics. These characteristics, in turn, reflect different adaptive abilities resulting from varying selection. According to Lengur *et al.* (2022), comb height as a morphological trait in chickens indicates that these chickens possess a high degree of adaptive capacity to elevated environmental temperatures. It has been demonstrated that an increase in comb height corresponds with an enhancement in the chicken's capacity to withstand elevated ambient temperatures.

The crowd diagrams generated from the size scores and shape scores of each kampong chicken, IPB D1 chicken, IPB D2 chicken, and IPB D3 chicken during the starter and grower periods for both cocks and hens are shown in Figure 2. The crowd diagrams depicted in Figure 2 are challenging to interpret directly; therefore, they have been subdivided into a series of more straightforward diagrams.

Starter Period Crowd Diagram

In this study, wing length, a characteristic of body size, was utilized as a reference to determine the body size of chickens. The largest wing length was observed in kampong chickens, followed by IPB D3 chickens, IPB D1 chickens, and IPB D2 chickens (Tables 1 and 2). As posited by Nishida *et al.* (1980), the wing length of chickens is associated with their body size. This phenomenon has been further elucidated by Herren (2000), who observed that the growth of the chicken wing is rapid from birth until adulthood, accompanied by continuous bone and muscle development. The wing length measurements of chickens during the starter phase correspond to the body size score or the X-axis on the scatter plot, as illustrated in Figure 3.

The X-axis, which indicates body size in the starter period data group of kampong chickens, is scattered and overlaps with the three types of IPB chickens, namely IPB D1, IPB D2, and IPB D3. The findings of this study suggest that the body size of kampong chickens during the starter period forms a cluster toward the far right, indicating a larger body size score. The kampong chickens utilized in this study exhibited larger body sizes in comparison to IPB D1, IPB D2, and IPB D3 chickens. This finding contrasts with the observations reported by Sumantri and Darwati (2017), who

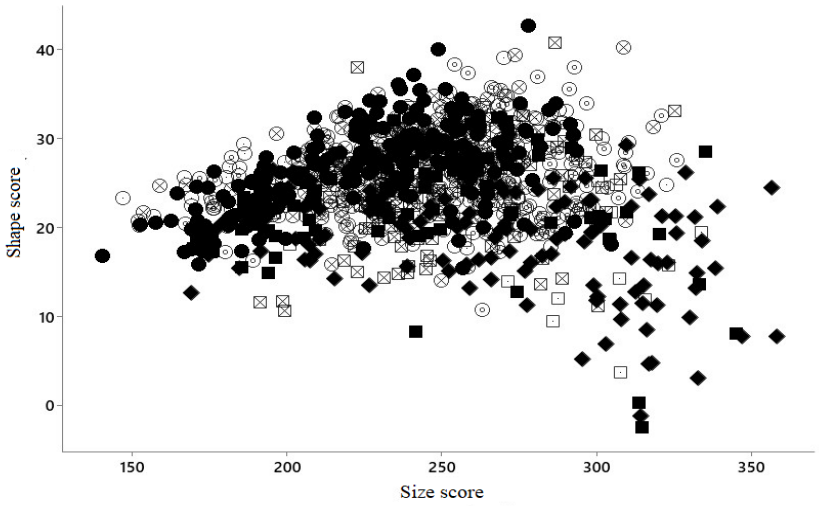

Figure 2. Diagram of the size and shape of the overall chicken population (◇ = kampong cocks, ⊕ = kampong hens, ▽ = IPB D1 cocks, ▼ = IPB D1 hens, ◆ = IPB D2 cocks, ◇ = IPB D2 hens, ⊕ = IPB D3 cocks, ○ = IPB D3 hens)

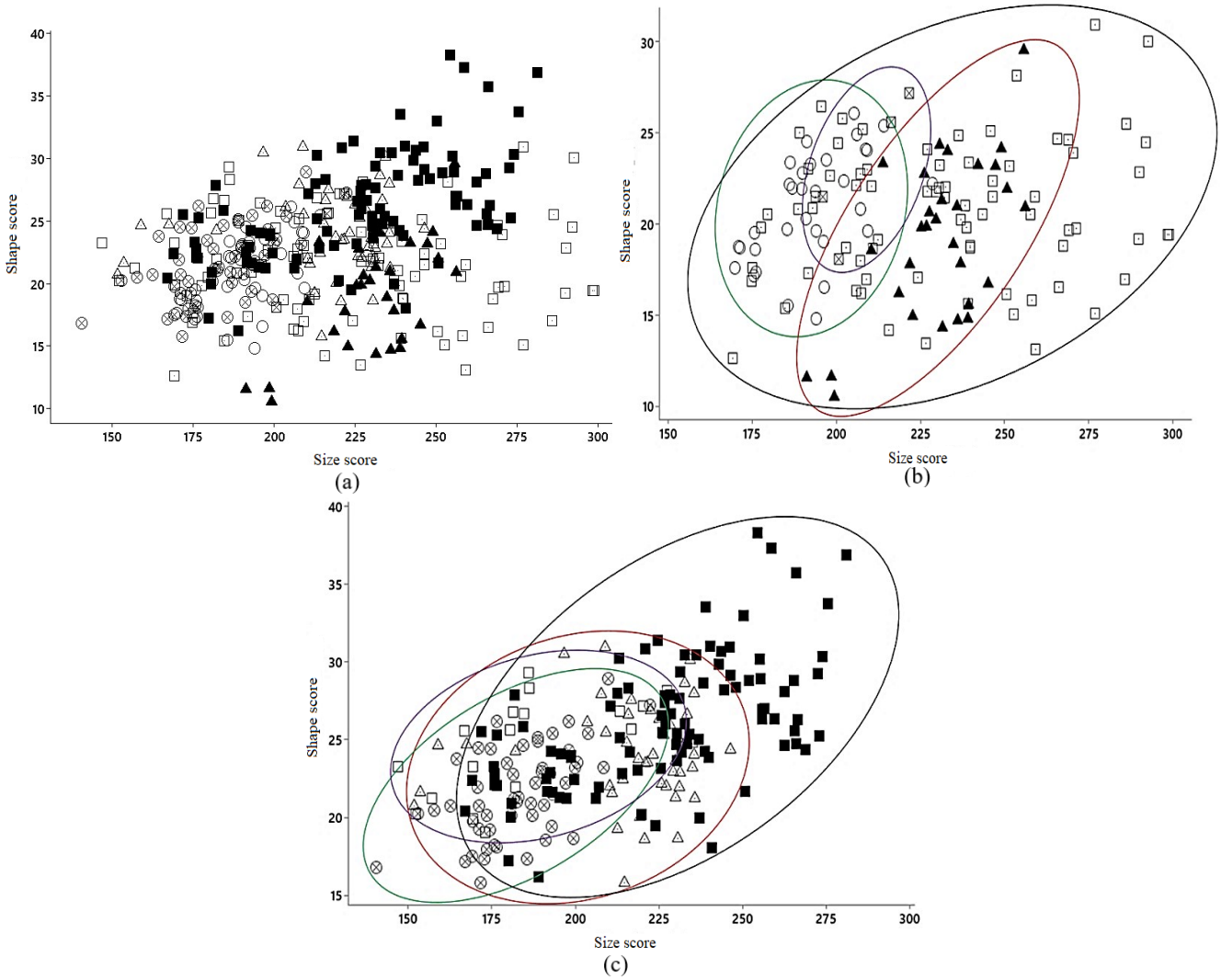

Figure 3. Diagram of the size and body shape of chickens during the starter period. a) cocks and hens during the starter period, b) cocks during the starter period, c) hens during the starter period. (◇ = kampong cocks, ⊕ = kampong hens, ▽ = IPB D1 cocks, ▼ = IPB D1 hens, ◆ = IPB D2 cocks, ◇ = IPB D2 hens, ⊕ = IPB D3 cocks, ○ = IPB D3 hens)

indicated that IPB D1 chickens exhibited superior growth performance and larger body dimensions compared to kampong chickens. This discrepancy can be attributed to the fact that the kampong chickens utilized in this study were not the population that was used for the development of IPB D1 chickens. The chickens utilized in this study were of a larger stature than the typical domestic breeds commonly found in the region. According to Putri *et al.* (2020), the environment and living conditions, objectives, and maintenance systems influence the body size of chickens. In addition to genetic and environmental factors, differences in the actual age of individuals also contribute to the observed variations in body size. The kampong chickens in this study were mostly at the end of the starter and grower periods, having achieved relatively high body weights; meanwhile, the IPB chickens were mostly at the beginning of these periods.

The data clusters for IPB D3, IPB D1, and IPB D2 chickens are distributed from right to left on the diagram for both cockss and hens (Figure 3b and Figure 3c). This finding suggests that IPB D3 chickens exhibit a larger body size compared to IPB D1 and D2 chickens. This is attributable to the fact that IPB D3 chickens have been the result of a selection process aimed at achieving faster growth than that of IPB D1 chickens (Damarani 2022). The positioning of IPB D2 chickens at the extreme left of the diagram signifies the outcomes of a selection process targeting resistance to ND, in contrast to IPB D1 chickens. The reduction in body size can be attributed to the fact that not all nutrients present in the feed are utilized for growth purposes. The majority of these nutrients are instead allocated towards maintaining bodily functions and survival, even in the face of disease threats. According to Miraj *et al.* (2022), IPB D2 chickens are descended from IPB D1 chickens that have been crossbred to exhibit resistance to ND.

In this study, the body shape of chickens was determined using a measurement of comb height, which is a characteristic of body shape. The Y-axis, which indicates body shape in the kampong cocks data group, overlaps with

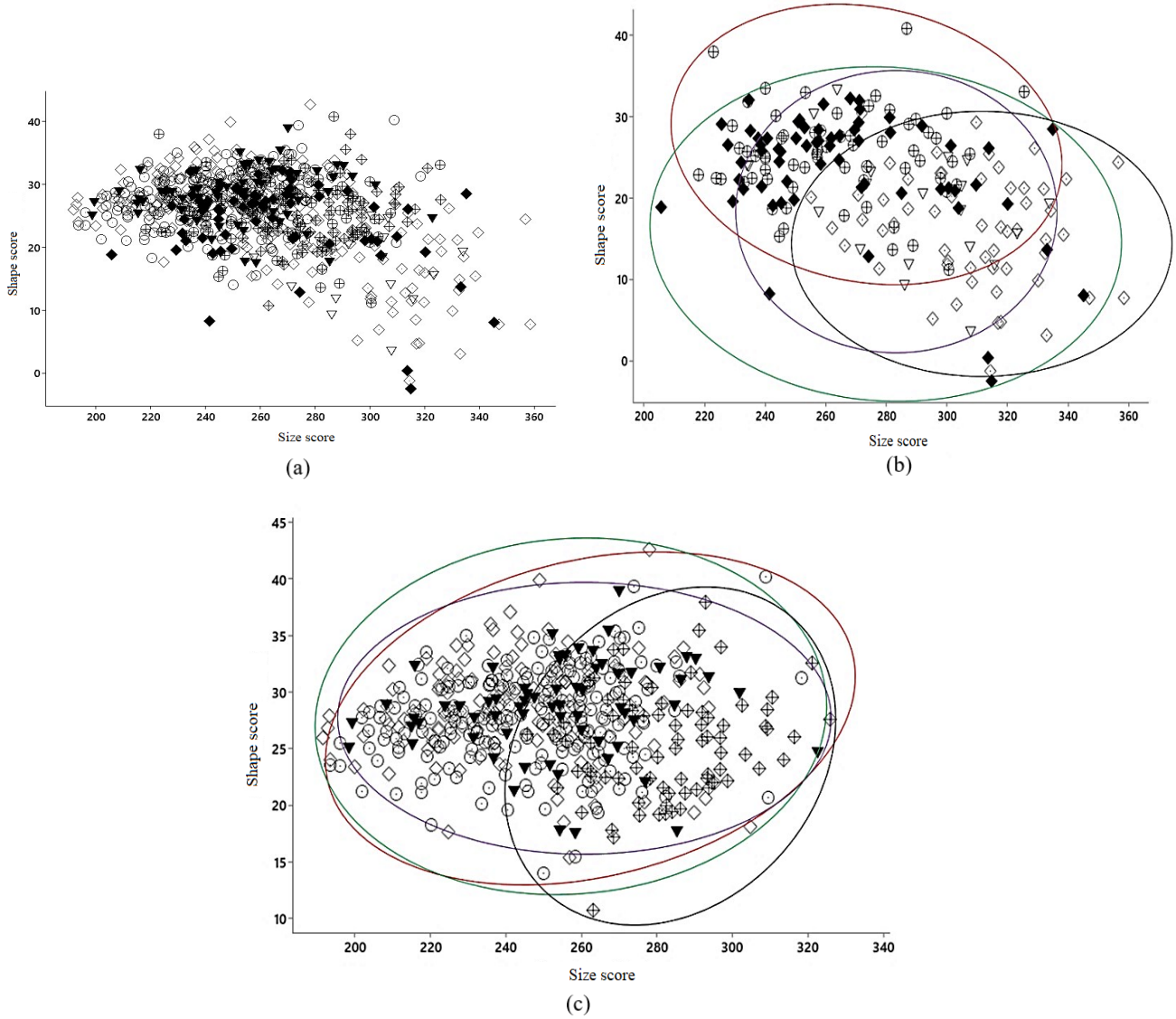

Figure 4. Diagram of the size and body shape of chickens during the grower period. a) cocks and hens during the grower period, b) cocks during the grower period, c) hens during the grower period (◇ = kampong cocks, ⨁ = kampong hens, ▽ = IPB D1 cocks, ▼ = IPB D1 hens, ◆ = IPB D2 cocks, ◇ = IPB D2 hens, ⨁ = IPB D3 cocks, ○ = IPB D3 hens)

the body shapes of IPB D1, D2, and D3 cocks. However, some IPB D3 cocks were found to have a different body shape from kampong chickens, tending toward lower body shape scores. In contrast, the body shapes of IPB D1 and D2 cocks were more uniform and overlapped. The body shapes of IPB D1 and IPB D2 cocks during the starter period are not yet distinguishable (Figure 3b).

During the starter period, significant differences were identified between hens and cocks (Figure 3c). The body shape of kampong hens still includes IPB D1, IPB D2, and IPB D3 hens, but some data from kampong hens are separated into the upper group. In consideration of the aforementioned factors, it can be concluded that the body shape of kampong hens in this study is not significantly different from that of kampong hens utilized in the development of IPB D1 chickens. Everitt and Dunn (1999) stated that animal body shape is more strongly influenced by genetic factors than by environmental influences. This phenomenon has been further elucidated by Depison *et al.* (2022), who contend that body shape characteristics are influenced by genetics, while body size characteristics are influenced by the environment.

Grower Period Crowd Diagram

Wing length as a characteristic of body size in the grower period is similar to that in the starter period. The results indicate that the largest wing length was observed in kampong chickens, followed by IPB D1, IPB D3, and IPB D2 chickens (Tables 3 and 4). In the crowd diagram, the X-axis, which indicates body size, demonstrates overlap between kampong chickens and IPB D1, IPB D2, and IPB D3 chickens. The wing length measurements of chickens in the grower period correspond to the body size scores displayed in the crowd diagram, as illustrated in Figure 4.

The group of kampong cocks in the grower phase was located on the far right of the diagram. IPB D2 cocks exhibited a lateral dispersal pattern, intersecting with kampong cocks. The IPB D1 cocks were distributed between the IPB D2 and IPB D3 cocks (Figure 4b). A subsequent analysis of the crowd diagram reveals a tendency for the IPB D3 cocks data to congregate on the left side of the diagram, thereby suggesting that the body size of IPB D3 cocks is comparatively diminutive compared to that of IPB D1 cocks. The disparity in selection direction for IPB D3 cocks is not yet sufficient to indicate that their body size is larger than that of IPB D1 cocks. This phenomenon can be attributed to the fact that IPB D3 chickens have only reached their fourth generation and have not yet achieved genetic stability. They are still in the candidate strain stage. Chickens that have reached the fifth generation have achieved a stable level of genetic homozygosity. As posited by Jingade *et al.* (2011), the degree of homozygosity of the crossbreed directly correlates with the quality of the offspring, with higher levels of homozygosity resulting in superior offspring compared to their parents.

A different finding was observed in the data set for hens during the grower period. The data sets for hens from the three populations (IPB D1, IPB D2, and IPB D3) exhibit overlap, as illustrated in the data crowd diagram. This finding suggests that the body size of hens from the three populations is nearly identical. The growth rate of IPB D1, IPB D2, and IPB D3 hens is comparatively diminished during the grower period when compared with their cocks counterparts. During this period, the expression of selected genes in hens was not yet observed in this study. According to Kurniawan *et al.* (2012), the growth rate of hens is generally lower than that of cocks.

The crowd diagram reveals an opposing shift in data groups between IPB D2 cocks, which possess disease resistance, and IPB D3 cocks, which demonstrate rapid growth. As illustrated in Figure 4b, the IPB D2 cocks data group exhibits a downward trend, while the IPB D3 cocks data group demonstrates an upward trend. The observed shift in the IPB D2 and IPB D3 cocks data groups in this study is exclusively evident during the grower phase, wherein the IPB D1 cocks are situated between the IPB D2 and IPB D3 cocks groups. Prolonged selection for these traits may result in the divergence of the IPB D2 and IPB D3 cocks data groups. Genetically, the expression of genes regulating rapid growth and disease resistance is already present at hatching; however, the body shape characteristics only become apparent when the chickens enter the grower phase.

The crowd diagram of hens during the grower period in Figure 4c demonstrates that IPB D1, IPB D2, and IPB D3 hens exhibit significant overlap with kampong hens. This finding suggests that IPB D1, IPB D2, and IPB D3 hens during the grower period in this study possess largely similar body size and shape. The data for kampong hens demonstrate a more uniform trend and are located further to the right, indicating that the body size of kampong hens during the grower period is larger than during the starter period.

The crowd diagram of hens during the grower period reveals no discernible difference in the direction of clustering between IPB D2 and IPB D3 hens. This finding suggests that the selection process employed for both types of hens was not adequate to elicit differences in body size and shape. Genetically, the expression of genes regulating disease resistance in IPB D2 chickens and rapid growth in IPB D3 chickens was already present at hatching. However, the body shape characteristics were not yet clearly visible when the hens entered the grower period in this study.

CONCLUSION

The body size and body shape characteristics of kampong chickens, IPB D1 chickens, IPB D2 chickens, and IPB D3 chickens are wing length, which has the highest correlation with size, and comb height, which has the highest correlation with body shape compared to other variables. The selection of chickens based on wing length and comb height, in conjunction with natural selection, has been demonstrated to enhance chicken productivity. During the starter period, IPB D1 and IPB D2 cocks exhibited comparable body shapes, while IPB D2 and IPB D3 hens demonstrated similar body shapes during this stage. A discrepancy in the selection direction between IPB D2

cocks, which tended to disease resistance, and IPB D3 cocks, which demonstrated a propensity for body weight growth, was observed. This discrepancy manifested in divergent trends, with the former exhibiting an upward trend and the latter displaying a downward trend, as depicted in the cluster diagram for cocks during the grower period. The body size of kampong chickens forms a cluster toward the far right in both the starter and grower periods and shows the body shape characteristics of hens in the starter period.

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