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Research Article

Optimizing Physiological Growth of Bayang Ducks During the Grower Phase: Determining the Optimal Dietary Protein Level for Future Breeders

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Abstract | Optimizing physiological growth during the grower phase is a critical prerequisite for preparing productive future breeders in local duck production systems. This study aimed to optimize the physiological growth performance of Bayang female ducks during the grower phase (6–19 weeks of age) through different dietary protein levels as an experimental approach. A total of 200 six-week-old ducks were randomly allocated into 20 floor pens (10 birds per pen) following a randomized block design with four dietary protein levels (14%, 16%, 18%, and 20% crude protein) and five replications. All diets were formulated to be iso-caloric (2,900 kcal/kg metabolizable energy). Feed was provided in controlled daily amounts, while drinking water was offered *ad libitum*. Physiological growth responses were evaluated based on feed consumption, protein and energy intake, body weight gain, daily growth rate, feed conversion ratio (FCR), mortality, and growth curve characteristics. The results demonstrated that ducks receiving the 16% crude protein diet exhibited the most favorable physiological growth response, characterized by balanced nutrient intake, and growth characteristics. Average feed intake reached 123.1 g/duck/day, with protein and energy intakes of 20.94 g/duck/day and 357.5 kcal/duck/day, respectively. Ducks attained a final body weight of 1,350 g/head, weekly body weight gain of 568 g/head/week, and a daily growth rate ranging from 14.8 to 18.6 g/day, accompanied by an average FCR of 2.17 and zero mortality across treatments. Growth curve analysis revealed a sigmoid growth pattern, with a rapid growth phase occurring between weeks 8 and 13, followed by a physiological growth plateau. Among the evaluated nonlinear models (Richards, Gompertz, Logistic, Weibull, and MMF), the Richards model provided the best fit (R^2 = 0.9957), predicting the onset of the physiological growth plateau at approximately 11.5 weeks of age with a corresponding body weight of 1.276 kg. In conclusion, optimizing physiological growth in Bayang ducks during the grower phase can be effectively achieved with a dietary protein level of 16% crude protein. This feeding strategy potentially supports metabolic balance, somatic tissue development, and reproductive organ maturation, thereby establishing a strong physiological foundation for early sexual maturity and improved breeder readiness under tropical conditions.

Keywords | Bayang ducks, Physiological growth, Dietary protein, Feed conversion, Growth modeling

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INTRODUCTION

Physiological growth during the grower phase is a primary determinant of breeder readiness and future productive potential in ducks. This phase is characterized by accelerated somatic tissue accretion, metabolic adjustment, endocrine regulation, and the initiation of reproductive organ development, which collectively define physiological preparedness prior to sexual maturity. In ducks, age-related changes in body weight and tissue development follow biologically regulated patterns that can be accurately described using nonlinear growth models. Such models enable the identification of physiological transition points and growth plateaus, providing biologically meaningful insight into growth regulation and developmental efficiency (Ghavi, 2025).

Efficient physiological growth during the grower phase is particularly critical for future reproductive success in poultry, especially in dual-purpose breeds such as ducks. Growth performance at this stage should not be interpreted solely as body weight gain, but also encompasses nutrient utilization efficiency, feed conversion efficiency, and controlled body composition. Collectively, these factors determine physiological balance and the readiness of ducks to function as productive breeders, highlighting the importance of grower-phase management beyond conventional growth metrics (Choi *et al*., 2022).

In tropical local duck production systems, achieving optimal physiological growth during the grower phase remains a major challenge due to environmental stressors, variability in feeding management, and differences in genetic adaptability. Locally adapted waterfowl genotypes exhibit distinct growth dynamics and physiological responses compared with commercial strains, indicating that growth standards derived from commercial ducks cannot be directly extrapolated to indigenous breeds (Mekonnen *et al*., 2023). Consequently, breed-specific, physiology-based growth management strategies are required to optimize development under local production conditions.

Among Indonesia's indigenous waterfowl, the Bayang duck (*Anas platyrhynchos javanicus*), native to West Sumatra, represents a valuable local genetic resource. This breed exhibits genetic distinctiveness, as evidenced by specific molecular markers (CMO.211 and AY.295), underscoring its importance for genetic conservation and targeted development programs (Rusfidra and Heryandi, 2013). From a productive standpoint, Bayang ducks possess promising dual-purpose characteristics. Females reach sexual maturity at approximately 5.5 months, with annual egg production ranging from 184 to 215 eggs, peak laying rates of up to 85%, and average egg weights of around 65 g. Adult body weights reach approximately 1.8 kg in males and 1.5 kg in females. Recent studies further confirm the adaptability and productive potential of Indonesian local ducks, including Bayang ducks, across diverse management systems (Sulaiman *et al*., 2023). Despite this potential, productivity remains suboptimal due to imprecise grower-phase management and the absence of breed-specific nutritional standards (Rahman *et al*., 2020).

Nutritional management, particularly dietary protein regulation, is one of the most effective tools for modulating physiological growth during the grower phase. Dietary protein functions as a key physiological regulator influencing muscle fiber development, protein turnover, metabolic homeostasis, and tissue differentiation. Recent evidence in waterfowl indicates that dietary protein levels not only affect growth performance but also shape physiological growth trajectories and long-term metabolic efficiency (Zhang *et al*., 2025). Inappropriate protein supply during the grower phase may result in asynchronous growth, inefficient nutrient utilization, excessive fat deposition, and impaired reproductive tissue development, ultimately compromising breeder performance (Kim *et al*., 2022, 2024).

Although the relationship between dietary protein and growth performance has been extensively studied in poultry, most available research has focused on commercial strains and production-oriented indicators (Arlina *et al*., 2021). Physiology-oriented approaches that integrate dietary protein modulation with nonlinear growth curve analysis to optimize breeder readiness in indigenous duck genotypes remain scarce. To date, no study has specifically modeled the physiological growth response of female Bayang ducks during the grower phase under controlled variation in dietary protein levels.

The novelty of the present study lies in integrating dietary protein manipulation with physiological growth curve analysis, employing nonlinear models and orthogonal polynomial approaches to identify optimal growth patterns in Bayang female ducks during the grower phase. Therefore, this study aims to optimize the physiological growth performance of Bayang female ducks through variation in dietary protein levels, providing a scientific basis for breed-specific nutritional strategies that support metabolic stability, breeder readiness, and sustainable reproductive performance under tropical production conditions.

MATERIALS AND METHODS

Materials and research animals

This study was conducted using two hundred female Bayang ducks originating from Day-Old Ducks (DOD) and reared until the grower phase. The experimental period focused on ducks aged 6 to 19 weeks, representing a critical physiological growth stage prior to sexual maturity. All ducks were maintained under intensive management conditions in an open-sided housing system with a total floor area of 225 m^2, divided into 20 floor pens. Each pen accommodated 10 ducks and was considered one experimental unit.

The housing environment was equipped with standard rearing facilities, including electric heaters, thermometers, feeders, and drinkers, to support stable physiological growth conditions. Throughout the experimental period, ducks were provided with clean drinking water *ad libitum*, while feed was supplied in controlled amounts according to treatment design.

Experimental design and dietary treatments

The experiment employed a Randomized Block Design (RBD) with a 4 × 5 factorial arrangement, consisting of four dietary protein levels and five replications. Each replication consisted of one pen containing ten ducks. The experimental treatments were four iso-caloric diets formulated to contain different levels of crude protein (CP), namely:

- Treatment A: 14% CP
- Treatment B: 16% CP
- Treatment C: 18% CP
- Treatment D: 20% CP

All diets were formulated to contain a similar metabolizable energy level of approximately 2900 kcal/kg and were prepared using locally available feed ingredients. The formulation aimed to ensure that differences in physiological growth responses were attributable primarily to variations in dietary protein levels rather than energy intake. The ingredient composition and calculated nutrient content of the experimental diets are presented in Table 1.

Table 1: Ingredients and nutrient content of the treatment diets.

Ingredients (%)	CP content of each treatment			
	14%	16%	18%	20%
Maize	63.0	59.5	56.0	53.0
Palm Kernel	25.0	24.0	23.0	22.0
Fish Meal	7.0	8.0	9.0	9.5
Rice bran	4.0	7.5	11.0	14.5
Coconut oil	1.0	1.0	1.0	1.0
Mineral–Vitamin B12	1.0	1.0	1.0	1.0
Nutrient content (%)				
Crude protein (%)	14.07	16.02	18.00	20.10
Crude fat (%)	3.18	3.20	3.25	3.46
Crude fiber (%)	5.40	5.09	4.93	4.80
Ca (%)	1.23	1.34	1.45	1.73
P (%)	0.84	0.86	0.90	1.05
Methionine	0.33	0.38	0.43	0.52
Lysine	0.76	0.92	1.09	1.30
Cystein	0.30	0.31	0.34	0.36
Metabolizable energy (kcal/kg)	2907.40	2927.60	2919.80	2920.40

Measured parameters

Physiological growth performance was evaluated over a 10-week experimental period. The parameters measured included feed intake, protein intake, and energy intake (expressed as g or kcal per duck per week), weekly body weight, body weight gain per week, daily growth rate, feed conversion ratio (FCR), and growth pattern characteristics derived from nonlinear growth models. These parameters were selected to comprehensively reflect physiological growth efficiency, metabolic balance, and developmental progression during the grower phase.

Statistical analysis

All data were analyzed using analysis of variance (ANOVA) based on the General Linear Model appropriate for a Randomized Block Design, following the procedure described by Steel and Torrie (1992). The statistical model applied was:

$$Y_{ij} = \mu + a_i + b_j + \varepsilon_{ij}$$

Where; Y_{ij} is the observed value, μ is the overall mean, a_i is the effect of dietary protein level, b_j is the block effect, and ε_{ij} is the experimental error.

When significant differences were detected, Duncan's Multiple Range Test (DMRT) was applied at a 5% significance level to compare treatment means. In addition, quadratic regression analysis was used to examine the relationship between dietary protein levels and physiological growth parameters.

Growth curve modeling and biological interpretation

Weekly body weight data collected from 6 to 19 weeks of age were used to analyze physiological growth dynamics through nonlinear regression modeling. Five commonly used growth models were evaluated:

Richards model:

$$y = a(1 + Be^{-kt})^{-1/v}$$

Gompertz model:

$$y = a \cdot \exp\left(-B \cdot \exp(-kt)\right)$$

Logistic model:

$$y = \frac{a}{1 + \exp[-k(t - M)]}$$

Weibull model:

$$y = a - b \cdot \exp(-c \cdot t^{d})$$

Morgan–Mercer–Flodin (MMF) model:

$$y = \frac{ab + ct^d}{b + t^d}$$

In these equations, y represents body weight at age t, while parameters a, b, c, d, B, k, M, and v describe asymptotic weight, growth rate, curve inflection, and shape characteristics. Model performance was evaluated using the coefficient of determination (R^2), with values above 0.90 considered to indicate good model fit and values above 0.95 indicating excellent accuracy in describing physiological growth patterns.

This modeling approach enabled the identification of critical growth phases, inflection points, and physiological growth plateaus, providing a comprehensive framework for interpreting growth performance and developmental readiness of Bayang ducks during the grower phase.

RESULTS AND DISCUSSION

Protein intake

As shown in Table 2 female Bayang ducks during the grower phase (6–16 weeks) exhibited daily protein intakes of 17.21, 20.03, 22.01, and 24.52 g/bird/day for diets containing 14%, 16%, 18%, and 20% crude protein, respectively ($P \leq 0.01$). This increase reflects higher dietary protein density rather than changes in feed volume, aligning with recommended requirements and underscoring the birds' capacity to modulate nutrient assimilation based on dietary composition.

Beyond structural roles, protein intake influences endocrine regulation and satiety mechanisms. Gut hormones such as cholecystokinin (CCK) and glucagon-like peptide-1 (GLP-1) play central roles in mediating feed intake and nutrient absorption in poultry (Lee, 2023). However, excessive protein can burden metabolic systems. Surplus amino acids are deaminated and excreted as uric acid, raising renal and hepatic loads (Leeson and Summers, 2018). This is particularly important for native ducks, which evolved under low-nutrient conditions. Rahardian *et al.* (2021) also warned that high CP levels, if not paired with adequate energy, may reduce palatability and increase nitrogen waste.

Dietary protein levels influenced feed consumption and nutrient intake during the grower phase. Ducks fed the 16% CP diet exhibited a balanced intake pattern compared with other treatments. Average feed intake reached 123.1 g/duck/day, corresponding to a protein intake of 20.94 g/duck/day and an energy intake of 357.5 kcal/duck/day. Lower or higher dietary protein levels resulted in either reduced protein intake efficiency or excessive nutrient intake without proportional physiological growth responses.

Protein quality also matters. Poor processing or amino acid imbalance especially methionine and lysine can impair feed preference (Liu *et al.*, 2022). Optimal formulation should thus balance quantity, quality, and digestibility. Our results align with Zhang *et al.* (2014), who identified 18% CP as optimal for duck growth. Polynomial regression (Figure 1) modeled protein intake (Y, g/bird/day) relative to CP level (X, %), showing a strong quadratic relationship:

$$Y = 4.135 + 1.417X - 0.031X^2 \ (R^2 = 0.98).$$

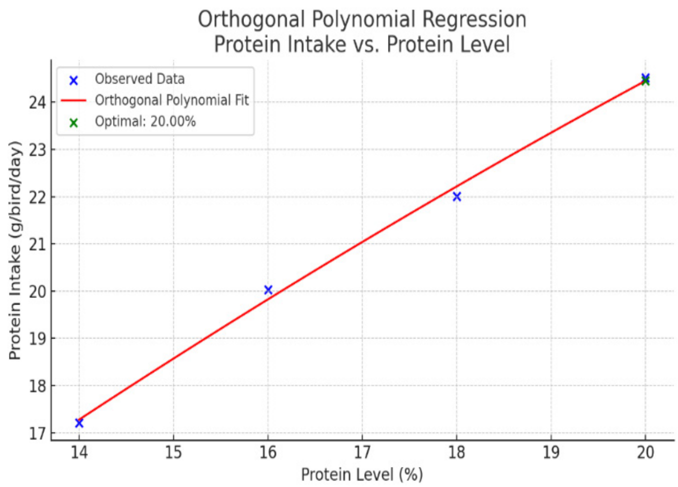

Figure 1: Quadratic relationship between dietary crude protein level and daily protein intake of female bayang ducks (6-16 week of age).

Table 2: Growth performance of female Bayang grower ducks (6 to 16 weeks).

Protein level (%)	Protein intake (g/bird/ day)	Energy intake (kcal/ bird/ day)	Body weight (kg)	Feed conversion ratio	Growth rate (kg/day)
A (14%)	17.21 ± 0.61[d]	356.4 ± 12.50	1.276 ± 4.48[b]	17.16 ± 1.67[ba]	0.0627 ± 0.0179 [a]
B (16%)	20.03 ± 0.35[c]	363.2 ± 6.19	1.496 ± 3.71[a]	12.22 ± 1.49[ba]	0.0657 ± 0.0118[a]
C (18%)	22.01 ± 0.53[b]	354.6 ± 8.47	1.320 ± 4.60[b]	15.64 ± 0.77[a]	0.0464 ± 0.0083[b]
D (20%)	24.52 ± 0.25[a]	355.8 ± 3.51	1.308 ± 7.08[b]	16.36 ± 0.99[a]	0.0450 ± 0.0062[b]
Mean	20.94	357.5	1.35	15.70	0.054

Description: Values within the same column with different superscripts differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test (DMRT).

The highest predicted intake (24.45 g/bird/day) occurred at 20% CP. Yet, no clear saturation was observed, suggesting that ducks can efficiently utilize protein within the studied range. Still, over-supplementation could cause inefficiencies in nitrogen metabolism or impair reproductive development. In summary, dietary CP of 16–18% appears optimal for grower-phase Bayang ducks supporting growth and hormonal function while avoiding metabolic costs.

Energy intake

As presented in Table 2, the metabolizable energy (ME) intake of female Bayang ducks (6–16 weeks) was not significantly influenced ($P \geq 0.05$) by dietary CP levels. Daily ME intake remained relatively constant across treatments ranging from 354.6 to 363.2 kcal/bird/day suggesting that the ducks regulated their feed intake to maintain energy balance regardless of protein concentration. This stable intake reflects a neuroendocrine-driven homeostatic system in poultry, centered in the hypothalamus, which integrates signals from glucose, insulin, leptin, and gut hormones (e.g., CCK, GLP-1) to control appetite (He *et al*., 2020). With energy density held constant, feed intake is modulated to meet basal energy demands (MacLeod, 2018).

The findings support the energy balance theory, which holds that poultry primarily adjust intake based on dietary energy density, not protein levels (Moss *et al*., 2021). Despite varying CP levels, the ME: Protein ratio remained within physiologically tolerable limits. Energy intake is the first-limiting factor for growth and nutrient partitioning (Azevedo et al., 2021). Once energy needs are met, excess intake can be directed toward protein utilization for tissue accretion and development (Liu *et al*., 2023). The observed differences in protein intake and growth performance, despite similar energy intake, reinforce this principle. Bayang ducks, being an indigenous genotype, possess adaptive traits such as stronger gizzards, longer digesta retention, and higher tolerance to fibrous diets (Mohammed *et al*., 2023), which support consistent energy extraction under variable feed conditions.

Quadratic regression analysis (Figure 2) produced the equation:

$$Y = -0.31x^2 + 10.12x + 210.6 \ (R^2 = 0.294)$$

The curve peaks at 16.26% CP with predicted ME intake of 359.4 kcal/bird/day. However, the low R^2 suggests that protein content only marginally influences energy intake. Overall, energy intake in Bayang ducks during the grower phase is primarily regulated by intrinsic physiological mechanisms rather than dietary protein variation. Maintaining isoenergetic diets with balanced protein is critical to support efficient growth without overloading metabolic processes in breeder development programs.

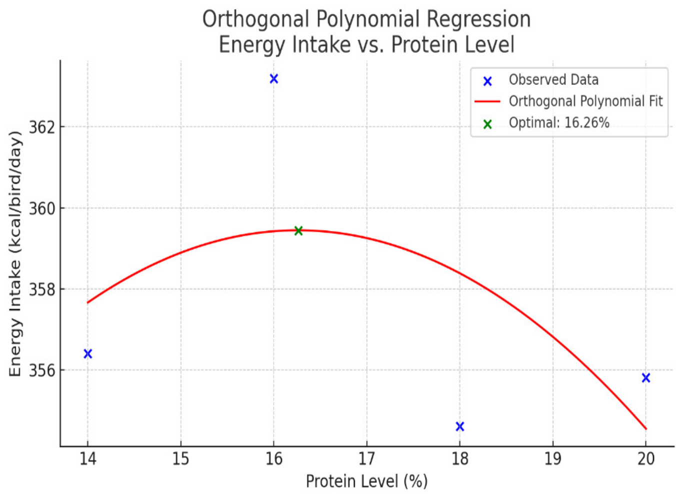

Figure 2: Quadratic relationship between dietary crude protein level and daily energy intake of female bayang ducks (6–16 weeks of age).

Body weight

As shown in Table 2, the body weight of female Bayang ducks during the grower phase was significantly affected by dietary protein levels ($P \leq 0.01$). The highest average body weight (1496 g) was recorded at 16% protein, while 14%, 18%, and 20% yielded 1276 g, 1320 g, and 1308 g, respectively. These results indicate that 16% dietary protein provides optimal growth, while higher levels do not offer further benefits and may reduce efficiency. The enhanced growth at 16% protein likely reflects a balanced energy–amino acid ratio, promoting efficient protein synthesis. In contrast, protein excess beyond physiological needs increases nitrogen excretion as uric acid, consuming metabolic energy and reducing growth efficiency (Pesti *et al*., 2019). Such inefficiency may divert nutrients toward maintenance instead of muscle accretion (Fouad and El-Senousey, 2014).

Body weight development and growth parameters differed among dietary protein levels. Ducks receiving the 16% CP diet achieved the highest final body weight, averaging 1,350 g/head at 19 weeks of age. Weekly body weight gain reached 568 g/head/week, while daily growth rate ranged from 14.8 to 18.6 g/day. This nonlinear response is consistent with outcomes reported in Pekin ducks, where excessive protein intake did not enhance growth performance and was associated with poorer feed conversion and carcass traits (Zhao *et al*., 2025). The 1496 g body weight at 16% CP in Bayang ducks also surpasses that of other local breeds, such as the Leizhou Black Duck (1235 g; Asiamah *et al*., 2020), underscoring their superior growth potential. Orthogonal polynomial regression ($Y= -0.0145x^2 + 0.489x - 2.700$; $R^2= 0.9992$) estimated a peak body weight of 1422.78 g at 16.86% protein, confirming the quadratic nature of the growth response (Figure 3).

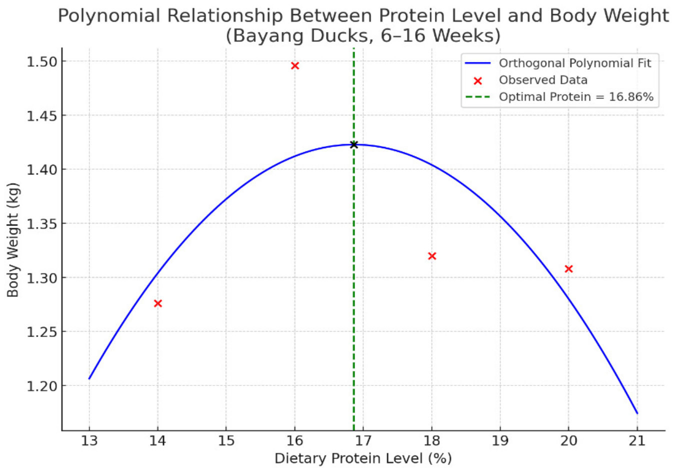

Figure 3: Quadratic relationship between dietary crude protein level and body weight of female bayang ducks (6–16 weeks of age).

Physiological explanations for the decline at 18–20% include increased metabolic load for nitrogen excretion (Attia *et al.*, 2021), reduced palatability, hormonal appetite suppression (Hou *et al.*, 2020), and oxidative stress in non-selected native ducks (Nguyen et al., 2019). These findings suggest that exceeding 16% protein may disturb the energy–protein balance, suppress feed intake, and elevate metabolic burden, leading to suboptimal growth performance.

Feed conversion

Table 2 illustrates that dietary CP levels significantly influenced the FCR of female Bayang ducks during the grower phase (6–16 weeks), with statistical significance at $P \leq 0.01$. The FCR values recorded for the ducks receiving 14%, 16%, 18%, and 20% CP were 14.60, 12.26, 17.72, and 18.34, respectively. Notably, the diet containing 16% CP resulted in the lowest FCR, indicating the most efficient conversion of feed into body mass. This suggests that, at this level, nutrient intake particularly amino acids and energy was optimally matched to the ducks' physiological demand for tissue accretion during growth. Physiologically, the grower phase in ducks is characterized by dynamic changes in nutrient partitioning, shifting from rapid somatic growth toward the development of reproductive tissues and internal organs (Ahmad et al., 2021). During this transitional stage, the efficiency of dietary protein utilization becomes critical. At the 16% CP level, the intake appears to support anabolic metabolism efficiently, ensuring that amino acids are incorporated into structural and functional proteins rather than being catabolized into nitrogenous waste products. This is corroborated by the theory of ideal protein nutrition, where the balance of essential amino acids relative to energy supply optimizes growth with minimal metabolic cost (Wang *et al.*, 2020).

Conversely, the elevated FCR observed at 18% and 20% CP suggest reduced nutrient utilization efficiency, potentially due to protein oversupply. When the dietary protein level exceeds the physiological requirement for growth, excess amino acids undergo deamination and are converted to uric acid for excretion a process that not only increases nitrogenous waste but also imposes an energetic burden on the liver and kidneys (Jiang *et al.*, 2021). This metabolic cost reduces the energy available for productive growth, leading to less efficient feed conversion. Moreover, high dietary protein levels have been associated with reduced feed palatability and inconsistent intake, which can further impair performance (Lin *et al.*, 2022). Further analysis using orthogonal polynomial quadratic regression revealed a significant curvilinear trend (Figure 4), represented by the equation:

$FCR = 14.805 + 0.834(x) + 0.185(x^2)$, $R^2 = 0.668$, where x denotes the centered protein level.

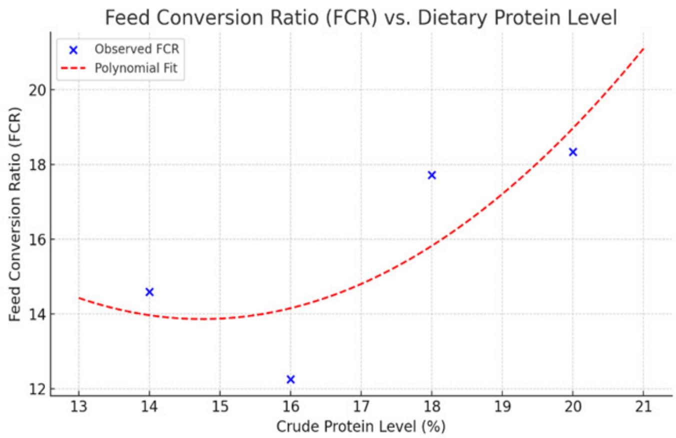

Figure 4: Quadratic relationship between dietary crude protein level and feed conversion of female bayang ducks (6–16 weeks of age).

This model suggests that the most efficient FCR (approximately 13.87) is achieved at a dietary protein concentration of around 14.75%. However, the actual FCR at 16% CP in this study (12.26) remains the numerically most favorable, even though the model predicts a slightly lower value at 14.75% CP. This outcome illustrates that empirical performance data may deviate from the theoretical model, potentially due to biological variability, environmental interactions, and feed composition. The Duncan Multiple Range Test further indicates that the FCR of the 14% and 16% CP treatments were statistically similar ($P > 0.05$), although 16% CP achieved the best numerical value. This finding implies that both levels are within the ducks' optimal physiological range for efficient nutrient conversion. Nonetheless, the superiority of 16% CP highlights its potential as the preferred dietary formulation during the grower phase, especially considering its better support for balanced protein-energy metabolism.

From a physiological standpoint, exceeding the anabolic threshold for protein intake not only increases metabolic waste but also risks adverse effects on liver and kidney health, endocrine balance, and long-term reproductive potential (El-Hack *et al.*, 2018; He *et al.*, 2020). Studies in laying and meat ducks (Zhao *et al.*, 2025) similarly show that optimal FCR values and growth performance are achieved at moderate CP levels (~16%), beyond which feed efficiency deteriorates. These patterns are also observed in broilers and other avian species (Li *et al.*, 2021; Chen *et al.*, 2016), reinforcing the broader applicability of precision protein feeding in poultry production.

Furthermore, efficient feed conversion during the grower phase plays a strategic role in preparing ducks for future reproductive performance. Poor FCR at this stage may result in excessive fat deposition, metabolic stress, and endocrine imbalances that compromise laying capacity and fertility (Xia *et al.*, 2019). Therefore, identifying a CP level that supports both current growth and future reproductive potential is essential in dual-purpose duck breeding programs.

Feed conversion ratio was significantly improved in ducks fed the 16% CP diet, with an average value of 2.17. No mortality was recorded across all treatments throughout the experimental period, indicating stable physiological conditions during the grower phase. In conclusion, the present study confirms that a dietary protein level of 16% provides the most efficient FCR for Bayang ducks during the grower phase, aligning with physiological growth demands and minimizing metabolic burden. This optimization not only supports the development of robust breeder candidates but also promotes environmental sustainability by reducing nitrogen emissions and improving feed resource utilization.

Growth rate

The growth rate of female Bayang ducks aged 6–16 weeks was significantly affected by dietary protein levels ($P \leq 0.01$), as shown in Table 2. Ducks receiving 14% and 16% CP exhibited the highest average daily gains (0.067 g/duck/day), while 18% and 20% CP diets reduced growth to 0.0464 and 0.0450 g/duck/day, respectively. This suggests that 16% CP supports optimal physiological growth during the grower phase. The superior growth at 16% CP is attributed to a balanced energy-to-protein (E/P) ratio of ~181 (2900 kcal/kg ME), aligning with optimal nutrient utilization ranges for growing ducks (Abdollahi *et al.*, 2016; Kang *et al.*, 2018). In contrast, diets with higher protein but lower E/P ratios (e.g., 161 at 18% CP) impair metabolic efficiency, increasing nitrogen excretion and energy loss through detoxification (Wu *et al*, 2024).

High-protein diets may also suppress appetite, disrupt IGF-1 signaling, and alter neuropeptides (He et al., 2020). Such imbalances strain hepatic and renal function due to increased deamination and uric acid excretion (Jiang *et al.*, 2021), reducing growth efficiency. Additionally, excessive protein fermentation in the hindgut produces toxic metabolites (Torok *et al.*, 2011), impairing gut health and nutrient absorption. Palatability issues at high CP levels especially with synthetic amino acids may further reduce feed intake (Kidd and Kerr, 1999), compounding growth limitations. Thus, the observed decline at ≥18% CP results from both metabolic and behavioral constraints.

Physiological growth efficiency, as reflected by the relationship between nutrient intake and body tissue accretion, was most favorable in ducks fed the 16% CP diet. These ducks demonstrated proportional increases in body weight relative to nutrient intake, suggesting efficient physiological utilization of dietary resources during growth.

The optimal 16% CP level not only supports efficient tissue development but also prepares ducks for reproductive maturity. Growth uniformity during this phase is crucial for synchronized laying performance in breeders (Wang *et al.*, 2021). An orthogonal polynomial regression model describing the relationship between CP level and growth rate was developed:

$$Y = -0.00055X^2 + 0.0173X - 0.0505 \ (R^2 = 0.826)$$

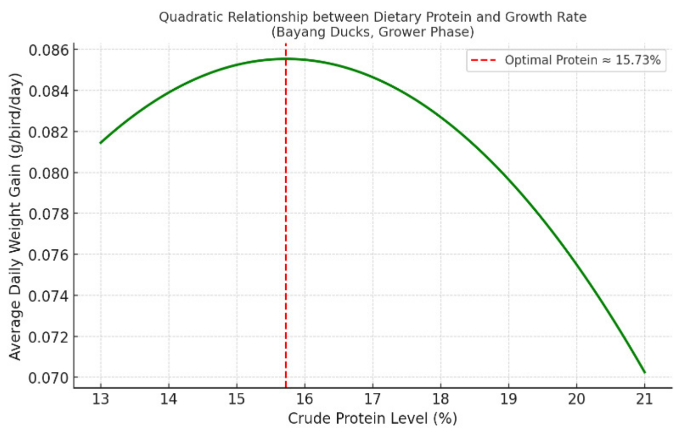

Figure 5: Quadratic relationship between dietary crude protein level and growth rate of female bayang ducks (6–16 weeks of age).

This quadratic curve confirms that 82.6% of growth variation is explained by dietary CP level, with a peak at 16%, supporting its use as the physiological optimum for Bayang ducks during the grower phase (Figure 5). These findings are consistent with previous work on local and exotic ducks (Asiamah *et al*., 2020), underscoring the importance of nutrient balance to optimize growth and future reproductive performance.

Modeling the growth trajectory of Bayang female ducks during the grower phase

To support optimal development in female Bayang ducks during the grower phase, dietary CP levels were evaluated, and 16% CP was identified as the most effective in promoting consistent physiological growth. In this context, a growth trajectory analysis was conducted from weeks 6 to 19 spanning the transition from juvenile to pre-laying phase. Body weight data were fitted to five nonlinear regression models Richards, Gompertz, Logistic, Weibull, and Morgan-Mercer-Flodin (MMF) to describe the growth curve accurately.

Among the models, the Richards model offered the best fit, with the inflection point of growth (plateau phase) estimated around week 11.55. This phase marks the onset of slower somatic growth and a likely metabolic shift toward the development of reproductive organs. The observed growth pattern reflects an efficient nutrient utilization strategy that supports both muscle tissue accretion and the physiological transition necessary for future laying performance.

Protein plays a pivotal role in regulating this growth-reproduction transition. Previous studies have shown that dietary protein between 15% and 17% can significantly influence ovarian follicle development, oviduct weight, and the timing of sexual maturity in ducks (Sultana *et al*., 2019; Wang *et al*., 2018). In this study, body weight stabilization around weeks 12 to 13 likely aligns with internal reproductive tract activation, as supported by Xu et al. (2024), who reported that reproductive organ differentiation becomes prominent during this window when nutrition is adequate.

Body weight of female Bayang ducks aged 6–19 weeks fitted with Orthogonal Polynomial Regression. Figure 6 showing the orthogonal polynomial regression results for the body weight of female Bayang ducks (age 6–19 weeks) at different dietary protein levels.

The growth curve analysis for Bayang female ducks fed a 16% crude protein diet from 6 to 19 weeks showed a consistent increase in body weight, with the plateau phase beginning around week 11.55 as predicted by the Richards model. This pattern indicates a transition from somatic to reproductive physiological development, as growth rate begins to stabilize and metabolic resources shift toward organ maturation. Thus, the fitted growth curve under 16% CP not only confirms optimal physiological growth but also suggests that this nutrient level facilitates early readiness for reproduction. The plateau trend emerging before 13 weeks may serve as a predictive marker of physiological maturity. The use of nonlinear growth models also provides a robust quantitative framework to forecast developmental milestones and inform breeder management strategies in Bayang ducks.

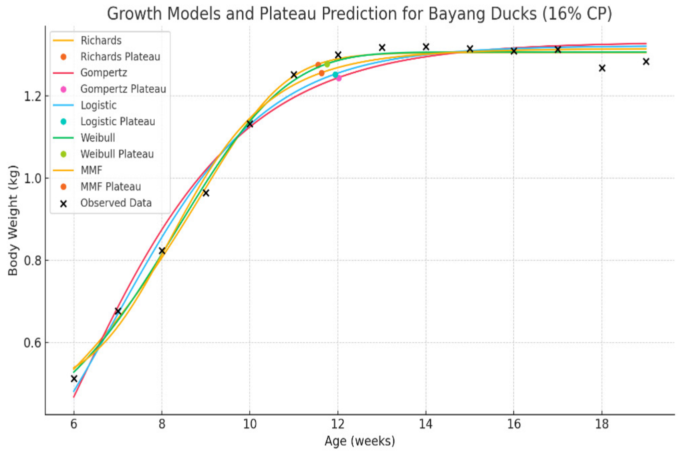

Figure 6: Growth curve of average body weight in Bayang female ducks aged 6–19 weeks fed a diet containing 16% crude protein.

CONCLUSION

Physiological growth of Bayang female ducks during the grower phase can be effectively optimized through appropriate modulation of dietary protein level. Among the evaluated treatments, a diet containing 16% crude protein provided the most favorable physiological growth response. Growth curve analysis confirmed that this dietary protein level supported a synchronized growth trajectory, with the onset of the physiological growth plateau occurring at an appropriate developmental stage. This balanced physiological growth pattern is essential for preparing future breeders, as it promotes body uniformity and supports the maturation of reproductive organs without imposing excessive metabolic stress. Therefore, feeding Bayang ducks a diet containing 16% crude protein throughout the grower phase represents an effective physiological strategy to enhance breeder readiness and reproductive potential in local duck production systems under tropical conditions.

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NOVELTY STATEMENT

Physiological growth–oriented nutritional regulation is introduced in this study as a novel framework for preparing future Bayang duck breeders during the grower phase. By integrating dietary protein modulation with growth-curve analysis, this research demonstrates that 16% crude protein optimally synchronizes growth rate, physiological plateau attainment, and metabolic stability, thereby ensuring balanced somatic development without inducing metabolic stress. This approach advances conventional performance-based feeding strategies by establishing a breed-specific, physiology-based feeding protocol, providing a robust scientific basis for breeder selection, nutritional programming, and sustainable genetic improvement of local ducks under tropical production systems.

AUTHORS CONTRIBUTION

YH, A, R, and DI as a research team contributed to the implementation of the study, while the research idea originated from YH as the principal investigator.

Generative AI and AI-assisted technology statement

The author declares that no artificial intelligence was used in the writing of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abdollahi MR, Ravindran V, Svihus B (2016). Pelleting of broiler diets: An overview with emphasis on pellet quality and nutritional value. Anim. Feed Sci. Technol., 220: 1–23.

Ahmad S, Rahman MM, Islam M A, Hossain ME (2021). Growth performance and physiological changes of ducks during grower phase. Journal of Poultry Science, 58(3), 145–152.

Arlina F, Suhartati L, Reski S (2021). Physiological performance and breeder development strategies in local ducks. Trop. Anim. Sci. J., 44(3): 245–253.

Asiamah J, Zhou H, Zhang Z (2020). Growth performance and carcass traits of Leizhou black ducks under different feeding regimes. Poult. Sci., 99(6): 3110–3118.

Attia YA, Al-Harthi MA, Abo El-Maaty HM (2021). The effect of protein and energy levels on the performance, carcass characteristics and nitrogen balance of growing ducks. Animals, 11(1): 198.

Azevedo JM, de Paula Reis M, Gous RM, Dorigam JC, de P, Balbino BL, Sakomura NK (2021). Response of broilers to dietary balanced protein: feed intake and growth. Animal Production Science, 61(14): 1425–1434. https://doi.org/10.1071/AN20655

Bakrie B, Iskandar A, Sulaiman Y (2023). Strategies for sustainable duck production in Indonesia: Policy and practice. Trop. Anim. Sci. J., 46(1): 55–64.

Chen X, Ma Q, Tang Z, Han X, Ji C (2016). Energy and protein requirements of broilers. Anim. Nutr., 2(3): 185–190.

Choi JH, Lee K, Song Y (2022). Nutritional management strategies for dual-purpose ducks: Implications for growth and reproduction. J. Anim. Physiol. Anim. Nutr., 106(2): 303–312.

Choi YH, Kim DH, Lee SR, Park JH (2022). Grower-phase growth efficiency as a determinant of reproductive readiness in dual-purpose poultry. Poult. Sci., 101(9): 102015.

Du H, Zhang J, Li X (2024). High-energy, low-protein diets induce lipid metabolism imbalance in laying ducks. Poult. Sci., 103(2): 102245.

El-Hack MEA, Mahgoub SA, Alagawany M (2018). Protein nutrition and its impacts on poultry performance and environment. J. Anim. Physiol. Anim. Nutr., 102(3): 1016–1025.

Fouad AM, El-Senousey HK (2014). Nutritional factors affecting abdominal fat deposition in poultry: A review. Asian-Australas. J. Anim. Sci., 27(7): 1057–1068. https://doi.org/10.5713/ajas.2013.13702

Ghavi Hossein-Zadeh N (2025). Nonlinear growth curve modeling as a biological tool for interpreting growth dynamics in ducks. Poult. Sci., 104(2): 104567.

He L, Meng Q, Sun P (2020). High protein diets and nitrogen metabolism in poultry. Poult. Sci., 99(7): 3531–3540.

Hou Q, Huang Y, Li H (2020). Excess protein alters appetite regulation in ducks via hypothalamic pathways. Animals, 10(5): 821.

Indarsih B, Haryati T, Daru T (2016). Production constraints of smallholder duck farming in Indonesia. J. Indones. Trop. Anim. Agric., 41(3): 147–155.

Ismoyowati I, Kismiati S, Yuwanta T (2020). Technical inefficiency of smallholder duck farming in Central Java, Indonesia. Trop. Anim. Health Prod., 52: 3503–3511.

Jiang S, Yang Z, Zhang H (2021). Effects of dietary protein oversupply on nitrogen metabolism and organ health in ducks. Poult. Sci., 100(9): 101253.

Kang HK, Park SB, Kim SH (2018). Effects of dietary protein levels on growth and carcass traits in growing ducks. Korean J. Poult. Sci., 45(3): 155–163.

Kidd MT, Kerr BJ (1999). L-Threonine for Poultry: A Review. Journal of Applied Poultry Research, 5(4): 358-367.

Kim HJ, Park JH, Lee SR (2024). Protein nutrition and physiological growth integrity during the grower phase in poultry. Animals, 14(3): 512.

Kim HJ, Ryu MH, Lee S (2022). Impact of early dietary management on egg size and reproductive efficiency in ducks. Anim. Biosci., 35(9): 1389–1397.

Lee SR (2023). Gut hormones and feed intake regulation in poultry. Anim. Nutr., 12: 267–275.

Leeson S, Summers JD (2018). Broiler nutrition. Nottingham University Press.

Li P, Wang F, Zhang L (2021). Precision nutrition and protein requirements of broilers. Front. Vet. Sci., 8: 641636.

Lin H, Li Y, Sun H (2022). Excess dietary protein impairs feed intake and growth performance in poultry. Animals, 12(9): 1193.

Liu G, Liu Y, Wang J (2023). Energy and protein interactions in poultry: Implications for feed formulation. Anim. Nutr., 11: 1–9. https://doi.org/10.1007/978-1-0716-3327-4_24

Liu Y, Chen J, Xu G (2022). Effects of amino acid balance on feed intake and performance in ducks. Poult. Sci., 101(8):

102014.
MacLeod M (2018). Energy utilization and partitioning in poultry. World's Poult. Sci. J., 74(1): 29–44.
Mekonnen T, Dessie T, Hanotte O (2023). Growth dynamics and physiological responses of indigenous waterfowl under tropical conditions. Trop. Anim. Health Prod., 55: 214.
Mohammed A, Hassan H, Ibrahim S (2023). Nutrient utilization and adaptive digestive traits in indigenous ducks. Animals, 13(2): 285.
Moss CW, Smith B, Classen H (2021). Dietary energy and feed intake regulation in poultry. Poult. Sci., 100(12): 101434.
Nguyen DH, Nyachoti CM, Kim IH (2019). Evaluation of effect of probiotics mixture supplementation on growth performance, nutrient digestibility, faecal bacterial enumeration, and noxious gas emission in weaning pigs. Italian Journal of Animal Science, 18:1, 466-473, DOI: 10.1080/1828051X.2018.1537726
Oguntunji AO, Adewumi OO, Akinola LA (2023). Genetic and nutritional management strategies for sustainable duck production. Trop. Anim. Health Prod., 55(1): 44.
Pesti GM, Vedenov D, Cason JA, Billard L (2019). A comparison of methods to estimate nutritional requirements from experimental data. Br. Poult. Sci., 60(6): 720–730.
Rahardian R, Nugroho H, Hidayat M (2021). Effect of protein-energy ratio on growth and nitrogen excretion in ducks. Indones. J. Anim. Vet. Sci., 26(1): 17–26.
Rahman EY, Rusfidra Y, Jamsari (2020). Nutritional challenges and productivity gaps in Indonesian local ducks. Anim. Prod., 22(1): 45–54.
Rahman MA, Sarker MSK, Islam MA (2020). Productivity and adaptability of indigenous ducks: A review. J. Bangladesh Agric. Univ., 18(2): 306–313.
Rusfidra R, Heryandi Y (2013). Molecular characterization of Bayang duck genetic resources. J. Indones. Trop. Anim. Agric., 38(2): 95–102.
Rusfidra Y, Heryandi Y, Jamsari, Rahman EY (2014). Characterization of Bayang duck genetic resources based on microsatellite markers CMO.211 and AY.295. J. Sain Peternakan Indones., 9(1): 19–29. https://doi.org/10.31186/jspi.id.9.1.19-29
Steel PGD, Torrie JH (1992). Prinsip dan Prosedur Statistika suatu Pendekatan Geometrik. Terjemahan B. Sumantri. PT. Gramedia. Jakarta
Sulaiman A, Wahyuni S, Hidayat R (2023). Adaptability and productivity of Indonesian local ducks under different management systems. Trop. Anim. Sci. J., 46(4): 389–398.
Sultana S, Rahman M, Hassan M (2019). Influence of dietary protein on reproductive organ development and sexual maturity in ducks. J. Appl. Anim. Res., 47(1): 118–124.
Torok VA, Hughes RJ, Ophel-Keller K (2011). Influence of high-protein diets on intestinal microbiota and fermentation metabolites in poultry. Br. Poult. Sci., 52(1): 72–81.
Wang J, Chen Y, Li X (2021). Effects of protein level on growth uniformity and reproductive performance in ducks. Animals, 11(5): 1296.
Wang Y, Xu Z, Feng J (2018). Dietary protein and ovarian development in ducks. Br. Poult. Sci., 59(2): 212–219.
Wu G, Bazer FW, Dai Z, Li D, Wang J, Wu Z (2014). Amino acid nutrition in animals: Protein synthesis and beyond. Annu. Rev. Anim. Biosci., 2(1): 387–417. https://doi.org/10.1007/s00726-013-1634-6
Wu Y, Zhang L, Zhao J (2024). Crude protein requirements of Pekin ducks under different energy-to-protein ratios. Poult. Sci., 103(5): 102557.
Xia W, Chen J, Huang Y (2019). Impacts of poor feed conversion ratio on reproductive performance in ducks. Anim. Reprod. Sci., 207: 108–116.
Xu M, Tang Q, Qi J, Han X, Tao Q, Lu Y, Bai Y, Hu S, Li L, Bai L, Hu J, Wang J, Liu H (2024). Integration of GWAS and transcriptomic analyses reveal candidate genes for duck gonadal development during puberty onset. BMC Genomics, 25:1151. https://doi.org/10.1186/s12864-024-11079-3
Zhang Y, Liu X, Wang J, Chen Z (2025). Dietary protein modulation shapes physiological growth trajectories and metabolic efficiency in waterfowl. Anim. Nutr., 11: 120–129. https://doi.org/10.1186/s40795-025-01157-4
Zhang Z, Li H, Zhou H (2014). Effects of dietary protein levels on growth performance in ducks. Poult. Sci., 93(8): 2107–2116.
Zhao J, Wu Y, Zhang L (2025). Dietary protein levels and growth efficiency in meat ducks. Poult. Sci., 104(1): 102780.