Short Communication

Duck Egg Quality: A Comparison of Rearing Systems in Tropical Indonesia

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Abstract | Duck farming in tropical regions such as Indonesia faces challenges in standardizing egg quality to meet rising consumer demand. Optimizing rearing systems is a pivotal strategy for enhancing production efficiency and product consistency. This study evaluated and compared external and internal egg quality metrics of local ducks reared under extensive, colony-intensive, and battery-cage systems in Banyumas, Indonesia. A total of 90 fresh eggs were collected from farms representative of each system, with 30 eggs allocated to each housing treatment. External traits, including weight and shape index, alongside internal parameters such as Haugh Unit, yolk color (L^*, a^*, b^*), and pH, were analyzed using Analysis of Variance followed by Duncan's Multiple Range Test. External morphometry analysis indicated no significant differences ($P > 0.05$) in egg weight or shape index among the groups. Internal quality assessment showed that eggs from intensive systems had significantly better albumen freshness, yielding higher Haugh Unit scores compared to the extensive method. Yolk color also differed. Eggs from the colony system had the most intense red color (a^*), while eggs from extensive systems were paler and more yellow. Eggs from battery cages had higher albumen pH, indicating faster loss of freshness, compared to those from the colony system. The colony system appears to offer a good balance, maintaining internal egg quality without changing physical yield. Implementation of this semi-intensive configuration provides a viable pathway for sustainable egg production in the region.

Keywords | *Anas platyrhynchos*, Haugh unit, Yolk pigmentation, Housing system, Albumen consistency

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INTRODUCTION

Duck farming is a crucial sector in Indonesia's poultry industry, contributing significantly to the national animal protein supply through meat and egg production (Ismoyowati *et al.*, 2020). Central Java serves as a major production center, where local duck breeds, such as the Magelang and Alabio ducks, are widely raised due to their adaptability and high phenotypic diversity (Ismoyowati *et al.*, 2018; Sulaiman *et al.*, 2023). Local farmers in areas like Banyumas typically rely on these waterfowl species to support their rural economies. Local duck breeders in Banyumas prefer the Mojosari duck, which is smaller and produces comparable yields to other breeds (Fitra *et al.*, 2024). Optimizing rearing systems remains a crucial strategy to meet the growing consumer demand for high-quality duck eggs (Shi *et al.*, 2022).

Egg quality metrics encompass a complex set of physical and chemical properties that determine consumer acceptance and processing functionality (Sun *et al.*, 2017). Internal and external characteristics, including shell thickness, albumen consistency, and yolk pigmentation, fluctuate in response to genetic potential and environmental factors (Liu *et al.*, 2021; Lewko and Gornowicz, 2025). Additional physical parameters, such as egg weight, index, and pH, serve as crucial indicators of quality preservation (Biyatmoko *et al.*, 2023). Nutritional strategies, such as the addition of omega-3 fatty acids or probiotics, have been shown to improve quality parameters and production performance (Rouhanipour *et al.*, 2022). Housing systems play a dominant role in modulating these environmental influences by altering the microclimate and bird behavior (Ferreira *et al.*, 2024).

Traditionally, extensive rearing systems allow ducks access to natural feed, exposing birds to uncontrolled climatic variables and diverse, albeit inconsistent, feed sources (Hossain *et al.*, 2021). Modernization of the poultry sector has driven a transition to intensive systems to standardize productivity and improve feed conversion ratios. Intensive management systems are categorized into two configurations: Battery cages and colony systems (Tuyttens *et al.*, 2012). Battery cages facilitate individual bird monitoring and hygiene control, but severely restrict movement, raising significant welfare concerns regarding their impact on poultry physiology (Hartcher and Jones, 2019). Intensive colony cage systems offer a compromise, allowing greater social interaction and movement within a controlled, high-density environment (Honig *et al.*, 2024).

Comparative data regarding the specific impacts of these divergent housing systems on egg quality within the tropical Banyumas landscape remain limited. The Banyumas region presents unique agroclimatic conditions, with altitudes ranging from 15 to 500 meters above sea level, encompassing both lowland and midland zones (Ogunlowo *et al.*, 2024; Honig *et al.*, 2024). Differences in physical activity and stress levels across systems could manifest as significant variations in egg weight and internal composition (Erek and Matur, 2024; Abou-emera *et al.*, 2025). This study evaluates and compares egg quality metrics of local ducks reared under extensive, colony-intensive, and battery-intensive systems in Banyumas, Indonesia, to provide scientific evidence for sustainable, welfare-conscious poultry production.

MATERIALS AND METHODS

Study site and period

The research was conducted from May to October 2024. Sample collection was carried out across three distinct rearing systems in the Banyumas Regency, Central Java, Indonesia. The specific sampling locations included smallholder farms (extensive system), open-house farms (colony intensive), and commercial farms (battery intensive), distributed across the Sokaraja, Sumbang, and Cilongok districts. All laboratory analyses regarding egg quality metrics were performed at the Laboratory of Animal Science, Faculty of Animal Science, Jenderal Soedirman University.

Experimental design and sampling strategy

This study used a field survey combined with purposive sampling to select farms that strictly adhered to the defined rearing systems. The experiment was arranged in a Completely Randomized Design (CRD) consisting of three treatments based on the housing system:

- T1: Extensive System (Traditional/Free-range scavenging).
- T2: Colony Intensive System (Deep litter or cement floor groups).
- T3: Battery-Intensive System (Individual Cages).

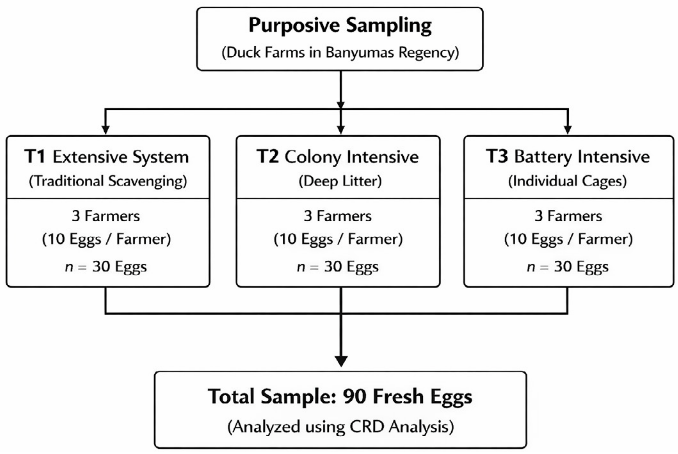

Figure 1: Experimental design and sampling strategy.

Figure 1 illustrates that a total of 90 fresh eggs (<24 hours old) were collected, with 30 eggs allocated to each treatment group, each taken from three farmers. To minimize bias from storage duration, eggs were collected immediately after laying. Samples were transported to the laboratory in egg trays with the blunt end (air pocket) facing upwards to maintain internal quality, with an average travel time of 2 hours for refrigeration. In addition, a structured questionnaire was used to collect data on farm management, bird age, and feeding patterns.

Measurement of egg quality metrics

Laboratory analysis utilized precision equipment, including a digital balance (0.01 g precision) for egg weight, a Vernier caliper (0.05 mm precision) for dimensional measurements, a tripod micrometer for albumen height, and a digital pH meter for albumen and yolk acidity. Yolk color was determined using the Roche Yolk Color Fan (RYCF) with a score range of 1–15.

The specific procedures for the measured parameters were as follows:

- Egg weight: Each egg was weighed individually using a digital balance.

- Egg shape index: The longitudinal axis (length) and transverse axis (width) of the egg were measured using a Vernier caliper. The shape index was calculated using the following equation:

$$Shape\ index = \frac{Width\ (mm)}{Length\ (mm)} \times 100$$

Internal quality assessment: Eggs were carefully broken onto a flat glass plate to prevent rupture of the vitelline membrane. Subsequent measurements for yolk and albumen indices were taken immediately upon breaking.

- Egg pH analysis: Acidity levels of the albumen and yolk were measured separately using a digital pH meter. The probe was rinsed with distilled water between measurements to prevent cross-contamination.
- Yolk pigmentation: Yolk color intensity was assessed visually by comparing the yolk surface against the Roche Yolk Color Fan (RYCF) standards under consistent lighting conditions. Scores ranged from 1 (pale yellow) to 15 (dark orange).
- Yolk index (YI): Yolk height (h) and yolk diameter (d) were measured using a Vernier caliper. The Yolk Index was subsequently calculated using the ratio of height to diameter:

$$YI = \frac{Yolk\ height}{Yolk\ diameter}$$

Haugh Unit (HU): The height of the thick albumen (H) was measured 1 cm from the yolk using a tripod micrometer. This value, combined with the egg weight (W), was used to determine the Haugh Unit, a primary indicator of internal egg quality, based on the following logarithmic formula:

$$HU = 100 \log(H + 7.57 - 1.7W^{0.37})$$

Where: H= Height of thick albumen (mm), W= Weight of intact egg (g).

Statistical analysis

All collected data were tabulated and subjected to Analysis of Variance (ANOVA) to evaluate the effect of rearing systems on egg quality traits. Significant differences among treatment means ($P < 0.05$) were further separated using Duncan's Multiple Range Test (DMRT). Statistical analyses were performed using SPSS version 26.0.

RESULTS AND DISCUSSION

External egg quality traits

The external characteristics of duck eggs, specifically egg weight and egg shape index, were evaluated across extensive, colony-intensive, and battery-intensive rearing systems. Table 1 summarizes the descriptive statistics and analysis of variance for these parameters.

Table 1: Means and standard deviations of external egg quality traits of ducks reared under different housing systems.

Parameters	Rearing systems			P value
	Extensive	Colony intensive	Battery intensive	
Egg weight (g)	64.78±7.33	63.41±7.99	64.55±3.91	0.887^{ns}
Egg shape index (%)	79.84±1.82	79.53±2.44	78.40±4.06	0.520^{ns}

Note: Data are presented as Mean ± Standard Deviation. ^{ns} indicates non-significant difference ($P > 0.05$).

Egg weight analysis revealed no significant differences (P> 0.05) among the three housing systems. Ducks reared under the extensive system produced eggs with an average weight of 64.78±7.33 g, which was statistically comparable to those from the colony intensive (63.41±7.99 g) and battery-intensive systems (64.55±3.91 g). Variability in egg weight appeared highest in the colony intensive group, as indicated by the larger standard deviation, while the battery intensive group demonstrated the most uniformity. Statistical uniformity in egg weight across the three rearing systems underscores the dominance of genetic potential over environmental configuration (Hossein-Zadeh, 2024). Local duck strains in Banyumas maintain a consistent egg mass profile when basic physiological needs are met, aligning with findings regarding the fixed phenotypic range of indigenous waterfowl (Ismoyowati *et al*., 2018). Genetic predisposition seemingly overrides the physical constraints of battery cages or the increased activity inherent to extensive foraging. Nutritional management likely neutralized the metabolic variance typically associated with different activity levels. Scavenging ducks in extensive systems presumably compensated for higher energy expenditure through supplementary feeding, mirroring the nutrient density provided by complete commercial rations in intensive setups (Kabir *et al*., 2020). Feed composition, particularly protein intake, exerts a more profound influence on egg weight than physical stocking density, a correlation (Suswoyo and Tugiyanti, 2021).

Higher standard deviations observed in colony-intensive systems suggest that social hierarchy influences feed accessibility. Dominant birds in group housing potentially monopolize resources, creating uneven nutrient intake, whereas individual battery cages eliminate such competition and ensure uniform egg sizes (England *et al*., 2022). Social dynamics within the flock thus appear to be the primary driver of weight variability rather than the housing system itself. Egg shape index values falling within the 78–79% range indicate that oviduct function remained stable regardless of spatial restriction. Isthmus muscle activity during shell membrane formation dictates this heritable trait, rendering it largely resistant to external housing manipulations (Sun *et al*., 2017). Housing systems rarely alter egg geometry unless chronic stress severely disrupts the calcification mechanism (Xin *et al*., 2023). Consistency in egg shape across diverse systems suggests that the birds utilized in this study did not experience stress levels sufficient to induce physiological malformation (Ncho *et al*., 2024). Physiological adaptability of Indonesian local ducks appears robust, preventing the irregular calcification often associated with welfare compromise in high-density environments (EFSA, 2023). These findings imply that intensive systems, when managed correctly, do not negatively impact the external morphometry of local duck eggs.

Internal egg quality traits

Internal egg quality metrics, encompassing physical indices, pH levels, and yolk colorimetric profiles, displayed varying degrees of sensitivity to the rearing systems (Table 2).

Haugh Unit (HU), the primary indicator of albumen freshness, differed significantly ($P < 0.01$) among the groups. Ducks reared in colony and battery intensive systems produced eggs with superior albumen consistency, recording HU values of 123.25 and 117.41, respectively. The extensive system yielded the lowest average HU (104.86), indicating a faster rate of albumen liquefaction under traditional management. Colorimetric analysis of the yolk revealed distinct pigmentation patterns associated with the housing method. Lightness (L^*) was significantly higher ($P < 0.01$) in eggs from the extensive system, corresponding to a paler visual appearance. Redness (a^*) values were highest in the colony intensive system (13.67), followed by the battery system (11.15), while the extensive system exhibited the lowest intensity (7.34). Yellowness (b^*) followed an inverse trend, where extensive eggs demonstrated a significantly higher yellow saturation (19.15) compared to both intensive groups. Chemical analysis showed that yolk pH remained stable across all treatments ($P > 0.05$). Albumen pH, however, showed significant variation ($P < 0.05$), with eggs from the battery-intensive system recording the most alkaline value (8.29) compared to the colony system (7.79). Structural parameters, specifically the Yolk Index and Albumen Index, showed no statistical deviation ($P > 0.05$), suggesting that the physical integrity of the yolk membrane and thick albumen height relative to width remained consistent regardless of the rearing system.

Superior Haugh Unit values observed in colony- and battery-intensive systems indicate enhanced preservation of albumen quality compared to the extensive rearing method. High Haugh Units in intensive groups reflect greater albumen thickness, signifying superior freshness and the structural integrity of the mucin-ovomucin complex. Extensive rearing conditions yielded significantly lower scores, indicating a rapid rate of albumen liquefaction. Environmental exposure constitutes a primary driver for this disparity, as eggs in extensive systems are subjected to uncontrolled ambient temperatures and humidity fluctuations prior to collection. Prolonged exposure to tropical heat in the Banyumas region accelerates the breakdown of carbonic acid within the egg, leading to a rise in pH and subsequent thinning of the albumen (Alig *et al*., 2023). Intensive systems, particularly battery cages, facilitate immediate egg separation from the bird and manure, thereby maintaining a more stable microclimate that preserves internal quality.

Sanitary conditions within the housing environment further influence internal egg integrity. Eggs laid in extensive scavenging settings face higher risks of microbial contamination from contact with soil and damp litter, which can compromise the cuticle barrier and hasten internal

Table 2: Means and standard deviations of internal egg quality traits of ducks reared under different housing systems.

Parameters	Rearing systems			P-value
	Extensive	Colony intensive	Battery intensive	
Haugh Unit (HU)	$104.86^{b} \pm 16.30$	$123.25^{a} \pm 6.30$	$117.41^{a} \pm 4.17$	0.0016^{**}
Yolk Index	0.41 ± 0.04	0.38 ± 0.05	0.37 ± 0.02	0.1016^{ns}
Albumen Index	0.07 ± 0.01	0.08 ± 0.02	0.06 ± 0.01	0.1061^{ns}
*Yolk color L (Lightness)**	$35.39^{a} \pm 1.63$$	$29.74^{b} \pm 4.30$	$30.55^{b} \pm 2.61$	0.0006^{**}
*Yolk color a (Redness)**	$7.34^{c} \pm 1.20$	$13.67^{a} \pm 2.30$	$11.15^{b} \pm 2.74$	0.0000^{**}
*Yolk color b (Yellowness)**	$19.15^{a} \pm 2.51$	$11.56^{b} \pm 3.42$	$11.29^{b} \pm 1.84$	0.0000^{**}
Yolk pH	6.13 ± 0.17	6.09 ± 0.25	6.16 ± 0.25	0.7840^{ns}
Albumen pH	$8.13^{ab} \pm 0.26$	$7.79^{b} \pm 0.56$	$8.29^{a} \pm 0.17$	0.0171^{*}

Note: Data are presented as Mean $\pm$ Standard Deviation. ^{a,b,c} Means in the same row with different superscripts differ significantly ($P < 0.05$). ^{ns} Non-significant ($P > 0.05$); * Significant ($P < 0.05$); ** Highly Significant ($P < 0.01$)

degradation (Rodríguez-Hernández *et al*., 2024). Battery and colony cages reduce this contact surface, effectively minimizing the microbial load that catalyzes protein denaturation. Nutritional consistency provided in intensive systems also supports optimal synthesis of thick albumen proteins. Balanced amino acid intake, specifically methionine and lysine found in commercial rations, ensures the structural stability of the albumen, a benefit often compromised by the variable nutrient density of the scavenging diet (Abduljalal and Ahmed, 2024). Data suggest that the controlled environment and standardized nutrition of intensive systems offer significant advantages in maintaining the viscoelastic properties of duck egg albumen.

Statistical uniformity observed in Yolk Index (0.37–0.41) and Albumen Index (0.06–0.08) across the three rearing systems demonstrates that housing configuration exerts minimal influence on the structural integrity of the vitelline membrane and the viscosity of the thick albumen relative to its width. These values fall within the standard physiological range for fresh duck eggs (0.35–0.45 for yolk index), indicating that the nutritional management in both intensive systems and the foraging activity in the extensive system were sufficient to support the synthesis of key structural proteins, such as ovalbumen and ovomucin. Genetic factors appear to override environmental variables in determining these specific indices, as the local duck strains in Banyumas maintained consistent egg geometry regardless of the stocking density or movement restrictions. Furthermore, the absence of significant deviation suggests that the birds in battery and colony cages did not experience chronic stress levels high enough to impair the oviduct's ability to secrete the plumping fluid required for maintaining internal pressure and shape. These findings align with previous studies suggesting that while housing affects external cleanliness and production rates, the fundamental internal architecture of the egg remains robustly conserved under proper management (Sun *et al*., 2017; Ismoyowati *et al*., 2018).

Distinct pigmentation profiles observed between the rearing systems serve as direct bioindicators of dietary carotenoid composition rather than as physiological consequences of the housing structure itself (Nabi *et al*., 2020; Alig *et al*., 2023). Intensive colony and battery systems yielded yolks with significantly higher redness values (a^*) and lower lightness (L^*), a phenomenon driven by the standardized inclusion of corn-based ingredients and specific pigment enhancers in commercial rations (Ortiz *et al*., 2021). Formulated feeds used in these intensive settings are typically fortified with xanthophylls or bioactive extracts to ensure consistent yolk presentation, a strategy proven to effectively increase antioxidant deposition and pigment stability in duck eggs (Chen *et al*., 2023). Metabolic conversion of these dietary pigments into the ovarian follicles occurs more efficiently under the controlled feeding regimes of intensive management, resulting in the deep orange hue that consumers often associate with high nutrient density.

The disparity in yolk pigmentation is strongly supported by the nutritional composition of the diets. Commercial feed (Malindo 9905 SP) used in intensive systems provides a guaranteed crude fat content of min. 3.0%, which is essential for the absorption of fat-soluble carotenoids. In contrast, crop content analysis of extensive ducks in Banyumas and surrounding lowlands revealed a critical deficiency in dietary fat (0.06–0.07%) and excessively high crude fiber (13.8–18.3%), far exceeding the commercial standard of max. 10%. The extremely low fat intake in scavenging ducks limits the bioavailability of pigments, resulting in paler yolks, whereas the balanced fat and pigment-fortified commercial diet ensures the intense redness observed in colony and battery systems (Table 3).

Scavenging ducks in the extensive system, conversely, produced eggs characterized by high lightness (L^*) and dominant yellowness (b^*) but significantly reduced redness (a^*). Diets in these traditional systems rely heavily on locally available agricultural by-products, such as rice bran,

Table 3: Comparison of nutrient composition between commercial feed used in intensive systems and crop contents of scavenging ducks in different agroecological zones.

Nutrient component (%)	Commercial feed[1]	Scavenging (Cilacap)	Scavenging (Purbalingga)	Scavenging (Banyumas)	Scavenging (Wonosobo)
Moisture	Max 14.00	43.80	52.59	48.40	56.77
Dry matter	Min 86.00	56.20	47.41	51.60	43.23
Crude protein	Min 17.00	16.48	25.55	16.87	22.35
Crude fat	Min 3.00	0.06	0.07	0.06	04.03
Crude fiber	Max 10.00	15.07	18.31	13.86	8.33
Ash	Max 14.00	8.36	32.04	21.87	7.20
NFE (Carbohydrate)	-	60.02	24.03	47.35	58.09

Note: [1]Commercial feed specification based on Malindo 9905 SP label (Guaranteed Analysis). Scavenging data represents proximal analysis of crop contents from free-range ducks. NFE: Nitrogen Free Extract.

sago waste, and harvested paddy residues, which are rich in yellow pigments but deficient in the red ketocarotenoids required to achieve a darker yolk score (Kabir *et al.*, 2020). Variation in foraging success further exacerbates this phenotype, leading to a paler visual appearance that reflects the inconsistency of nutrient intake in free-range environments (Ismoyowati *et al.*, 2018). High lightness values recorded in the extensive group indicate lower saturation of total pigments, suggesting that, while these birds have access to diverse natural feeds, the total volume of carotenoids consumed is often insufficient to match the concentrated pigment delivery of commercial intensive diets.

Figure 2 illustrates the distributional patterns of yolk color metrics (L^*, a^*, b^*) across the three rearing systems. Boxplot analysis for lightness (L^*) reveals a distinct separation where the extensive system exhibits the highest median value, indicating a paler yolk appearance compared to the intensive counterparts. Redness (a^*) values demonstrate a clear hierarchy, with the colony intensive system achieving the peak intensity, followed by the battery system, while the extensive system remained significantly lower. Yellowness (b^*) metrics mirror the lightness trend, showing a dominant yellow saturation in eggs from free-range ducks, whereas intensive systems displayed reduced yellow pigmentation. Data dispersion evident in the boxplots highlights the variability within the colony system, contrasting with the tighter distribution observed in the battery cage dataset.

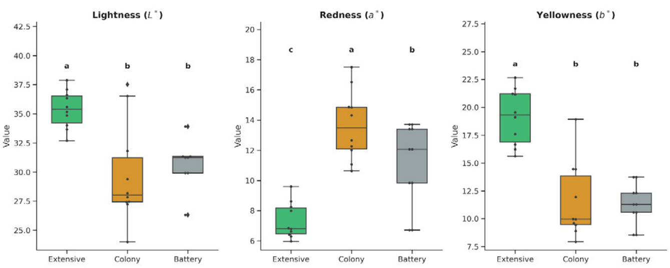

Figure 2: Distributional patterns of yolk color metrics (L^*, a^*, b^*) across the three rearing systems.

Stability in yolk pH across rearing systems indicates that the vitelline membrane maintained its barrier function against ion exchange regardless of the external housing environment. Physiological homeostasis of the yolk appears resistant to the microclimatic variations inherent to extensive or intensive management, supporting findings regarding the chemical robustness of the vitellus in fresh waterfowl eggs (Sun *et al.*, 2017). Albumen pH variations, specifically the higher alkalinity observed in the battery-intensive system (8.29), point to an accelerated rate of carbon dioxide escape through the shell pores compared to the colony setting (7.79). Elevated pH levels in battery-cage eggs suggest a more rapid shift in the bicarbonate buffer system, potentially driven by the greater surface exposure of the egg to ambient airflow in floor cages, which hastens gas exchange (Alig *et al.*, 2023). Colony housing appears to retard this gaseous escape, thereby preserving a lower, fresher pH profile closer to the initial physiological state at oviposition.

CONCLUSION

Rearing systems significantly modulate the internal quality profiles of local duck eggs while exercising negligible influence on external morphometry. Egg weight and shape index remained statistically uniform across extensive, colony, and battery configurations, underscoring the dominance of genetic factors over environmental constraints in determining physical dimensions. Internal quality metrics, specifically Haugh Unit scores, demonstrated the superiority of intensive management in preserving albumen viscosity and freshness compared to the rapid liquefaction observed in extensive scavenging. Colorimetric analysis revealed that dietary standardization in intensive systems enhanced yolk redness and pigment saturation, contrasting with the paler, yellow-dominant yolks typical of the variable scavenging diet. Chemical stability was maintained in the yolk pH, yet the battery cage environment accelerated albumen alkalinization, likely due to increased surface aeration. Colony intensive systems emerged as an optimal compromise, effectively balancing internal quality preservation with controlled microclimatic conditions. Adoption of intensive management strategies in the Banyumas region offers a viable pathway to standardize egg quality parameters without compromising physical yield.

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NOVELTY STATEMENT

This study provides novel comparative data regarding the specific impacts of extensive, colony-intensive, and battery-intensive rearing systems on local duck egg quality within the unique agroclimatic landscape of the Banyumas region, Indonesia, an area where such comparative data remains limited. A distinct contribution of this research is the integration of physical egg quality metrics with a direct nutritional assessment, specifically comparing the proximal analysis of crop contents from scavenging ducks across different local zones against commercial feed specifications to elucidate variations in yolk pigmentation. By synthesizing these environmental and nutritional dynamics, the study uniquely identifies the colony-intensive system as an optimal, welfare-conscious compromise for standardizing egg quality and ensuring sustainable poultry production in tropical environments.

AUTHOR'S CONTRIBUTION

SS designed the study, conducted the field survey, drafted the original manuscript, and served as the project administrator. ET and NAS performed the laboratory analyses and collected the data. AS conducted the statistical analysis and data curation. II and RR provided critical supervision, validated the methodology, and contributed to reviewing and editing the manuscript. All authors have read, critically revised, and approved the final submitted version of the manuscript.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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