BIODIVERSITAS
Volume 27, Number 6, June 2026
Pages: 8

ISSN: 1412-033X
E-ISSN: 2085-4722
https://doi.org/10.13057/biodiv/d270607

Observational characterization of Central Javanese local ducks across agroecological zones and rearing systems

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Manuscript received: 22 December 2025. Revision accepted: 10 June 2026.

Abstract. *Supranoto, Tugiyanti E, Setianto NA. 2026. Observational characterization of Central Javanese local ducks across agroecological zones and rearing systems. Biodiversitas 27 (6): d270607. https://doi.org/10.13057/biodiv/d270607.* Local duck farming in Central Java spans heterogeneous agroecological zones and management systems, yet field data on phenotype, natural feed, and egg quality are limited. This observational study characterized qualitative and quantitative phenotypic traits, natural-feed (crop-content) composition, and selected egg-quality parameters of local ducks across four altitude-based zones (coastal, lowland, midland, highland) and three rearing systems (extensive grazing, intensive colony, intensive battery). Qualitative traits were scored in 300 ducks, morphometrics in 90 ducks, crop contents in 12 ducks (three per zone), and egg quality in two one-way ANOVA subsets. Brown and light-brown plumage predominated, whereas beak and shank pigmentation were consistent. Body length, neck length, and shank length were significantly larger under battery rearing ($p<0.01$), whereas body weight and five other traits did not differ. Because breed and farm were not modeled, these differences reflect combined genetic and management associations. On an as-fed basis, natural feed in all zones fell below commercial protein and energy specifications. Egg weight, yolk color, yolk pH, and albumen pH differed among zones, partly reflecting duck type; among systems, only albumen pH differed. These baseline findings require replicated genetic, nutritional, and production studies before management recommendations are generalized.

Keywords: Agroecological zone, egg quality, local duck, morphometrics, natural feed

INTRODUCTION

Local ducks (*Anas platyrhynchos domesticus*) are valuable poultry genetic resources for smallholder farming systems in Indonesia, including Central Java, where they contribute to household income, egg supply, food security, and the conservation of locally adapted waterfowl populations (Rahayu et al. 2019; Sulaiman et al. 2023). Unlike commercial poultry kept under relatively uniform and standardized conditions, local ducks are maintained in heterogeneous field environments ranging from coastal wetlands and irrigated rice fields to cooler upland farming areas. These environments provide diverse scavenging resources, including crop residues and aquatic organisms, but also impose management constraints related to feed availability, housing, water access, and seasonal conditions (Ismoyowati 2020). Consequently, variation in external phenotype, body size, and egg quality may be associated with local ecology, feed resources, and housing systems, although these associations are difficult to separate under smallholder conditions (Susanti 2020b; Elly et al. 2024).

Phenotypic characterization remains an essential first step in describing local animal genetic resources and supporting their sustainable use. Qualitative traits such as plumage, beak, and shank color describe population appearance and visual diversity, whereas morphometric measurements provide information on body size, structural variation, and possible adaptation to local production environments (Maharani et al. 2019). Egg-quality traits, including egg weight, egg index, yolk color coordinates, yolk pH, and albumen pH, influence product quality and may reflect differences in genotype, diet, handling, management, and environment (Kroger et al. 2024). However, field-based interpretation must be cautious because visible and productive traits are influenced by both biological and non-biological factors, including age, nutrition, rearing history, and farmer practices (Hossein-Zadeh 2024).

Previous studies have shown that native duck populations can differ in plumage pattern, body measurements, and egg characteristics across regions and rearing practices (Yeboah et al. 2023; Libanio et al. 2025). Nevertheless, observational data from smallholder farms are frequently complicated by breed or strain composition, farmer management, feed availability, bird age, farm microenvironment, and sampling structure (Kadurumba et al. 2023). These factors may act together to create apparent differences that cannot be attributed confidently to a single environmental or management factor. Therefore, field studies should distinguish among statistically tested effects, descriptive tendencies, and possible biological explanations that require controlled validation before broader conclusions are made.

Central Java provides a useful setting for observational characterization because duck farming occurs across a broad agroecological gradient. Coastal, lowland, midland, and highland areas differ in altitude, landscape structure, water availability, climatic conditions, and locally accessible feed materials (Susanti et al. 2025). Extensive grazing allows ducks to use rice fields, wetlands, household residues, and aquatic organisms, whereas intensive colony and battery systems rely more heavily on controlled housing and farmer-provided diets (Libanio et al. 2025). These systems are not distributed equally across zones: intensive systems are concentrated in specific locations, while extensive grazing is more widely practiced (Rahayu et al. 2022). A full factorial zone-by-system analysis is therefore not appropriate when not all combinations are represented; the present design accommodates this constraint by using two restricted comparison subsets.

Information on crop-content composition can indicate the short-term feed materials consumed by grazing ducks, but crop contents reflect recent intake rather than complete daily ration composition, and small zone-level samples cannot estimate individual or seasonal variation (Kokoszyński et al. 2019; Kowalska et al. 2020). Such data are best interpreted as indicative profiles. Few observational studies have simultaneously described qualitative phenotype, morphometric traits, crop-content profiles, and egg-quality parameters in Central Javanese local ducks from smallholder environments (Susanti 2020a). This study aimed to characterize phenotypic traits, natural-feed composition and egg-quality parameters of Central Javanese local ducks across selected agroecological zones and rearing systems, to describe field patterns and to test for egg-quality and morphometric differences within clearly defined, restricted subsets.

MATERIALS AND METHODS

Study area

The research was conducted in four districts of Central Java, Indonesia: Banyumas (7°22′27.7″S-7°27′31.7″S; 109°09′08.2″E-109°17′18.2″E), Purbalingga (7°25′38.3″S; 109°19′38.8″E), Cilacap (7°41′05.7″S; 109°09′02.1″E), and Wonosobo (7°24′30.2″S-7°22′33.2″S; 109°09′08.2″E-109°56′19.4″E) (Figure 1). The reported coordinates denote the centroid of each sampling cluster (subdistrict level) rather than individual farm points, which were not georeferenced. Sampling subdistricts were selected purposively to represent altitude classes: coastal (<5 m asl) in Adipala, Cilacap; lowland (5-99 m asl) in Kalimanah, Purbalingga; midland (100-500 m asl) in Cilongok, Banyumas; and highland (>500 m asl) in Selomerto, Wonosobo. Rearing systems were distributed according to prevailing local practice. Extensive grazing occurred across the gradient, whereas intensive colony and intensive battery systems were available only in the midland zone of Banyumas. The dataset was therefore not a full factorial combination of zone and system. Accordingly, agroecological-zone comparisons were restricted to extensive-grazing ducks, and rearing-system comparisons were restricted to the midland zone.

Ethical approval

All procedures involving animals were approved by the Animal Ethics Committee of LPPM, Universitas Jenderal Soedirman (protocol No. 053/03/KEPST/25). Crop-content sampling involved 12 ducks from the extensive-grazing system (three per zone). Birds were handled carefully and slaughtered by trained personnel following halal procedures and national animal-welfare principles to minimize stress and suffering.

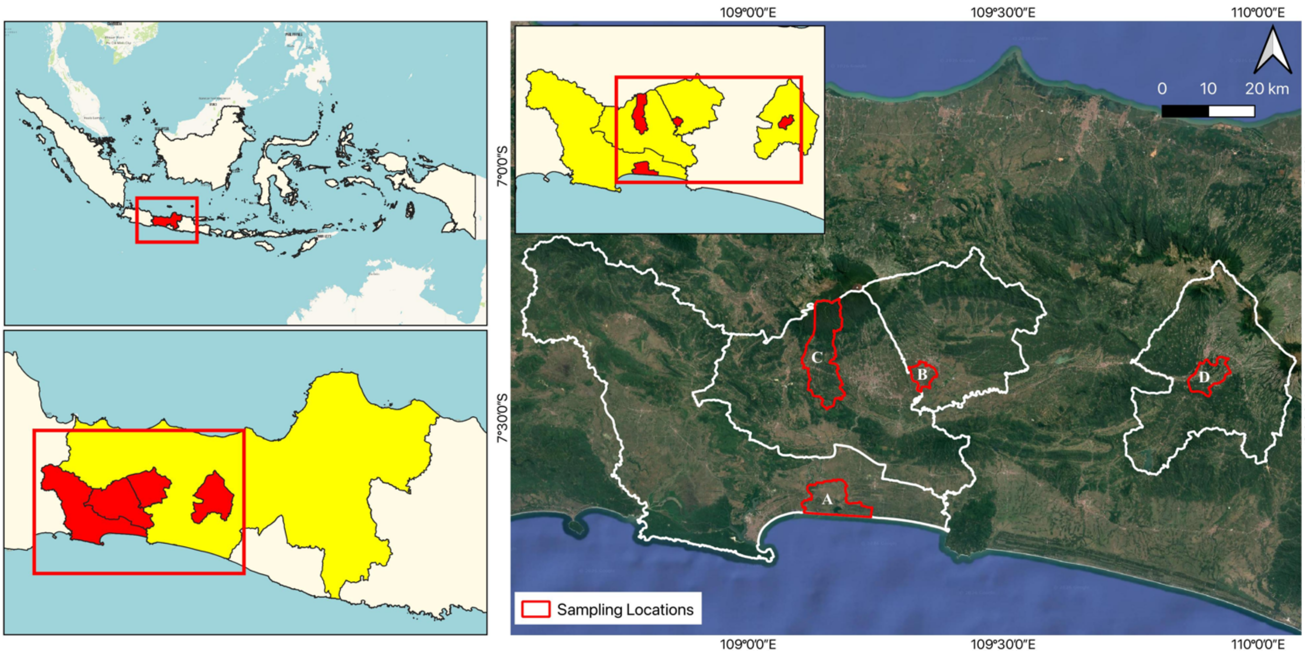

Figure 1. Sampling locations in Central Java, Indonesia, representing four altitude-based agroecological zones. A. Coastal (Adipala, Cilacap), B. Lowland (Kalimanah, Purbalingga), C. Midland (Cilongok, Banyumas), D. Highland (Selomerto, Wonosobo)

Table 1. Structure, experimental unit, and analytical status of each study component

Study component	Comparison/subset	Experimental unit	Sample size	Analytical status
Qualitative color traits	All farms and rearing systems	Individual duck	300 ducks (15 farms)	Descriptive frequency only
Morphometric traits	Three rearing systems	Individual duck	90 ducks (25/30/35)	Assumption testing and One-way ANOVA
Crop-content profile	Extensive-grazing ducks, four zones	Individual crop sample	12 ducks (3 per zone)	Descriptive (mean±SD); no inference
Egg quality by zone	Extensive-grazing ducks, four zones	Farm-replicate mean	n: 5 replicates per zone	One-way ANOVA (restricted subset)
Egg quality by system	Midland ducks, three systems	Farm-replicate mean	n: 10 replicates per system	One-way ANOVA (restricted subset)

Note: Each egg-quality replicate is the mean of five eggs (subsamples) from one farm; replicate means were used as experimental units to avoid pseudo replication. Eggs from the same farm are not fully independent, and farm-level clustering was not modeled (see Data analysis)

Sampling design and experimental units

A multistage stratified purposive design was used. Four districts were selected to represent altitude-based zones; 15 smallholder farms with stable populations (>100 birds) and identifiable rearing systems were then selected; and adult female ducks (30-35 weeks) were sampled. Because both farms and birds were purposively selected rather than randomly sampled, more accessible animals may have been overrepresented; the results are therefore presented as a baseline characterization and are not assumed to be fully representative of the wider regional population. The highland population was phenotypically identified as Magelang ducks, whereas coastal and lowland populations were identified mainly as Mojosari, Soloan, and Rambon ducks. Because breed identity was based on external markers rather than on pedigree or molecular confirmation, breed or strain composition was identified as a major limitation in interpreting zone-related differences (Muluneh et al. 2023). The structure, experimental unit, and analytical status of each dataset are summarized in Table 1.

Morphometric measurement

A single trained researcher conducted all morphometric measurements between 07:00 and 09:00 to minimize interobserver variation. Body weight was recorded with a calibrated digital scale (kg). Linear traits (body length, neck length, beak length, beak width, wing width, shank length, middle-toe length, and shank circumference) were measured with a digital caliper and measuring tape with birds held in a natural standing position. Body length was measured dorsally from the beak tip to the pygostyle, neck length from the atlas to the clavicle, and shank length along the tarsometatarsus from the hock joint to the toe pad.

Crop-content sampling and proximate analysis

Crop contents were collected from 12 representative extensive-grazing ducks (three per zone) after afternoon grazing. Each crop sample was removed, weighed, homogenized, and stored at approximately 4°C before analysis. Proximate composition (moisture, dry matter, crude protein, crude fat, crude fiber, and nitrogen-free extract, NFE) was determined for each of the three samples per zone following AOAC (2019) methods, and values are reported as zone-level means±SD (n: 3). Because of the small number of samples per zone, crop-content data were interpreted descriptively only, and no inferential statistics were applied. To allow biologically relevant comparison with commercial layer-duck specifications, nutrient values were additionally expressed on an as-fed basis using as-fed value: dry-matter-basis value × (dry matter %/100); moisture and dry matter are presented as analyzed. Calcium and phosphorus were not determined because mineral assay requires separate instrumentation beyond the present scope; the absence of mineral data is acknowledged as a limitation.

Egg-quality measurement

Yolk color was measured with a tristimulus chroma meter (CR-400, Konica Minolta, Osaka, Japan; 8-mm aperture, Illuminant C, 2° observer), calibrated against the white reference tile (CR-A43) before each session, and recorded in CIELAB space as L* (lightness), a* (redness), and b* (yellowness) from the mean of three readings per yolk. Immediately after egg breaking, the pH of the yolk and albumen was determined in duplicate with a benchtop pH meter (HI2211, Hanna Instruments, Woonsocket, RI, USA) fitted with an HI1131B electrode and a temperature probe, two-point calibrated daily (pH 4.01 and 7.01 at 25±1°C). For each zone or system, five eggs were collected from each farm and averaged to obtain a replicate mean; replicate means were the experimental units (Table 1).

Data analysis

Morphometric data for the nine traits were first checked for the assumptions of One-way ANOVA: normality of residuals (Shapiro-Wilk) and homogeneity of variance (Levene, median-based; and Bartlett). All variables met both assumptions (Table 3), justifying One-way ANOVA among the three rearing systems, with Tukey's honestly significant difference (HSD) test for pairwise comparison when $p<0.05$ (Agbangba et al. 2024). Egg-quality data were analyzed by one-way ANOVA in two restricted subsets: (i) extensive-grazing ducks across coastal, lowland, midland, and highland zones; and (ii) midland-zone ducks across extensive, intensive colony, and intensive battery systems. For both egg-quality subsets, the same assumptions (normality of residuals and homogeneity of variance) were verified before analysis, and the eta-squared (η^2) effect size was computed for every parameter and is reported alongside the p-value to indicate the proportion of variance associated with zone or system and to support interpretation of the ANOVA results. A two-way ANOVA was not used because the field design did not include all zone-by-system combinations. Because farm-level clustering and breed composition were not modeled, the ANOVA results test differences among restricted zone or system groups rather than pure environmental effects; a linear mixed model with farm as a random effect, nested within zone, is recommended for future, more replicated datasets to account for clustering and to support wider generalization. Qualitative traits and crop-content profiles were summarized descriptively and were not subjected to inferential testing. Analyses used IBM SPSS Statistics v26.0.

RESULTS AND DISCUSSION

Qualitative traits

Observations of 300 ducks across the three rearing systems showed that brown and light-brown plumage variants predominated, while beak and shank pigmentation were highly consistent (Table 2; Figure 2). Color was recorded per body part as mutually exclusive ground-color categories that sum to 100% within each system, except that the white-collared brown neck pattern, a diagnostic marker of Magelang ducks, was recorded as an additional co-occurring marking and is flagged separately. The white-collared variant appeared in about 10% of extensive and colony ducks but was absent under the battery system, consistent with the predominance of Magelang ducks at the highland (extensive) site. Beak and shank were almost entirely black (≥88%) across all systems.

Brown and light-brown plumage is consistent with previous descriptions of Indonesian and other indigenous duck populations (Maharani et al. 2019; Sulaiman et al. 2023). Plumage color is useful for preliminary field identification but should not be read as direct evidence of adaptation or genetic purity without pedigree or molecular confirmation (Kamal et al. 2022; Zhang et al. 2024; Kim et al. 2025). The greater uniformity of beak and shank pigmentation suggests phenotypic consistency in these external traits; nonetheless, all qualitative traits are presented here as descriptive markers rather than breed standards, because the sample included several local duck types across farms. The white-collared neck pattern provides a practical visual marker for the Magelang type at the highland site, but its inheritance and frequency require genetic confirmation.

Table 2. Qualitative color traits of local ducks under three rearing systems (percentage of birds within each system)

Body part	Color	Extensive (%)	Colony (%)	Battery (%)
Neck	White	1	0	0
	Black	1	1	0
	Brown	35	46	48
	Light brown	53	54	52
	White-collared brown*	10	10	0
Back	Brown	38	40	60
	Light brown	60	59	40
	Other (spotted/black)	2	1	0
Chest	Brown	35	40	65
	Light brown	60	58	35
	Other (spotted/white)	5	2	0
Wings	Brown	40	42	75
	Light brown	58	56	25
	Other (white/black)	2	2	0
Tail	Brown	40	38	80
	Light brown	55	57	20
	Other (white/black)	5	5	0
Shank	Black	88	90	92
	Brown/grey	12	10	8
Beak	Black	94	95	98
	Dark brown	6	5	2

Note: Within each body part, ground-color categories are mutually exclusive and sum to 100% per system. *White-collared brown is a co-occurring diagnostic marking of Magelang ducks recorded separately; the neck column may therefore exceed 100%. n: 100 birds scored per system

Figure 2. Representative qualitative color traits of local ducks. A. Neck plumage, B. Back plumage, C. Chest plumage, D. Shank pigmentation

Quantitative (morphometric) traits

All nine morphometric traits satisfied the normality and homogeneity-of-variance assumptions of one-way ANOVA (all p>0.05; Table 3), supporting parametric analysis. One-way ANOVA showed that three of nine traits differed significantly among rearing systems (p<0.01): body length (F: 21.67), neck length (F: 6.81), and shank length (F: 6.37), each largest in the intensive battery system (Table 4). The remaining six traits, including body weight (p: 0.072) and middle-toe length (p: 0.570), did not differ significantly. Tukey HSD grouped the battery system separately (b) from the extensive and colony systems, which formed one homogeneous group (a).

The larger axial and appendicular dimensions (body length, neck length, shank length) under the battery system are interpreted cautiously, because the observational design does not separate genetic (breed) effects from management effects: Indonesian local ducks comprise several morphologically distinct types (Maharani et al. 2019); in the present study, breed composition differed among systems, with Mojosari and Rambon types more common under intensive systems and Soloan and Rambon under grazing. Biologically, two interacting mechanisms are plausible. First, battery and colony ducks received formulated layer feed (crude protein ≥17%) at higher and more consistent nutrient density than the natural feed of grazing ducks (8.70-12.11% crude protein, as-fed; see below), favoring skeletal protein deposition (Adamski et al. 2016). Second, restricted movement in battery cages lowers locomotor energy expenditure, leaving more energy available for long-bone growth; consistent with this, free-range birds with higher step counts have shown shorter shanks than caged birds (Ren et al. 2024). These mechanisms remain hypotheses based on observational data; common-garden experiments or the inclusion of breed as a covariate are needed to disentangle them.

Importantly, body weight did not differ significantly among systems (1.52-1.61 kg), indicating that the linear-dimension advantage under battery rearing was not reflected in greater total mass and that skeletal and muscle growth are partly independent (Ren et al. 2024). Cranial dimensions (beak length and width) and middle-toe length were the most stable traits, consistent with their high heritability and limited environmental plasticity, making them more suitable as breed-differentiation markers than as indicators of management. The middle-toe difference highlighted in the earlier version of this study was not statistically supported (P: 0.570; η^2: 1.3%) and is therefore not interpreted as a terrain-related adaptation.

Table 3. Tests of parametric assumptions (p-values) for nine morphometric traits across three rearing systems

Trait	Shapiro-Wilk: Extensive	Colony	Battery	Levene	Bartlett
Body weight	0.899	0.955	0.321	0.543	0.388
Body length	0.213	0.918	0.493	0.230	0.184
Neck length	0.406	0.562	0.478	0.191	0.234
Beak length	0.624	0.743	0.531	0.398	0.492
Beak width	0.381	0.489	0.672	0.287	0.341
Wing width	0.452	0.387	0.629	0.651	0.738
Shank length	0.320	0.463	0.613	0.305	0.092
Middle-toe length	0.134	0.693	0.752	0.491	0.219
Shank circumference	0.255	0.265	0.725	0.055	0.165

Note: All p>0.05 indicate that normality (Shapiro-Wilk) and homogeneity of variance (Levene, median-based; Bartlett) assumptions were met for every trait

Table 4. Means±SD and one-way ANOVA of nine morphometric traits of local ducks under three rearing systems

Trait	Unit	Extensive (n: 25)	Colony (n: 30)	Battery (n: 35)	F	p
Body weight	kg	1.57±0.18	1.52±0.14	1.61±0.15	2.71	0.072 ns
Body length	cm	48.93±2.75a	48.03±3.10a	52.20±2.23b	21.67	<0.001 **
Neck length	cm	11.50±0.92a	11.47±0.88a	12.13±0.65b	6.81	0.002 **
Beak length	cm	5.30±0.35	5.23±0.32	5.40±0.28	2.38	0.098 ns
Beak width	cm	2.80±0.21	2.77±0.19	2.87±0.15	2.59	0.081 ns
Wing width	cm	32.33±2.10	32.30±2.25	33.27±1.85	2.31	0.106 ns
Shank length	cm	4.10±0.28a	4.07±0.26a	4.27±0.19b	6.37	0.003 **
Middle-toe length	cm	7.73±0.52	7.60±0.48	7.67±0.38	0.57	0.570 ns
Shank circumference	cm	3.23±0.25	3.23±0.24	3.33±0.18	2.19	0.118 ns

Note: Different superscripts within a row indicate significant differences (Tukey HSD, α: 0.05). **p<0.01; ns: not significant (p≥0.05). Because breed composition and farm were not modeled, differences reflect combined genetic-management associations

Crop-content (natural-feed) profile

Proximate analysis described the short-term ingested material of grazing ducks. Because only three crop samples were obtained per zone, values are presented as zone-level means±SD (n: 3) and interpreted descriptively only; no statistical comparison was made. On an as-fed basis, crude protein ranged from 8.70 to 12.11%, crude fat from 0.03 to 1.74%, crude fiber from 3.60 to 8.68%, and NFE from 11.39 to 33.73% (Table 5). Relative to common commercial layer-duck specifications (moisture ≤14%, dry matter ≥86%, crude protein ≥17%, crude fat ≥3%, crude fiber ≤10%) (National Research Council 1994; National Standardization Agency 2006), the natural feed in all zones was markedly more dilute, with much higher moisture and lower protein and fat; only crude fiber remained within range (Table 6). This indicates that scavenged feed can meet maintenance needs but is generally too nutrient-dilute to maximize egg production, so production and feed efficiency in grazing systems are expected to be lower than with balanced commercial diets (Mandal 2022; Susanti et al. 2025). The high-water content is the most prominent feature across zones: to obtain the protein contained in 1 kg of a 17% commercial ration, a grazing duck consuming midland natural feed (8.70% crude protein, as-fed) would need to ingest roughly 2 kg of wet material, an intake that approaches the physiological limit of the adult crop and helps explain the generally lower productivity of grazing ducks.

Descriptively, each zone showed a distinct profile. The coastal (Cilacap) feed had the highest NFE (33.73%) and dry matter, suggesting a larger contribution of carbohydrate-rich residues such as spilled grain in post-harvest rice fields; the midland (Banyumas) feed had the lowest protein (8.70%); and the highland (Wonosobo) feed had the highest crude fat (1.74%) and lowest crude fiber. The lowland (Purbalingga) profile combined the highest protein (12.11%) with the lowest NFE (11.39%), a pattern consistent with selective grazing on protein-rich aquatic invertebrates (snails, worms, aquatic insects) in productive irrigated rice fields, where animal-source intake rises as readily digestible carbohydrate declines. These ecological readings remain interpretive: proximate analysis indicates chemical composition rather than feed-item identity, and direct botanical or DNA-based identification of crop fragments along with repeated seasonal sampling is needed to confirm them (Ando et al. 2022).

Egg quality across agroecological zones (extensive grazing)

Among extensive-grazing ducks, egg weight differed highly significantly among zones ($p<0.01$), being highest in the highland group (72.87±5.58 g) and lowest in the midland group (58.95±5.65 g) (Table 7). Yolk redness (a*) and yellowness (b*), yolk pH, and albumen pH also differed among zones, whereas egg index and L* did not. These zone differences should not be attributed to altitude alone, because duck type was partly confounded with zone: the highland group comprised mainly Magelang ducks, which tend to be larger and lay heavier eggs, whereas coastal and lowland groups were mainly Mojosari, Soloan, and Rambon (Rahayu et al. 2019; Kroger et al. 2024).

Egg index was stable across zones, indicating that egg shape varied less than egg mass. Yolk color differed among zones, with the midland group lowest in redness and yellowness; however, because carotenoids, xanthophylls, and antioxidant capacity were not measured, these colorimetric differences are reported as such and not as evidence of specific pigment intake. Albumen pH was lowest in the midland group. Although albumen pH is associated with internal quality and freshness, storage duration, ambient temperature, and handling were not controlled, and albumen height and Haugh unit were not measured, so this difference is interpreted with caution. Effect sizes for the significant parameters were large (η^2: 0.54-0.66), but with only five replicate means per zone, all zone-level egg-quality results are preliminary, and a farm-nested mixed model is recommended for confirmation.

Table 6. Comparison of natural-feed characters (as-fed) with commercial layer-duck specifications

Component (%)	Commercial specification	Natural feed (as-fed range)	Status
Moisture	≤14	43.80-56.77	Far above the limit
Dry matter	≥86	43.23-56.20	Far below the limit
Crude protein	≥17	8.70-12.11	Below specification
Crude fat	≥3	0.03-1.74	Below specification
Crude fiber	≤10	3.60-8.68	Within range

Note: Commercial specifications follow the National Research Council (1994) and National Standardization Agency (2006). The comparison is descriptive and contextual; it is not used to diagnose nutritional deficiency in individual ducks

Table 5. Proximate composition of natural feed (crop contents) of extensive-grazing ducks by agroecological zone, expressed on an as-fed basis (mean±SD, n: 3 per zone)

Component (%)	Coastal (Cilacap)	Lowland (Purbalingga)	Midland (Banyumas)	Highland (Wonosobo)
Crude protein	9.26±0.36	12.11±0.55	8.70±0.43	9.66±0.39
Crude fat	0.03±0.00	0.03±0.00	0.03±0.00	1.74±0.06
Crude fiber	8.47±0.20	8.68±0.37	7.15±0.30	3.60±0.17
NFE	33.73±1.23	11.39±0.47	24.43±0.67	25.11±1.10
Moisture	43.80±1.59	52.59±1.07	48.40±1.53	56.77±1.09
Dry matter	56.20±0.79	47.41±1.91	51.60±0.84	43.23±1.42

Note: NFE: nitrogen-free extract. Crude protein, crude fat, crude fiber, and NFE were converted from a dry-matter basis to an as-fed basis; moisture and dry matter are as analyzed. Values are indicative profiles and were not statistically compared

Table 7. Egg-quality characteristics of extensive-grazing ducks across agroecological zones (mean±SD, n: 5 replicate means per zone)

Parameter	Coastal	Lowland	Midland	Highland	p-value	η²
Egg weight (g)	65.03±2.15 ^{bc}	69.80±1.54 ^{ab}	58.95±5.65 ^{c}	72.87±5.58 ^{a}	0.000 **	0.66
Egg index (%)	80.68±3.93	80.35±2.28	79.34±1.26	80.14±3.20	0.894 ^{ns}	0.04
L* (lightness)	34.33±1.26	35.45±2.14	35.33±1.19	33.92±1.45	0.351 ^{ns}	0.18
a* (redness)	8.39±0.94 ^{b}	8.25±1.02 ^{b}	6.43±0.33 ^{a}	9.03±1.40 ^{b}	0.005 **	0.54
b* (yellowness)	18.22±1.61 ^{ab}	21.17±1.30 ^{c}	17.14±1.53 ^{a}	20.50±1.48 ^{bc}	0.002 **	0.60
Yolk pH	5.85±0.16	6.16±0.22	6.10±0.13	6.11±0.18	0.049 *	0.37
Albumen pH	8.26±0.08 ^{b}	8.32±0.24 ^{b}	7.94±0.07 ^{a}	8.30±0.10 ^{b}	0.002 **	0.60

Note: Different superscripts within a row indicate significant differences (Tukey HSD, $p<0.05$). **$p<0.01$, *$p<0.05$; ns: not significant. η^2: eta-squared effect size (proportion of variance among zone groups). For yolk pH, the ANOVA was marginal (p: 0.049) and Tukey HSD detected no significant pairwise difference, so all groups share one letter; this result should be regarded as preliminary given n: 5 per zone

Table 8. Egg-quality characteristics of local ducks under three rearing systems in the midland zone (mean±SD, n: 10 replicate means per system)

Parameter	Extensive	Intensive battery	Intensive colony	p-value	η²
Egg weight (g)	59.77±4.28	62.09±6.02	63.41±7.99	0.433 ^{ns}	0.06
Egg index (%)	79.92±1.42	78.40±4.06	77.00±3.62	0.151 ^{ns}	0.13
L* (lightness)	32.06±3.75	30.55±2.61	29.87±5.07	0.455 ^{ns}	0.06
a* (redness)	9.88±3.76	11.15±2.74	12.20±2.94	0.280 ^{ns}	0.09
b* (yellowness)	14.05±3.72	11.29±1.84	10.88±4.83	0.130 ^{ns}	0.14
Yolk pH	6.08±0.15	6.16±0.25	6.05±0.33	0.612 ^{ns}	0.04
Albumen pH	8.12±0.22 ^{a}	8.29±0.17 ^{a}	7.49±0.30 ^{b}	0.000 **	0.70

Note: Different superscripts within a row indicate significant differences (Tukey HSD, $p<0.05$). **$p<0.01$; ns: not significant. η^2: eta-squared effect size. Only albumen pH differed among systems, with a large effect size

Egg quality across rearing systems (midland zone)

Within the midland zone, rearing system did not significantly affect egg weight, egg index, yolk color coordinates, or yolk pH (Table 8). Albumen pH was the only parameter affected ($p<0.01$), with the lowest value in the intensive colony system (7.49±0.30). Although redness (a*) was numerically higher in intensive systems, the difference was not significant (p: 0.280) and should not be overinterpreted; comparable yolk color across systems suggests that both scavenged resources and farmer-provided diets supplied sufficient pigment precursors under midland conditions.

Lower albumen pH in the colony system may indicate better internal freshness or slower CO_2 loss, but because albumen height, Haugh unit, CO_2 concentration, and storage duration were not measured, the interpretation is limited to the observed pH difference (Shi et al. 2022; Kroger et al. 2024). As with the zone subset, eggs within a farm are not fully independent, so these system-level results should be confirmed with designs that model farm clustering.

Overall implications and limitations

This study documents visible phenotypic variation, statistically tested morphometric differences within rearing systems, indicative differences in recent natural-feed composition, and measurable differences in selected egg-quality traits among Central Javanese local ducks under real smallholder conditions. Several factors limit causal interpretation: breed composition was not confirmed genetically; not all zone-by-system combinations were available; crop samples were few and analyzed descriptively; farm-level clustering was not modeled; and key egg-quality indicators were not measured. The results are best used to identify traits and environments that merit controlled investigation. Future work should include replicated sampling across seasons, molecular or pedigree-based breed confirmation, direct feed-item and mineral analysis, mixed-model analyses accounting for farm clustering, and additional egg-quality indicators (Haugh unit, albumen height, shell quality, carotenoid content, storage stability), together with production and socio-economic measures, before location-specific management recommendations are generalized.

In conclusion, Central Javanese local ducks showed clear field variation across agroecological zones and rearing systems. Brown and light-brown plumage predominated, while beak and shank pigmentation were consistent. Body length, neck length, and shank length were significantly greater under intensive battery rearing, but body weight and most other traits were unaffected and; these differences reflect a combination of genetic and management effects rather than the rearing system alone. Natural feed in all zones was nutrient-dilute relative to commercial specifications and was interpreted descriptively. Egg weight, yolk color, yolk pH, and albumen pH differed among zones, partly reflecting duck type; within the midland zone, only albumen pH differed among systems. Replication of genetic, nutritional, production, and socio-economic studies is required to validate these baseline findings before management recommendations are made.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Faculty of Animal Science, Universitas Jenderal Soedirman, Indonesia, for institutional support and research facilities. This study was financially supported by the Directorate of Research, Technology, and Community Service (DRTPM), Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, under Contract No. 20.53/UN23.35.5/PT.01.00/VI/2024, dated 11 June 2024.

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