

EGG MORPHOLOGY AS PRE-HATCH SEX PREDICTOR IN *ItikPINAS* MALLARD DUCKS

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ABSTRACT

This study assessed the potential of egg morphometric traits, particularly shape index (SI), as non-invasive predictors of post-hatch sex in *ItikPINAS* (IP) mallard ducks (*Anas platyrhynchos* L.) across three genetically distinct lines: IP-Kayumanggi, IP-Itim, and IP-Khaki. A total of 269 hatching eggs were subjected to both manual and digital morphometric measurements using digital calipers and ImageJ EggTools software, respectively. Key traits measured included egg length and width, with computed values for volume, surface area, and shape index. Hatchling sex was determined through vent sexing. Descriptive statistics, correlation analysis, principal component analysis (PCA), and logistic regression were used to analyze the data. Significant morphometric differences were observed among the IP lines; however, these breed-level variations did not affect sex outcomes, justifying data pooling. In all variables, sex-based comparisons showed non-significant differences. PCA revealed considerable overlap among lines and between sexes, while logistic regression showed no trait combination capable of reliably predicting sex. Despite high measurement consistency among traits, egg morphology alone was not a sufficient predictor of duckling sex. These findings highlight the need for further studies using larger datasets, non-linear modeling techniques, and internal imaging tools to improve the feasibility of morphometry-based sex prediction in mallard duck production systems.

Keywords: egg morphometry, mallard ducks, non-invasive methods, sex determination

INTRODUCTION

Early sex determination in poultry has become a critical concern due to ethical, economic, and operational pressures. The culling of over 7 billion male chicks annually, resulting from the inability to identify sex before hatch, has sparked global backlash and motivated innovations for more humane and sustainable hatchery practices (Kayadan and Uzun, 2023; Luo *et al.*, 2024). Traditional post-hatch sexing methods such as vent sexing and feather dimorphism, although widely practiced, are labor-intensive, invasive, and often

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error-prone (Cerit and Avanus, 2007). These limitations have intensified the search for non-invasive, cost-effective, and scalable alternatives, particularly those applicable before incubation (Lv *et al.*, 2025; Zhang and Jacobs, 2025).

One emerging method is the use of egg morphometry for pre-hatch sex prediction. This approach examines physical characteristics of eggs—length, width, volume, surface area, and shape index (SI)—to detect subtle differences potentially linked to the sex of the developing embryo. In white layer chickens, significant differences in SI between male- and female-producing eggs have been reported (Yilmaz-Dikmen and Dikmen, 2013). In Pekin ducks, SI alone has demonstrated predictive value: rounded eggs produced 82% females, whereas elongated eggs produced 77.7% males, with SI showing a strong correlation with offspring sex ($r = 0.71$, $p < 0.001$) (Indarsih *et al.*, 2021). Meanwhile, studies on Philippine native ducks using digital imaging and machine-learning algorithms achieved up to 87% accuracy based on traits such as SI, eccentricity, and sphericity (Dioses *et al.*, 2021), suggesting that SI becomes more powerful when paired with image-derived traits.

In the Philippines, native and improved mallard duck breeds are vital to both commercial and backyard production. The *ItikPINAS* lines—Itim, Khaki, and Kayumanggi—were developed through long-term selection programs aimed at improving egg production and overall flock performance (Julian *et al.*, 2022; Santiago *et al.*, 2022). Although these lines exhibit fairly consistent egg morphology, including an average SI of ~75.96% (Santiago *et al.*, 2022), this refers to general uniformity and not necessarily to sex-related differences within each line. To date, no published studies have evaluated whether egg morphometric traits correlate with hatchling sex in these improved lines.

Sex determination in birds is fundamentally genetic: females are heterogametic (ZW) and males homogametic (ZZ). Although the chromosomal mechanism is fixed, phenotypic traits influenced by genetics—such as egg size, SI, and shell morphology—may still show sex-linked patterns or maternal allocation effects. Exploring relationships between egg morphometry and hatchling sex, therefore, provides insight into whether subtle, genetically influenced differences exist early in development and whether they may be detectable through non-invasive measurements.

This study aims to evaluate whether egg morphometric traits can serve as reliable, non-invasive predictors of sex in day-old *ItikPINAS* ducklings even before incubation. It hypothesizes that length, width, volume, surface area, and SI show significant associations with hatchling sex, and that breed and environmental influence play a moderating role in morphometric variation. Moreover, this study will validate the use of image analysis (Image J Eggtools) in *ItikPINAS* mallard duck eggs.

MATERIALS AND METHODS

The study was conducted from March to May 2025 at the Bureau of Animal Industry – National Swine and Poultry Research and Development Center (BAI-NSPRDC) poultry hatchery in Tiaong, Quezon, Philippines. All experimental procedures—including egg collection, morphometric measurement, image analysis, incubation, hatching, and sex identification—were conducted under standard protocol with IACUC approval (Permit No. UPLB 2025-039).

Study Population and Egg Collection

A total of 400 eggs were collected from 24-month-old *ItikPINAS* breeders (200 Kayumanggi, 100 Itim, 100 Khaki) maintained under standardized management in open-sided semi-confined housing with a 1:5 male-to-female ratio and restricted feeding. Eggs were collected daily, labelled individually, and stored at 20°C for not more than 14 days or until enough eggs were collected. Two incubation batches yielded 188 and 95 fertile eggs, respectively, for a total of 269 hatched egg samples for analysis. Only *ItikPINAS* Kayumanggi required a second batch due to low fertility (~30%) in the first.

Egg Morphometric Measurement

All eggs were manually measured after storage but immediately before incubation using a digital caliper (0.01-mm precision) to obtain egg length and width. Standardized images were also taken for digital analysis using ImageJ (EggTools). Digitally derived width, surface area, estimated volume, and ellipse deviation were computed from manually measured length. Shape index and volume were manually calculated using the formulas $SI = (\text{Width} / \text{Length}) \times 100$ and $\text{Volume} = (\pi / 6) \times \text{Length} \times \text{Width}^2$ (Hoyt, 1979).

A higher shape index (SI) corresponds to a more rounded egg, while a lower SI indicates a more elongated shape (Indarsih *et al.*, 2021; Yilmaz-Dikmen and Dikmen, 2013).

To assess correspondence between methods, correlation analysis between manual and digital measurements (length, width, SI, and volume) was performed before downstream analyses to confirm measurement alignment and suitability for pooled multivariate analysis.

Incubation and Sex Identification

Eggs were incubated in a forced-draft single-stage incubator for 28 days (25 days in the setter, 3 days in the hatcher) at 37.5°C and 60% relative humidity. Fertility was confirmed via candling on Day 11, and eggs were transferred to the partitioned hatcher trays (necessary to trace back the duckling with its egg ID) on Day 25. Hatchability was recorded on Day 28. Sexing was performed using a down feather color pattern (black for males, brown for females) for *ItikPINAS* Kayumanggi, and the sex of all ducklings was verified via vent sexing done by trained personnel at BAI-NSPRDC.

Data Collection and Statistical Analysis

Morphometric data from both manual and digital methods were recorded. Descriptive statistics summarized means and standard errors. To evaluate sex-based differences, a General Linear Model (GLM) of SAS On Demand for Academics was applied:

$$y_{ij} = \mu + S_i + \beta_j + \varepsilon_{ij}$$

where μ is the overall mean, S_i is the fixed effect of sex, β_j is the fixed effect of breed, and ε_{ij} is the random error. Post-hoc comparisons between sexes were performed using Tukey-Kramer with significance declared at $p < 0.05$.

Pearson's correlation analysis was performed to examine inter-trait relationships before PCA, and to assess whether trait co-variation justified integration into multivariate models. Principal Component Analysis (PCA) was conducted (1) by breed to visualize morphological variation among lines, and (2) by sex, using pooled data after confirming that

sex effects were not breed-specific.

Multiple logistic regression analysis was done using SAS On Demand for Academics to establish the effect of each variable on the sex of the ducklings. A stepwise procedure was employed using variables with $p < 0.3$ for model entry and $p < 0.05$ for retention. The accuracy of ImageJ EggTools in estimating width and SI was further evaluated using an unpaired sample t-test in Prism v10.5.

RESULTS AND DISCUSSION

Significant variations ($p < 0.01$) in egg morphometric traits were observed among the three *ItikPINAS* mallard duck lines: IP-Itim, IP-Khaki, and IP-Kayumanggi, except for ellipse deviation, indicating a strong breed effect on egg morphology (Table 1). The IP-Kayumanggi line exhibited more elongated eggs compared to IP-Itim and IP-Khaki, while IP-Khaki produced the highest average shape index, followed by IP-Itim and IP-Kayumanggi. Poultry classification thresholds (e.g., ATAK-S layers) categorize $SI < 72$ as sharp, $72-76$ as standard, and > 76 as round (Duman *et al.*, 2016; Sarica and Erensayin, 2009), placing most IP eggs within the standard to rounded range.

Table 1. Comparison of egg morphology profile of three *ItikPINAS* mallard duck genetic groups.

Variable	Breed			$\pm$ SEM	p-value (Breed)	Pooled data (n=269)
	ItikPINAS Itim (n=84)	ItikPINAS Khaki (n=76)	ItikPINAS Kayumanggi (n=109)			
Length, mm	58.43 ^b	58.75 ^b	59.65 ^a	0.1160	<0.0001	58.57
Width, mm	43.73 $\pm$ 0.10 ^b	44.71 $\pm$ 0.14 ^a	44.38 $\pm$ 0.10 ^a	0.0790	<0.0001	44.71
Volume, mm ³	5.86 $\times$ 10 ⁴ ^b	6.16 $\times$ 10 ⁴ ^a	6.16 $\times$ 10 ⁴ ^a	263.6633	<0.0001	6.14 $\times$ 10 ⁴
Shape Index	74.89 ^b	76.14 ^a	74.45 ^b	0.1515	0.0007	76.37
Ellipse deviation	3.83 $\times$ 10 ⁻⁵	2.91 $\times$ 10 ⁻⁵	3.49 $\times$ 10 ⁻⁵	0.9513 $\times$ 10 ⁻⁵	0.2446	3.43 $\times$ 10 ⁻⁵
Surface area, mm ²	7.32 $\times$ 10 ³ ^b	7.64 $\times$ 10 ³ ^a	7.62 $\times$ 10 ³ ^a	24.2322	<0.0001	7.53 $\times$ 10 ⁻⁵
Area, mm ²	1.28 $\times$ 10 ⁵ ^c	3.31 $\times$ 10 ⁵ ^b	6.71 $\times$ 10 ⁵ ^a	3.2221 $\times$ 10 ⁴	<0.0001	5.19 $\times$ 10 ⁵

Means in the same row with the same superscript are not significantly different ($p > 0.05$).

Previous studies emphasized that differences in egg size and shape among duck breeds are influenced by genetic selection, age, and management practices, especially in intensively managed flocks (Julian *et al.*, 2022). The non-significant differences in ellipse deviation suggest that while size and proportions vary, egg symmetry remains relatively consistent, likely due to shared ancestry or selection history among lines.

These breed-level differences reflect meaningful genetic variation, which plays a key role in breeding programs, as genetic diversity provides the raw material for adaptation to changing environments, improves resistance to diseases and parasites, and enables sustained genetic improvement through selection programs (Koyun *et al.*, 2016; Oldenbroek, 2021).

However, follow-up analysis revealed that despite significant differences in morphology across breeds, these traits did not influence duckling sex. Therefore, data were pooled across all lines for sex-based analysis.

Female-producing eggs exhibited slightly higher shape index values (rounder eggs), whereas male-producing eggs were more elongated (Table 2). Sex-based comparison of all morphometric traits using a linear model revealed no statistical differences ($p>0.05$).

Table 2. Comparison of egg morphometric traits (mean±SEM) between male and female *ItikPINAS* mallard ducklings.

Variable	Observed Sex		±SEM	p-value ¹
	Female (n=132)	Male (n=137)		
Length, mm	58.97	59.05	0.1160	0.6005
Width, mm	44.30	44.24	0.0790	0.7633
Volume, mm ³	6.07×10 ⁴	6.06×10 ⁴	263.6633	0.9743
Shape Index	75.17	74.96	0.1515	0.4297
Ellipse deviation	3.32×10 ⁻⁵	3.53×10 ⁻⁵	0.9513×10 ⁻⁵	0.6027
Surface area, mm ²	7.53×10 ³	7.52×10 ³	24.2322	0.9662
Area, mm ²	4.99×10 ⁵	5.39×10 ⁵	3.2221 ×10 ⁴	0.9048

¹Variable with p-value >0.05 are not significantly different between the observed sexes.

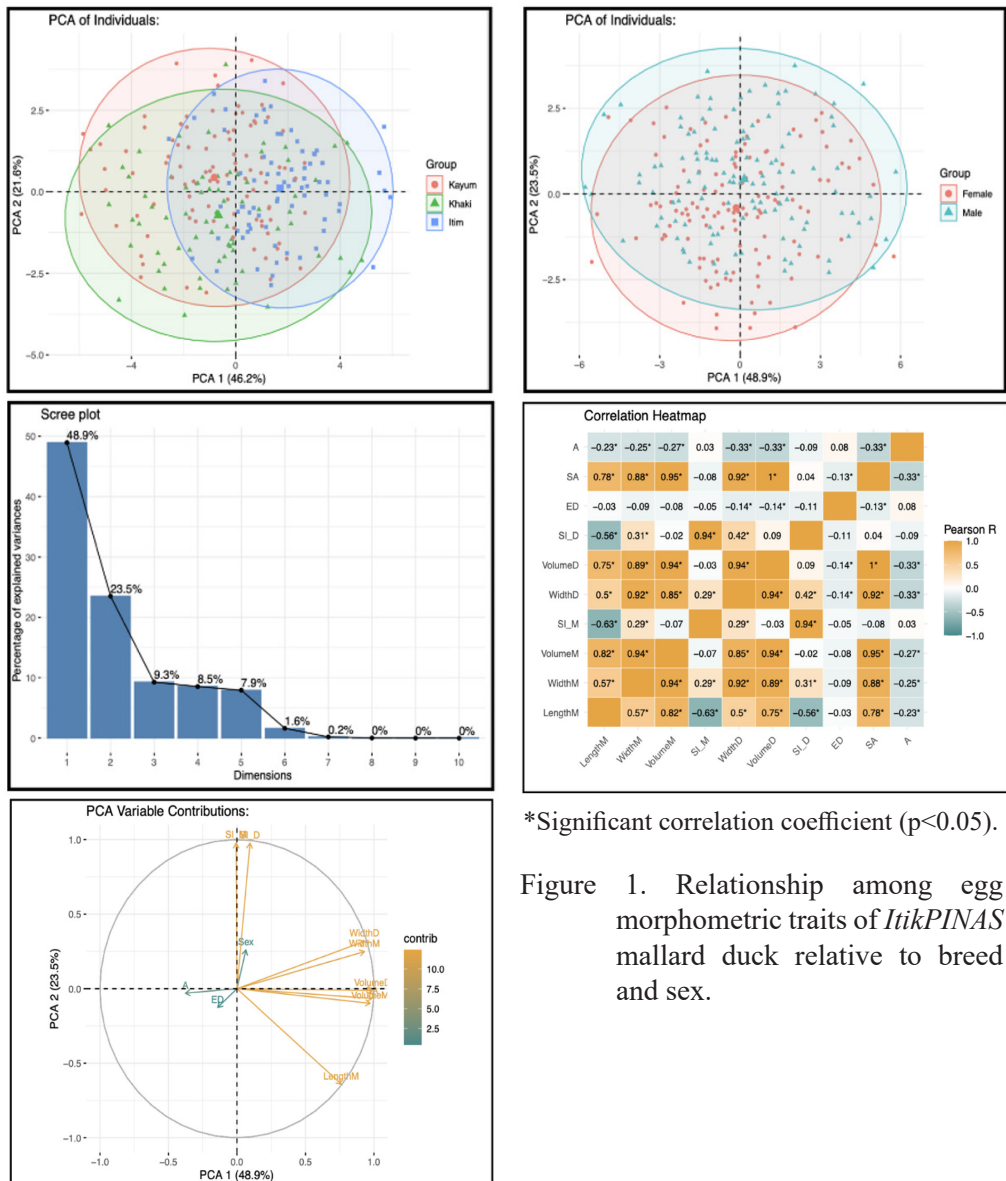
These trends are not consistent with earlier findings in poultry species, where elongated eggs were more likely to hatch males and rounder eggs tended to produce females (Yilmaz-Dikmen and Dikmen, 2013; Indarsih *et al.*, 2021; Dioses *et al.*, 2021). The lack of statistical significance in this study suggests that if sex-based morphological differences exist, they are either too subtle to be detected through linear models or require a larger sample size to achieve statistical power. Small effect sizes that are biologically real may remain undetected in studies with moderate sample sizes (Rosnow and Rosenthal, 1989).

In birds, sex is genetically determined at fertilization (ZW females, ZZ males). Because egg morphology is a maternal trait shaped by oviduct structure and physiological condition, it is not expected to directly reflect the embryonic chromosomal sex. Any potential association would arise only through indirect maternal allocation mechanisms, which are typically subtle and easily masked by environmental variability. Egg morphology could be influenced by several intrinsic and extrinsic factors, including incubation batch, farming system, and environmental conditions such as temperature, humidity, and season (Julian *et al.*, 2022; Naeem, 2024; Travel *et al.*, 2010). Even under controlled hatchery settings, breeder age, nutritional status, and overall health can introduce measurable variability in egg characteristics (Lee *et al.*, 2016; Meijerhof, 2005; Shim *et al.*, 2013). This genetic–environmental interaction helps explain why only minor tendencies were observed in ItikPINAS eggs and why none reached statistical significance in the present study.

Principal component analysis (PCA) was conducted to further examine whether multivariate patterns in egg morphology could differentiate either the three IP lines or the sex of the ducklings. The scree plot (Figure 1) shows that the first principal component (PC1) explained 48.9% of the total variance, while PC2 accounted for an additional 23.5%,

together capturing 72.4% of the overall variation. This concentration of variance in the first two axes justified their use for subsequent visual interpretation.

When PCA was performed using pooled egg morphometric data across the three *ItikPINAS* lines (regardless of sex), no distinct clustering among IP-Itim, IP-Khaki, and IP-Kayumanggi was observed (Figure 1). Although PC1 and PC2 together explained 67.8% of the variance, the egg traits broadly overlapped, consistent with the genetic origin of IP-Kayumanggi (a cross between IP-Itim females and IP-Khaki males) (Parungao, 2017). Previous reports of high egg uniformity in IP lines—such as consistent SI ($\sim 76\%$), and egg weights >66 g (Santiago *et al.*, 2022; Julian *et al.*, 2022)—support the absence of multivariate separation.



*Significant correlation coefficient ($p < 0.05$).

Figure 1. Relationship among egg morphometric traits of *ItikPINAS* mallard duck relative to breed and sex.

A second PCA performed on pooled data across lines to evaluate sex-related patterns similarly showed no visible separation between male- and female-producing eggs (Figure 1). Despite capturing the same 72.4% of explained variance, the two groups clustered closely together. This result supports the earlier GLM findings, indicating that the subtle differences observed in raw means (e.g., females slightly rounder, males slightly elongated) are not strong or consistent enough to produce multivariate separation.

These outcomes differ from earlier reports in chickens and Pekin ducks, where shape index contributed to partial sex discrimination (Yilmaz-Dikmen & Dikmen, 2013; Indarsih *et al.*, 2021). The lack of separation in IP ducks likely reflects minimal sexual dimorphism in external egg traits and high within-line uniformity, limiting the potential of external morphology for detecting sex-linked variation.

The correlation heatmap and PCA based on variable contribution (Figure 1) provide further context for understanding the internal structure of the dataset. Strong, statistically significant correlations were observed among variables, in accordance with their mathematical relationship. Variables such as volume (manual and digital), surface area, and length clustered tightly in the lower right quadrant, contributing strongly to PC1 and representing the primary size-related axis. Pairs of manual and digital traits were located close to one another and pointed in similar directions, indicating high measurement agreement and reinforcing the internal validity of the dataset from manual and digital measurements.

The sex variable, by contrast, was represented by a short vector, indicating a minimal contribution to variance. Positioned near the shape index vectors, it showed only a weak association with the roundness-related traits. Nonetheless, this directional trend aligns with observed patterns in this and prior studies, where higher shape index (i.e., more rounded eggs) tend to produce female ducklings, and more elongated eggs (lower SI) are more likely to hatch males (Yilmaz-Dikmen and Dikmen, 2013; Indarsih *et al.*, 2021).

Multiple logistic regression was also performed to test whether egg morphometric traits could predict duckling sex following a non-linear model (Table 3). The model included variables such as length, width, volume, shape index, surface area, and ellipse deviation. The Wald chi-square ($p = 0.7605$) and residual chi-square ($p = 0.7357$) were both non-significant.

Table 3. Multiple logistic regression analysis.

Analysis	Parameter Estimate	P-value
Maximum likelihood for the intercept (Wald Chi-square)	-0.0372±0.1220	0.7605
Residual chi-square	6.8908	0.7357

On the other hand, Figure 2 provides strong evidence for the reliability and consistency of the digital imaging tool (ImageJ EggTools) in measuring other egg morphometric traits using egg length as the single variable. This is especially relevant for studies involving large sample sizes or high-throughput measurement pipelines. However, more data are required in recalibrating the estimation for ellipse deviation based on egg length data since the two variables were not significantly correlated in this study.

These findings indicate that while trait distributions differ subtly, they lack sufficient discriminant power even under non-linear modeling. Sex-linked morphological

cues may follow other non-linear trends or be embedded in traits not captured by external measurements. This underscores the limitations of this approach and points to advanced imaging technologies and artificial intelligence as a potential next step, as already being explored in parallel studies.

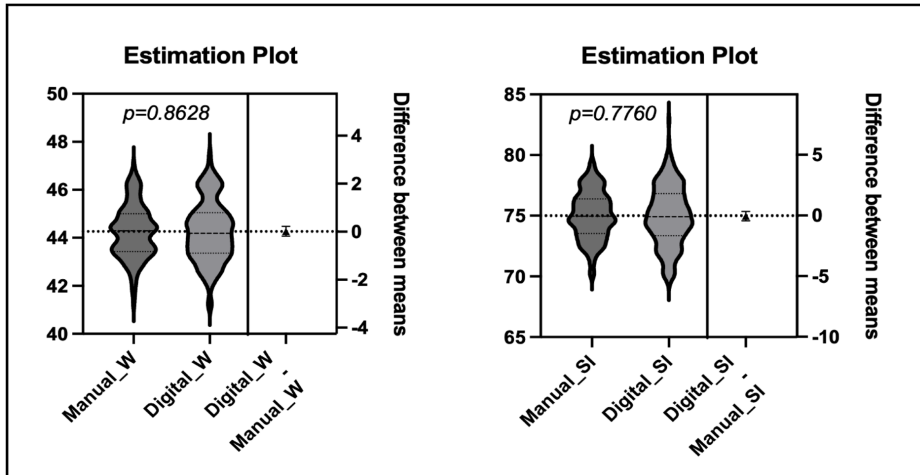


Figure 2. Comparison of the width (W) and shape index (SI) of *ItikPINAS* eggs using manual measurement and digital imaging analysis.

Recent research has demonstrated the effectiveness of hyperspectral imaging (HSI) combined with machine learning algorithms for non-destructive pre-incubation sex determination in chicken eggs, achieving accuracies above 75% by detecting internal biochemical differences (Ahmed *et al.*, 2025). Similarly, deep learning applied to blood vessel imaging inside eggs has shown promising results, with mean average precision nearing 89% for sex classification based on vascular patterns during early incubation (Jia *et al.*, 2023). Other studies have used optical coherence tomography (OCT) coupled with deep learning to accurately determine chick sex shortly after hatching, providing a non-invasive alternative to traditional methods (Saetiew *et al.*, 2025).

Overall, the study demonstrated that although the three *ItikPINAS* lines differed significantly in egg morphology, these variations—as well as the subtle tendencies observed between male- and female-producing eggs—were not strong enough to predict duckling sex using external morphometric traits. Multivariate analyses, including PCA and logistic regression, showed substantial overlap among breeds and sexes, indicating minimal discriminating power and supporting the conclusion that external egg traits are weak indicators of chromosomal sex in ducks. This outcome aligns with the biological expectation that egg morphology, being a maternal trait shaped by oviduct structure, breeder age, nutrition, and environmental conditions such as temperature and humidity, is highly susceptible to environmental modulation that can mask any subtle genetic or sex-linked patterns. Despite the lack of statistical significance, the study effectively identified consistent intraline morphometric patterns and validated the reliability of ImageJ EggTools for digital measurement. Future research integrating larger sample sizes, non-linear or machine-

learning models, and internal imaging technologies may uncover deeper developmental or physiological cues not captured by external traits, thereby advancing non-invasive and ethical pre-hatch sex prediction methods for ItikPINAS.

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REFERENCES

- Ahmed MW, Sprigler A, Emmert JL, Dilger RN, Chowdhary G and Kamruzzaman M. 2025. Non-destructive pre-incubation sex determination in chicken eggs using hyperspectral imaging and machine learning. *Food Control* 173:111233.
- Cerit H and Avanus K. 2007. Sex identification in avian species using dna typing methods. *World's Poult Sci J* 63(1):91-100.
- Dioses JLJ, Medina R, Fajardo A, Hernandez AA and Dioses IAM. 2021. Performance of egg sexing classification models in Philippine native duck. Paper presented at the 2021 IEEE 12th Control and System Graduate Research Colloquium
- Duman M, Sekeroglu A, Yildirim A, Eleroglu H and Camci O. 2016. Relation between egg shape index and egg quality characteristics. *Eur Poult Sci* 80: 1–9.
- Hoyt DF. 1979. Practical methods for estimating volume and fresh weight of bird eggs. *The Auk: Ornithol Adv* 96:7377.
- Indarsih B, Tamzil MH, Kisworo D and Aprilianti Y. 2021. *Egg shape index for sex determination of post-hatch chicks in pekin ducks: a solution for smallholder duck farming in Lombok Indonesia*. Retrieved on 10 July 2025 from <http://www.lrrd.org/lrrd33/4/3348budii.html>.
- Jia N, Li B, Zhao Y, Fan S, Zhu J, Wang H and Zhao W. 2023. Exploratory study of sex identification for chicken embryos based on blood vessel images and deep learning. *Agriculture* 13(8):1480.
- Julian JKD, Julian D, Velasco VV, Manlapig JJDG, Manlapig D and Orden EA. 2022. Laying performance and egg quality traits of itik (ip)-kayumanggi (*Anas platyrhynchos*) under intensive and semi-intensive farming system. *Philipp J Vet Anim Sci* 48(2):35-42.
- Kayadan M and Uzun Y. 2023. High accuracy gender determination using the egg shape index. *Sci Rep* 13(1):504.
- Koyun H, Koncagul S and Karakus K. 2016. Significance of genetic diversity in farm animal production. *Turk J Sci Rev* 9(1):82-83.
- Lee MH, Cho EJ, Choi ES, Bang MH and Sohn SH. 2016. The effect of hen age on egg quality in commercial layer. *Korean J Poult Sci* 43(4):253–261.
- Luo X, Guo J, Zhang J, Ma Z and Li H. 2024. Overview of chicken embryo genes related to sex differentiation. *PeerJ* 12(11):17072.
- Lv X, Sun C, Liu X, Liu G, Gong W, Qian H, Li Z, Wu J, Zhu X, Song J, Niu Y, Sun H, Han W, Chen GH, Jin K, Li B and Zuo Q. 2025. Key events in the process of sex determination and differentiation in early chicken embryos. *Anim Biosci* 38(6):1081-1104.

- Meijerhof R. 2005. *Incubation effects on chick quality*. Retrieved on 10 July 2025 from <https://www.thepoultrysite.com/articles/incubation-effects-on-chick-quality>.
- Naeem M. 2024. *From calcium to care: key factors influencing eggshell quality in layers*. Retrieved on 10 July 2025 from <https://nutrinews.com/en/from-calcium-to-care-key-factors-influencing-eggshell-quality-in-layers/amp/>.
- Oldenbroek JK. 2021. The use of genomic information for the conservation of animal genetic diversity. *Animals (Basel)* 11(11):3208.
- Parungao ARM. 2017. *Itik pinas: development, promotion, and utilization in building rural enterprises*. Retrieved on 10 July 2025 from <https://www.pcaarrd.dost.gov.ph/index.php/quick-information-dispatch-qid-articles/itik-pinas-development-promotion-and-utilization-in-building-rural-enterprises>
- Rosnow RL and Rosenthal R. 1989. Statistical procedures and the justification of knowledge in psychological science. *Am Psychol* 44(10):1276-1284.
- Saetiew J, Nongkhunsan P, Saenjae J, Yodsungnoen R, Molee A, Jungthawan S, Fongkaew I and Meemon P. 2025. Automated chick gender determination using optical coherence tomography and deep learning. *Poult Sci* 104(5):105033.
- Santiago RC, Villareal KD, San Agustin MM, Balotro RB, Rey CR, Esguerra JPM, Lambio AL and Magpantay VA. 2022. Growth, egg production, and phenotypic characteristics of the commercial hybrid egg-type Philippine mallard duck (ip kayumanggi) under intensive management system. *Philipp J Sci* 151(3):1287-1296.
- Sarica M and Erensayin C. 2009. Poultry Products. In: Poultry Science. Turkey pp. 89-138
- Shim MY, Song E, Billard L, Aggrey SE, Pesti GM and Sodsee P. 2013. Effects of balanced dietary protein levels on egg production and egg quality parameters of individual commercial layers. *Poult Sci* 92(10):2687–2696.
- Travel A, Nys Y and Lopez E. 2010. Physiological and environmental factors affecting egg quality. *INRA Prod Anim* 23(2):155-166.
- Yilmaz-Dikmen B and Dikmen S. 2013. A morphometric method of sexing white layer egg. *Braz J Poult Sci* 15(3):203-210.
- Zhang D and Jacobs L. 2025. Morphology-based in-ovo sexing of chick embryos utilizing a low-cost imaging apparatus and machine learning. *Animals* 15(3):384.