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Original article

Sex determination of Bangkok Zebra dove (*Geopelia striata*) based on wing and tail feather morphometrics at 3 and 6 months of age

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ABSTRACT

This study aimed to determine the sex of Bangkok Zebra doves (*Geopelia striata*) based on external body morphometric measurements. A total of 32 doves were used, consisting of 16 females (8 bird each at 3 and 6 months of age) and 16 males (8 birds each at 3 and 6 months of age). Four morphometric parameters were measured: wing chord, *antebrachium* (forearm) length, longest primary feather, and longest tail feather. Wing and forearm lengths were measured using digital calipers with a precision of 0.01 mm, while the longest primary and tail feathers were measured using a ruler with 0.05 mm precision. The results showed that the average wing chord, longest primary feather, and longest tail feather lengths were significantly greater ($p < 0.05$) in males compared to females. At six months of age, males also had a significantly longer forearm than females ($p < 0.05$). However, no significant difference ($p > 0.05$) was found in forearm length between sexes at three months of age. It could be concluded that wing and tail feather morphometrics can be used to distinguish between male and female Bangkok Zebra doves at both three and six months of age, except for forearm length at three months.

Keywords: female, male, monomorphic, morphometrics, sex determination

INTRODUCTION

The Bangkok Zebra dove (*Geopelia striata*) is a widely kept avian species among bird enthusiasts, particularly in Indonesia. As a member of the family Columbidae, this species is highly valued or it soft, melodious vocalizations, especially those produced by males (Cerit and Avanus, 2007a). Due to their pleasant calls and associated cultural significance, Zebra doves have become extensively domesticated, and their economic value, especially for males, has increased significantly in recent years (Cambrone *et al*., 2022). However, many bird species, including the Zebra dove, are monomorphic, meaning that males and females are visually indistinguishable based on external morphology. This monomorphism presents a major challenge in sex identification, limiting our understanding of the species' biology, ecology, and breeding behavior. Moreover, inaccurate sex

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determination can hinder effective breeding management and conservation efforts, potentially resulting in economic losses due to inefficient pairing, misdirected care, and failed reproductive attempts (Cerit and Avanus, 2007b). Thus, reliable methods for sex determination are essential to support successful breeding programs and population management.

Sex identification is a fundamental aspect of avian biology. It plays a critical role in ecological studies, breeding strategies, and conservation planning. While species that exhibit sexual dimorphism can often be sexed visually due to marked differences in plumage, size, or coloration, monomorphic species like the Zebra dove require more refined techniques (Çakmak *et al*., 2017; Piro *et al*., 2018). Genetically, male Zebra doves possess two Z chromosomes (ZZ), while females carry one Z and one W chromosome (ZW). On a molecular level, the presence of the W chromosome triggers pathways that lead to female reproductive organ development, while expression of the DMRT1 gene (Doublesex and Mab-3 Related Transcription Factor 1) is higher in males (ZZ) than in females (ZW). Nevertheless, these differences do not manifest in distinguishable external feather coloration or body structure (Wee and Wang, 2008).

Various sexing methods have been developed for avian species, including karyotyping, hormonal profiling, laparotomy, laparoscopy, vent sexing, and molecular techniques. Among these, molecular assays are considered the gold standard due to their high accuracy. However, they are often time-consuming, invasive, and costly (Dechaume-Moncharmont *et al*., 2011; Morinha *et al*., 2012). In contrast, morphometric analysis offers a non-invasive, cost-effective alternative, especially suitable for monomorphic species. This method can be conducted in the field with minimal equipment and training, making it particularly advantageous for routine or large-scale applications (Fuchs *et al*., 2017). Bangkok Zebra doves are reported to reach sexual maturity at around 6 months of age (Wee and Wang, 2008). Local breeders in Surabaya have observed that egg-laying typically begins at this age, suggesting it as a practical marker of sexual maturity. Based on these observations and prior studies, this research focused on birds aged 3 and 6 months to evaluate the effectiveness of morphometric sexing at different developmental stages. Preliminary data from breeders indicate that sex prediction at 3 months is only about 20% accurate for males, whereas female identification is approximately 80% accurate (Dhamayanti *et al*., 2023). Meanwhile, Audet *et al*. (2014) reported that morphometric analysis of wing and tail feathers in another monomorphic species, i.e. the Barbados Bullfinch (*Loxigilla barbadensis*) achieved up to 97% accuracy in sex determination.

However, no published data are currently available regarding the use of wing and tail feather morphometrics for sexing Zebra doves. Therefore, the objective of this study was to investigate the effectiveness of sex determination in Bangkok Zebra doves based on morphometric measurements of the wings, wing feathers, and tail feathers at 3 and 6 months of age.

MATERIALS AND METHODS

The study was conducted at the Animal Laboratory of the Faculty of Veterinary Medicine, Universitas Airlangga, Mulyorejo district, Surabaya city, East Java, Indonesia, between August and September 2023. Ethical approval was required due to the involvement of surgical procedures on animals. This approval was obtained to prevent animal abuse and to ensure adherence to animal welfare principles. Ethical clearance was obtained from the Universitas Airlangga Ethics Committee (Approval No. 1036/HRECC.FODM/VIII/2023).

A total of 32 Bangkok Zebra doves (*Geopelia striata*) were used as experimental subjects. These birds were sourced from a bird farm in Manukan Kulon, Surabaya. All individuals were confirmed to be clinically healthy, free of physical deformities, and without signs of feather loss.

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Initial sex classification of the birds (male and female) was based on preliminary research (Dhamayanti *et al*., 2023). From the available population, eight males and eight females were randomly selected at both three and six months of age. Final confirmation of sex was conducted via laparotomy, by identifying the presence of testes in males or ovaries in females.

Parameter measurement

Wing length and forearm length were measured using digital calipers with a precision of 0.01 mm. The longest primary feather and the longest tail feather were measured using a ruler calibrated to 0.05 mm. All morphometric data, including wing length, forearm length, length of the longest primary feather, and length of the longest tail feather, were recorded in millimeters (mm).

Wing morphometrics

Wing length (wing chord) was measured from the carpal joint (bent wing tip or wrist) to the tip of the longest primary feather, as described by Seyer *et al*. (2020). Forearm length was measured from the junction of the ulna and radius bones (Analla *et al*., 2022). Measurements were taken after full extension (Figure 1).

Feather morphometrics

The length of the longest primary feather was measured from the point where the feather emerges from the skin to the feather tip (Ma *et al*., 2025).

Tail feather morphometrics

The length of the central tail feather was measured from the base where it emerges from the skin to the tip of the longest tail feather, with the tail in a closed position (Fitzpatrick, 2001) (Figure 2).

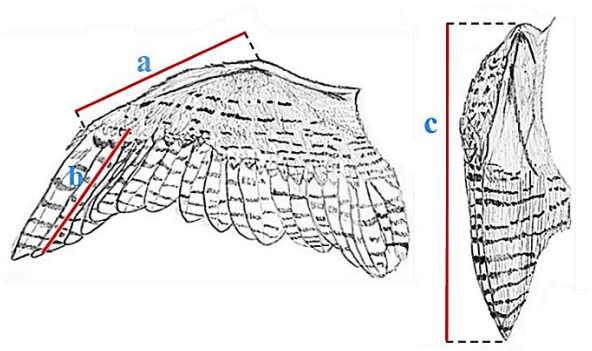

Figure 1 Illustration of bird wing measurement (Analla *et al*., 2022): a) forearm, b) length of the longest primary feather, c) wing length.

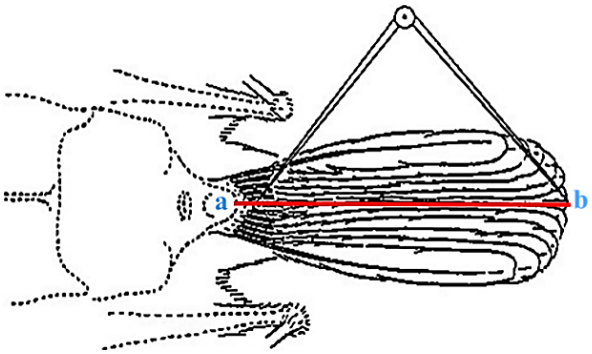

Figure 2 Illustration of tail feather measurement (Fitzpatrick, 2001); a) base of the feather emerging from the skin; b) tip of the longest tail feather.

Sex confirmation

Sex confirmation was carried out after the collection of morphometric data for all birds. Laparotomy was performed on all 32 dove samples to determine their sex. Each bird was euthanized by ventral neck decapitation, severing the trachea, esophagus, and both carotid arteries in a single incision. A postmortem abdominal incision was then made to expose the internal reproductive organs. The presence of testes confirmed male birds, while the presence of ovaries confirmed females. All carcasses and remaining tissues were disposed of by burial at a depth of 50 cm in accordance with ethical and biosecurity protocols.

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Data analysis

Morphometric data, including wing, wing feather, and tail feather measurements, were presented in tabular form. Differences between male and female birds were analyzed using an independent samples t-test with a significance level of 5% ($p < 0.05$). All statistical analyses were conducted using SPSS for Windows, version 28.

RESULTS

Laparotomy of 6-month-old Bangkok Zebra doves confirmed the presence of testes in males and ovaries with developing follicles in females (Figure 3).

Figure 3 Laparotomy findings in Bangkok Zebra doves: A) 3-month-old male (white arrow: testis), B) 6-month-old male (white arrow: pair of testes), C) 3-month-old female (white arrow: developing follicles), D) 3-month-old female (white arrow: ovary).

Wing length

Wing length was measured from the carpal joint (wrist or bent wing tip) to the tip of the longest primary feather. Morphometric comparisons of wing length between sexes at each age are presented in Table 1. Male Bangkok Zebra doves showed significantly greater average wing lengths than females at both 3 and 6 months of age ($p < 0.05$).

Table 1 Wing length (mm, mean ± SD) in Bangkok Zebra doves

	male	female
3 months	101.89 ± 1.59 [a]	94.46 ± 2.57 [b]
6 months	104.57 ± 0.52 [a]	99.82 ± 1.59 [b]

Different superscripts within the same row indicate significant differences ($p < 0.05$); wing measurements were taken after full extension.

Forearm length

Forearm length was measured in millimeters (mm) for both sexes at 3 and 6 months of age. No significant difference was found at 3 months ($p > 0.05$). However, at 6 months, males exhibited significantly longer forearms than females ($p < 0.05$), as shown in Table 2.

Table 2 Forearm length (mm, mean ± SD) in Bangkok Zebra doves

	male	female
3 months	32.78 ± 0.01	33.09 ± 1.09
6 months	37.46 ± 0.13 [a]	35.71 ± 0.92 [b]

Different superscripts within the same row indicate significant differences ($p < 0.05$); forearm length was measured after full extension

Length of the longest primary feather

The length of the longest primary feather was measured from the point of emergence from the skin to the feather tip (Ma *et al*., 2025). No significant difference was observed at 3 months ($p > 0.05$). At 6 months, however, males had significantly longer primary feathers than females ($p < 0.05$) (Table 3).

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Table 3 Length of the longest primary feather (mm, mean ± SD) in Bangkok Zebra doves

	male	female
3 months	79.48 ± 0.54 [a]	74.81 ± 2.64 [b]
6 months	86.00 ± 1.12 [a]	77.25 ± 3.15 [b]

Different superscripts within the same row indicate significant differences ($p < 0.05$).

Length of the longest tail feather

Tail feather length was measured from the base where the feather emerges from the skin to the tip, with the tail in a closed position (Fitzpatrick, 2001). As shown in Table 4, males exhibited significantly greater tail feather lengths than females at both 3 and 6 months ($p < 0.05$).

Table 4 Length of the longest tail feather (mm, mean ± SD) in Bangkok Zebra doves

	male	female
3 months	95.50 ± 0.53 [a]	89.63 ± 2.35 [b]
6 months	100.50 ± 0.56 [a]	94.13 ± 1.81 [b]

Different superscripts within the same row indicate significant differences ($p < 0.05$).

DISCUSSION

The measurements of wing length (wing chord), forearm length, the length of the longest primary feather (P8), and the length of the longest tail feather showed significant differences at 6 months of age. Conversely, at 3 months, only forearm length displayed no statistically significant difference. Morphometric variability in wing length can occur at specific times due to periodic molting at the tips of the primary feathers, which may reduce wing length by several millimeters in individual birds (Meissner *et al*., 2017). Therefore, this study was conducted during a period when the birds were not undergoing molting. Besides genetic factors and sex, growth in wing length is also influenced by hormones, habitat, and diet (Names *et al*., 2024; Dias *et al*., 2025). Since the Bangkok Zebra doves used in this study originated from the same farm, with identical habitat and feeding conditions, environmental influences on wing morphometrics are considered unlikely.

In many bird species, males typically possess brighter plumage, larger body size, longer wings, greater aggressiveness, and more persistent singing behavior. These traits are crucial during mate selection, as visual and vocal displays are used to attract partners; larger males often have higher success rates in mating (Amy *et al*., 2018). Longer wings can also provide advantages in physical contests among males, increasing their likelihood of winning fights (Fülöp *et al*., 2022). The activity of testosterone plays a vital role in growth and development; it influences spermatogenesis, physical appearance, and behavioral traits in males (Pikus *et al*., 2018). Males generally have higher testosterone levels, which stimulate the secretion of growth hormone (Møller *et al*., 2005). Elevated growth hormone levels promote faster growth, resulting in larger and more aggressive male birds (Soma *et al*., 2006; Yan *et al*., 2020). Even juvenile birds produce testosterone, although at lower levels than adults (Templeton *et al*., 2012; Varga and Juhász, 2019). Juveniles can be grouped based on behavioral characteristics (Freeland *et al*., 2025). Body size and sex influence feeding behavior and anti-predator responses, especially in juvenile birds (Nadal *et al*., 2018b).

The results of this study support the use of wing morphometry to determine the sex of Bangkok Zebra doves. Other research has shown that the sex of Eastern White-crowned Sparrows (*Zonotrichia leucophrys leucophrys*) can be accurately determined using wing band length. In male Eastern White-crowned Sparrows, the wing band length is longer than in females (Leys and Grieves, 2023). Henry *et al*. (2015) reported that male pale-winged starlings have longer tails and longer wings than females.

Wing morphology relates directly to flight style and behavior (Cabodevilla *et al*., 2018). Juvenile males with longer wings tend to survive longer and evade predators more effectively than females (Maness and Anderson, 2013). Longer wings facilitate better flight maneuverability and predator avoidance (Ruaux *et al*., 2020). Flight speed, energy expenditure, acceleration, agility,

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and energy efficiency are all affected by wing morphology. Shorter juvenile wings reduce flight efficacy, increasing mortality risk from predation (Cabodevilla *et al*., 2018).

Bangkok Zebra doves are ground-feeding species; during high-risk situations, such as predator attacks, acrobatic flight and perching behaviors are useful for evading threats. They often fly and perch on trees when disturbed (Tang and Schwarzkopf, 2013; Wee and Wang, 2008). The morphometric results in this study show that male Bangkok Zebra doves possess longer wings at both 3 and 6 months of age compared to females, with significant differences at both ages. These findings likely relate to the influence of testosterone and behavioral differences in males. The longer juvenile wings in males support the hypothesis that longer wings contribute to better predator evasion, aligning with previous findings that juvenile males are more capable of surviving predator attacks due to wing length (Maness and Anderson, 2013).

Bones and muscles grow more slowly and follow different growth patterns compared to feathers (Heers *et al*., 2018). Developing birds must gradually grow all their feathers before the development of other body parts. Juvenile muscles become sufficiently strong to support wing flapping when balanced with better-quality feathers (Heers *et al*., 2018). In this study, the morphometric measurement of forearm length in 6-month-old male Bangkok Zebra doves was longer than in females. A significant difference was observed at 6 months, whereas at 3 months, there was no significant morphometric difference in forearm length. The measurement results indicate that forearm length is not a reliable alternative method for sex determination in Bangkok Zebra doves at 3 months of age. This is related to the slower growth rate of bones compared to feathers (Heers *et al*., 2018). Since at 3 months, the Zebra doves are still in the developmental stage toward maturity.

The eighth primary feather (P8) is the longest primary feather on average in individual birds; therefore, this study refers specifically to P8 when discussing the longest primary feather. In addition to the influence of testosterone, numerous studies on bird feathers indicate that mate selection based on competitive ability and male aggressiveness supports the use of conspicuous signals in male plumage (Tang and Schwarzkopf, 2013). The length of the longest primary feather significantly contributes to flight performance (Terrill and Shultz, 2023). Both tail and wing feathers are flight feathers. Nearly all birds utilize flight feathers to escape predators. Male birds generally have longer primary feathers compared to females, as speed and maneuverability are affected by factors such as size, age, and sex. Birds employ their wings and legs to evade predators, and flight feathers, particularly wing feathers, enhance efficiency during predator evasion (Nadal *et al*., 2018a). The morphometric measurement of the longest primary feather (P8) shows that the length of this feather in male Bangkok Zebra doves is longer than in females at both 3 and 6 months of age. This disparity is likely related to higher testosterone levels in males, which results in longer wing feathers. According to Maness and Anderson (2013), juvenile males are better able to withstand predator attacks, making wing length a crucial factor in survival.

The central tail feather in Bangkok Zebra doves is the longest tail feather on average per individual, and thus, the study refers specifically to the central tail feather when discussing the longest tail feather. Beyond the influence of testosterone, longer tails confer advantages over shorter tails, primarily in maneuverability. Longer tails significantly improve flight control during escape from predators (Mueller *et al*., 2002). Rectrices (tail feathers) generally serve functions related to balance and lift during flight, acting as steering mechanisms to guide and stabilize birds while flying and functioning as brakes during landing (Pittman *et al*., 2013). The length of the tail feathers in male Bangkok Zebra doves is longer than in females at both 3 and 6 months of age. The significant differences at both ages are associated with elevated testosterone levels in males, which result in longer tail feathers. According to Maness and Anderson (2013), juvenile males are more capable of surviving predator attacks, and thus, longer tail

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feathers are highly advantageous in survival scenarios.

This study used Zebra doves from breeders, thus providing the same care and nutritional intake. The type, quantity and quality of nutrition a bird receives influence its wing and feather tail growth (Catfolis *et al*., 2023). Birds in their wild habitat eat from sources food ingredients available in nature (Hološková *et al*., 2023). Meanwhile, the bird food in the wild is greatly influenced by the season (Liukkonen *et al*., 2024). Therefore, the applicability of this study's findings is limited to captive-bred Bangkok Zebra doves. Further research is needed to assess their applicability to wild Zebra doves.

CONCLUSION

Based on the findings of this study, it can be concluded that wing morphometric parameters—specifically wing length and forearm length—can be used for sex determination in Bangkok Zebra doves (*Geopelia striata*) at 6 months of age. At 3 months of age, only wing length proved to be a reliable morphometric indicator for sex classification. Furthermore, wing feather morphometrics were effective in distinguishing between sexes at both 3 and 6 months. Similarly, tail feather morphometrics were also found to be reliable for sex determination at both ages.

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AUTHOR CONTRIBUTIONS

Kamilah Nurizza (KN), Yeni Dhamayanti (YD), Epy Muhammad Luqman (EML), Gracia Angelina Hendarti (GAH), Boedi Setiawan (BS), Soeharsono Soeharsono (SS).

KN, YD: conceived the idea, designed the mainframe of this manuscript, and manuscript drafting, KN: acquisition data, YD: analysis and interpretation of data, EML, GAH, BS, SS: critically read and revised the manuscript for intellectual content. All authors read and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

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