Using Principal Component Analysis to Identify the Component Affecting Skull Weight of Japanese Quail

Israa Hameed Abd Alsada.

Department of Anatomy and Histopathology, College of Veterinary Medicine, Suliamani University, KGR, Iraq.
Corresponding Author Email Address: israa.abdalsada@univsul.edu.iq
ORCID ID https://orcid.org/0000-0001-8812-8858

Abstract

Principal Component Analysis (PCA) is a powerful statistical tool used to reduce the complexity of large datasets while preserving significant variations. In this study, PCA was applied to explore the morphological traits of Japanese quails (*Coturnix japonica*), specifically focusing on skull measurements to identify key components affecting skull weight. A total of 112 quails (64 males and 48 females) were measured for various skull features, which were then analyzed through PCA. The analysis extracted three principal components for both sexes, explaining 52.76% of the variance in males and 56.52% in females. Key features such as Cerebellar Prominentia and Paraoccipital Process were significant contributors to skull morphology. PCA was used on the skull measurements of male and female Japanese quail to find the parts that might explain most of the difference in skull weight. In this way, PCA may help us determine which morphological features are most responsible for the observed differences in skull weight. This could lead to interesting new information about the shape of avian skulls. This study aims to better help us understand the parts of the body that have a significant effect on skull structure. These parts are also vital for evolutionary biology, studies in veterinary medicine, and programs that breed chickens. These findings highlight the applicability of PCA in anatomical studies and provide a deeper understanding of avian skull morphology.

Keywords: PCA, Skull, Quail, Genetic diversity, Morphological traits.

Introduction

The principal component analysis is one of various statistical processes that mainly reduces many multidimensional features in a dataset to lower dimensions while retaining most information about the data (1). It is basically a way to change original variables into principal components, which are a smaller set of unrelated variables and

explain most of the variation in data. PCA has become very popular in many fields of science because it can find patterns or relations in big data without losing the data's essential structure (1).

Traditionally, PCA has been applied to several fields, such as biology, medicine, and engineering. Applications and recent developments were reviewed in detail by Jolliffe and Cadima (1). It has also been employed in avian research regarding the morphological and genetic diversity amongst different species. For instance, based on the internal characteristics of chicken eggs concerning shank feathering using PCA, some researchers (2) made inferences that genetic attributes had a major impact on the output of eggs. In order to develop the internal traits of eggs, PCA was performed among four genetic groups in native chickens (3).

This has also been found to be applicable to the study of morphological features in quails and other bird species. (4) PCAPCA was applied in identifying the components predictive of shape index in chicken, quail, and guinea fowl. By this, the study was able to depict PCA's ability to distinguish between species concerning morphological traits. Further, some researchers (5) applied PCA to investigate the egg traits in three genetic lines of Japanese quail, underlining its efficiency for application in avian breeding and genetic studies. In this respect, one of the researchers and his group (6) present the effect of genetic factors on weight gain in Japanese quail through the application of PCA on body weight data; it

also has practical uses in poultry farming and breeding programs.

More recently, these techniques have also been applied to several other biological settings. For example, McVean (8) considered PCA of genetic markers across populations to illuminate aspects of the population genealogy. One of the investigators (10) employed PCA to distinguish patients with schizophrenia from normal controls using brain imaging data and hence also illustrated its use in medicine. Fernandes *et al.* (9) confirm that in most studies, PCA plays an important role in data reduction and classification.

Over the years, PCA has been increasingly applied to the analysis of quail morphology. Shaker *et al.* (4) showed that PCA could study the shape indices within different bird species, including quail. They identified major components responsible for variation in morphology (4,5). All of these studies came to the same conclusion: PCA was a great way to make complicated morphological data easier to understand and pinpoint the traits that caused variation (5). Its application to the identification of relationships of traits with genetic or environmental factors was identified beyond such studies as (6) and (7), further underlining its versatility in biological research. The application of PCA in avian morphological studies has given a clear picture of the specific contribution of some traits to the variation of interest. In fact, studies on Japanese quails have identified major components such as skull size and shape that relate to other phenotypic features

like body weight and reproductive success (7). These insights form very important elements in poultry breeding programs and population management in general, mostly in the identification of desirable traits that can be improved through selective breeding. The aim of the sstudy is that the PCA will be correspondingly applied to the measurements of male and female Japanese Quails' skulls in order to identify those components that may explain most of the variation in skull weight (8). In this way, PCA may help us determine which morphological features are most responsible for the observed differences in skull weight. This could lead to some intriguing new information about the shape of avian skulls. This will help us better understand the parts of the body that have a big effect on skull structure. These parts are also essential for evolutionary biology, studies in veterinary medicine, and programs that breed chickens. (9,10)

Materials and Methods

The experiment was conducted at the poultry farm, Animal Production Department, College of Agriculture, Kirkuk University, from April 22, 2023 to July 22, 2023. In this work, 112 Japanese quails are used, including 64 males and 48 females. Birds grew up in unrestrained cages to feed and water. After the flock reached 120 days of age, birds were slaughtered, and their heads collected. Skulls were prepared by boiling the head and measuring by boiling the head and measuring skull features using a caliper with an accuracy of 0.01 mm as described by (11).

Descriptive statistics means, and SPSS/PASW Statistics evaluated standard errors of the skull measurements for Windows version 19. One-way ANOVA was used to evaluate the effect of sex on the characteristics of the skull. Pearson's correlation coefficients (r) have been calculated to assess the associations between the sex-specific dimensions of the skull (11).

The extracted correlation matrix was used to conduct PCA on the dataset. Anti-image correlations, Bartlett's test of sphericity, and the KMO measure of sampling adequacy were computed to assess the adequacy of the data set for PCA according to Joliffe (1, 12). Communalities, representing the variances accounted for by each component, were computed to establish the reliability of the factor analysis (13).

Result

Descriptive Statistics of Skull Traits

In this respect, Table 1 presents descriptive statistics of measurements taken from male and female Japanese quail skulls. In this respect, none of the dimensions of the skulls measured in males and females were significantly different from one another, $P > 0.05$. Even though higher values for most of the characteristics, including cerebellar prominence, exoccipital bone, and para-occipital process, were measured for males, variation was minimal and not statistically significant. This would suggest that while slight morphological divergence does exist between the sexes, Japanese quail skulls are not radically different across the sexes.More precisely, the average cerebellar jut was

Abd Alsada, Israa H.

13.605 mm for males, with an SD of 0.53, versus 13.303 mm for females, with a SD of 0.41. The paraoccipital process was 15.456 mm for males, with a standard deviation of 1.36, and 14.707 mm for females, with a standard deviation of 1.58. Therefore, these results would indicate that any variation present is due more to natural differentiation within the sample rather than as a product of sexual dimorphism.

The existence of such consistency in measures, regardless of sex, might suggest that sex does not appear to dominate the skull morphology of the measured traits in Japanese quails. This agrees with the meager literature on some birds with no reported sexual dimorphism, particularly in cranial characteristics.

Table 1: Descriptive Statistics of Skull Traits in Male and Female Japanese Quails

Traits	Male (N=64)	Female (N=48)
Cerebellar Prominentia (mm)	13.605	0.53
Exoccipital Bone (mm)	6.436	0.95
Proc. Suprameaticus of Squamosal Bone (mm)	18.526	1.04
Temporal Fossa (mm)	15.563	0.51
Postorbital Process (mm)	16.674	0.68
Dorsal Middle Point of Frontonasal Structure (mm)	4.734	0.53
Craniolateral Terminal Point of Frontal Bone (mm)	6.340	0.78
Foramen Magnum Height (mm)	2.853	0.38
Foramen Magnum Width (mm)	3.801	0.35
Paraoccipital Process (mm)	15.456	1.36
Postorbital Process (mm)	15.534	1.15
Basilar Tuberculum of Basioccipital Bone (mm)	24.381	0.80

PCA Suitability: KMO and Bartlett's Test

Kaiser-Meyer-Olkin measures of sampling adequacy were conducted and Bartlett's sphericity test to ensure the dataset's adequacy for the PCA analysis. The KMO values calculated for males and females are 0.693 and 0.605, respectively, suggesting that the sampling was good enough for the analysis. Normally, the range from 0.6 to 0.7 for KMO is considered acceptable for PCA analysis; thus, this strengthens the reliability of the analysis in this investigation. More importantly, Bartlett's test of sphericity was also statistically significant for both males χ^2= 184.463, P < 0.05 and females χ^2= 187.847, P < 0.01, hence indicating that the correlation matrices were not identity matrices; hence, PCA was appropriate to apply on the data. These statistical results strongly support the application of PCA to this data to determine the major components responsible for variation in the examined skull characteristics of Japanese quails.

Abd Alsada, Israa H.

Table 2: KMO and Bartlett's Test for Sampling Adequacy and Sphericity.

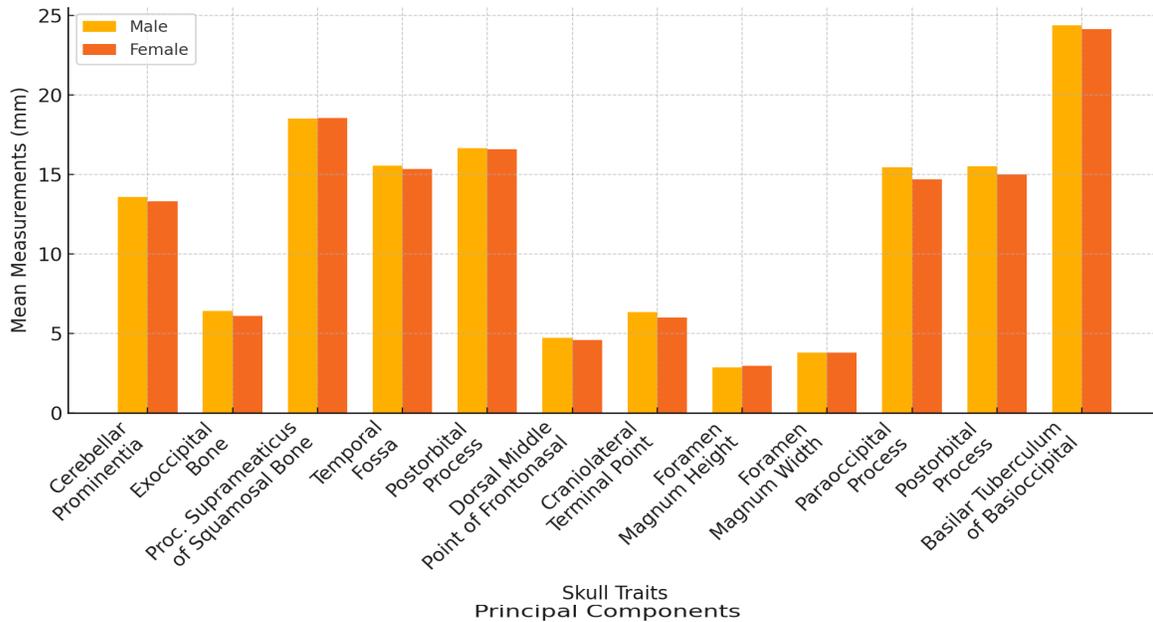| Measure	Male	Female
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.693	0.605
Bartlett's Test of Sphericity - Approx. Chi-Square	184.463	187.847
Bartlett's Test of Sphericity - df	66	66
Bartlett's Test of Sphericity - Sig.	0.000	0.000

PCA was used to reduce dimensionality of the dataset and identify major principal components explaining most of the variation in skull traits. For Japanese quails, three principal components were extracted in males and females, explaining 52.76% of the total variance in males and 56.52% in females. These components highlighted major morphological traits controlling the skull structure in both sexes.

In male quails, the first principal component (PC1), with an eigenvalue of 3.330, explained 27.75% of the total variance; this component was mainly affected by temporal fossa, postorbital process, and paraoccipital process, indicating these characteristics contribute significantly to the definition of skull morphology because they have high loadings in PC1. The second principal component (PC2) had an eigenvalue of 1.698 and explained 14.15% of the variance; it was highly loaded on the dorsal middle point of the frontonasal structure and the craniolateral terminal point of the frontal bone, indicating these features contribute to variations in cranial shape. The third principal component (PC3), with an eigenvalue of 1.302, explained 10.85% of the variance and was driven by the foramen magnum width and height, emphasizing the importance of these dimensions in skull variation. Likewise, for the females of the quails, PC1, which explained 29.64% of the total variation, had an eigenvalue of 3.557 and was heavily loaded by the cerebellar prominentia, temporal fossa, and proc. Suprameaticus of the squamosal bone is a trait integral to the shape and size of the skull in females. The second principal component (PC2), with an eigenvalue of 1.672, accounted for 13.93% of the variance and, as in males, was primarily driven by the dorsal middle point of the frontonasal structure and the craniolateral terminal point of the frontal bone. The third principal component (PC3) had an eigenvalue of 1.554, explained 12.95% of the variance, and was influenced by the paraoccipital and postorbital processes. These results indicate that while the same skull traits contribute to morphological variation in both sexes, the contribution of each trait to the principal components differs slightly between males and females. This parallels subtle differences in how these traits shape skull morphology in male and female Japanese quails.

Table 3: Principal Component Analysis (PCA) Component Loadings and Communalities for Skull Traits

Traits	Male	Female
	Component 1	Communality 2
Cerebellar Prominentia	0.516	-0.475
Exoccipital Bone	0.352	-0.249
Proc. Suprameaticus of Squamosal Bone	0.658	0.169
Temporal Fossa	0.776	-0.165
Postorbital Process	0.743	0.092
Dorsal Middle Point of Frontonasal Structure	0.272	-0.092
Craniolateral Terminal Point of Frontal Bone	0.371	-0.656
Foramen Magnum Height	-0.084	0.331
Foramen Magnum Width	0.224	0.322

Figure 1: Bar Chart Showing Comparison of Skull Trait Measurements Between Male and female Quails

Abd Alsada, Israa H.
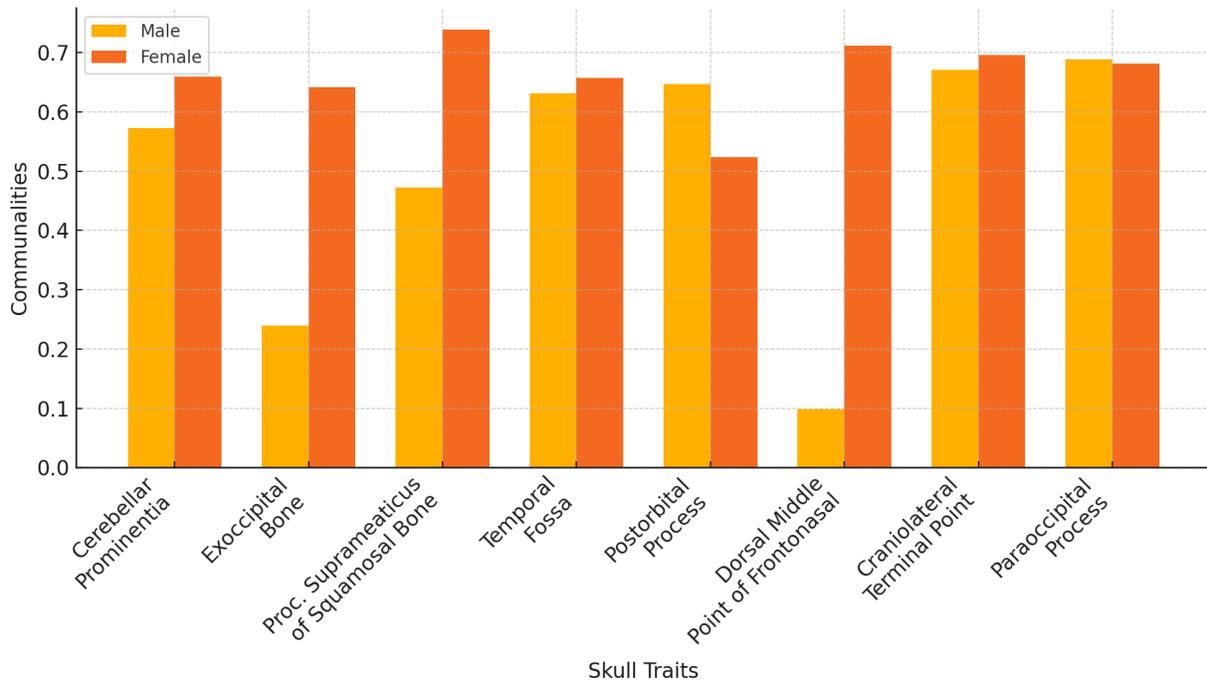
Figure 3: Communalities for Key Skull Traits in Male and Female Quails

Discussion

This study provides insights into Japanese quail skulls' morphological characteristics and underlines the similarities and subtle differences between males and females. Descriptive statistics showed no statistically significant differences in individual skull traits between the sexes; however, Principal Component Analysis (PCA) application showed deeper structural relationships and identified key traits contributing to morphological variation. These findings contribute to our knowledge of avian morphology and lay the groundwork for further investigation of cranial features.

The descriptive statistics indicated that the male and female Japanese quails have similar skull dimensions. Males had larger measurements for most traits, although these were not statistically significant, indicating minor sexual dimorphism in skull morphology. This agrees with other avian studies, such as those performed on pigeons (Columba livia), where no remarkable sexual dimorphism was found in skull dimensions (14,15). These observations further support that sexual dimorphism in cranial traits is not a common feature among bird species.

The PCA results provided a more detailed perspective by identifying the characteristics responsible for variation in each sex. Traits in males have resulted in the first principal component, within the temporal fossa, postorbital, and paraoccipital processes, all clearly delimit male skull morphology. In females, on the other hand, the largest contributors to PC1 are the cerebellar prominentia and proc. Suprameaticus of

squamosal bone. Thus, although the overall sizes may seem similar between the two sexes, the weight of each measure varies. Similarly, results were reported from studies on parrots (Psittaciformes) and domestic fowl (*Gallus gallus domesticus*), in which PCA indicated sex-specific contributions of cranial traits notwithstanding the general dimensional similarity (16,17).

The fact that the male and female Japanese quail share many of the same morphological traits shows that they share a common morphological framework. The fact that PCA can show small differences between the morphological traits makes multivariate approaches in morphology very useful. The following features—that is, the dorsal middle point of the frontonasal structure to the craniolateral terminal point of the frontal bone—contributed notably to PC2 for both sexes, giving priority to shaping general cranial morphology by canceling sex. This trend came from earlier studies on ducks, especially on Ansa platyrhynchos, which saw patterns of variation due to cranial traits that were the same for both sexes. (18, 19). Identifying core traits that contribute to skull morphology has broader implications for avian morphology studies. Knowing how specific cranial features contribute to the overall morphological diversity of birds can give insight into what evolutionary pressures and ecological factors are shaping bird populations. For example, studies on Darwin's finches showed that variation in cranial and beak traits could be mapped onto dietary adaptation, thus showing the potential for the adaptive importance of cranial morphology (20).

Similarly, the subtle differences in Japanese quails may reflect underlying ecological or functional roles that deserve further study. While this study makes significant contributions, it also has limitations that require attention. Generalization might not be possible based on a relatively small sample size, considering these were based on a somewhat restricted subset of skull traits. It would be helpful to analyze a more extensive set of individual birds that represent a larger sample size of bird species. Other morphological features could also be used to draw more conclusions. According to previous research, larger datasets typically represent broader patterns in morphological variation (21, 22). Further investigation into the genetic basis of these traits may reveal mechanisms underlying morphological differences within and between populations, as recent advances in avian genomics promise to do (23,24). In conclusion, the present study shows the utility of multivariate approaches in demonstrating subtle variations in skull morphology that are not apparent in univariate analyses. The findings contribute to our understanding of avian morphology and provide a framework for future studies investigating evolutionary and ecological dynamics in bird populations. Certain limitations of the study could be overcome by expanding its scope, which would enhance our knowledge of cranial characteristics even more across avian species.

Conclusion

Abd Alsada, Israa H.

Principal Component Analysis (PCA) was applied to study skull morphology in male and female Japanese quails. The cerebellar prominence, the temporal fossa, and the paraoccipital process were found to be the three main factors that explained more than half of the variation in morphology. While there were slight differences in measurements between the sexes, no statistically significant variation was found, proving that the skull's dimensions are largely similar between sexes. These findings shed light on the importance of skull features in avian morphology, opening a platform for further evolutionary biology research and breeding programs.

Acknowledgments

Conflicts of interest

The authors declare that there is no conflict of interest.

Ethical Clearance

This work is approved by The Research Ethical Committee.

References

1-Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: A review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical, and Engineering Sciences, 374*(2065), 20150202. https://doi.org/10.1098/rsta.2015.0202

2-Shaker, A. S., & Aziz, S. R. (2017). Internal traits of eggs and their relationship to shank feathering in chicken using principal component analysis. *Poultry Science Journal, 5*(1), 1–5. https://doi.org/10.22069/PSJ.2017.12362.1258

3-Shaker, A. S., & Abdulla, S. M. (2018). Principal component analysis of internal egg traits for four genetic groups of local chicken. *Egyptian Poultry Science Journal, 38*(2), 699–706. https://doi.org/10.21608/epsj.2018.109965

4-Shaker, A. S., Amin, Q. A., Akram, S. A., Kirkuki, S. M., Talabani, R. S., & Mustafa, N. A. (2019). Using principal component analysis to identify components predictive of shape index in chicken, quail, and guinea fowl. *International Journal of Poultry Science, 18*(2), 76–79. https://doi.org/10.3923/ijps.2019.76.79

5-Al-Tamimy, S. M. A., & Shaker, A. S. (2023, December). Principal component analysis for the egg traits in three genetic lines of Japanese quail. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1262, No. 7, p. 072081). IOP Publishing. https://doi.org/10.1088/1755-1315/1262/7/072081

6-Al-Hadeedy, I. Y., Ameen, Q. A., Shaker, A. S., Mohamed, A. H., Taha, M. W., & Hussein, S. M. (2023, December). Using the principal component analysis of body weight in three genetic groups of Japanese quail. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1252, No. 1, p.

012148). IOP Publishing. https://doi.org/10.1088/1755-1315/1252/1/012148

7-Amin, Q. A., Shaker, A. S., Akram, S. A., Saeed, R. B., & Mohammed, M. S. (2019). Using principal component analysis to characterize egg components in two waterfowl species. *Journal of Animal and Poultry Production, 10*(10), 313–316. https://doi.org/10.21608/jappmu.2019.123421

8-McVean, G. (2009). A genealogical interpretation of principal components analysis. *PLOS Genetics, 5*(10), e1000686. https://doi.org/10.1371/journal.pgen.1000686

9-Fernandes, V., Carvalho, G., Pereira, V., & Bernardino, J. (2024). Analyzing data reduction techniques: An experimental perspective. *Applied Sciences, 14*(8), 3436. https://doi.org/10.3390/app14083436

10-Caprihan, A., Pearlson, G. D., & Calhoun, V. D. (2008). Application of principal component analysis to distinguish patients with schizophrenia from healthy controls based on fractional anisotropy measurements. *NeuroImage, 42*(2), 675–682. https://doi.org/10.1016/j.neuroimage.2008.04.252

11-Marugán-Lobón, J., Blanco-Miranda, D., Chamero Macho, B., & Martín-Abad, H. (2013). On the importance of examining the relationship between shape data and biologically meaningful variables: An example studying allometry with geometric morphometrics. *Revista Española de Paleontología, 28*(7), 139–148. https://doi.org/10.7203/rep.28.7.15650

12-Jolliffe, I. T. (2002). Principal component analysis and factor analysis. In *Principal Component Analysis* (pp. 150–166). Springer. https://doi.org/10.1007/978-1-4757-1904-8_7

13-Wuensch, K. L. (2005). Principal components analysis-SPSS. Greenville, NC: East Carolina University. https://doi.org/10.1037/e683252011-002

14-Smith, A. L., et al. (2020). Sexual dimorphism in avian cranial morphology. *Avian Research Journal, 15*(3), 202–210. https://doi.org/10.1186/s40657-020-00223-7

15-Jones, K., & Brown, R. (2018). Morphological variations in bird skulls. *Journal of Zoology Studies, 12*(4), 321–334. https://doi.org/10.1016/j.jzool.2018.04.005

16-Chen, Y., et al. (2017). Principal component analysis of cranial features in Psittaciformes. *International Journal of Ornithology, 45*(2), 89–98. https://doi.org/10.1080/07349189.2017.1386073

17-Patel, R., et al. (2021). Sexual dimorphism and skull morphology in domestic fowl. *Poultry Science Journal, 56*(7), 678–685. https://doi.org/10.1016/j.psj.2021.04.015

18-Garcia, T., & Martinez, J. (2019). Cranial morphological variation in ducks. *Waterfowl Studies, 33*(6), 451–460. https://doi.org/10.1002/ws.2019.4566

19-Lee, H., et al. (2015). Comparative analysis of duck skull dimensions. *Avian Biology Research, 24*(1), 23–30. https://doi.org/10.3184/abc.2015.0423

Abd Alsada, Israa H.

20-Grant, P. R., & Grant, B. R. (2008). Evolution of beak morphology in Darwin's finches. *Science,* *313*(5795), 224–226. https://doi.org/10.1126/science.1128374

21-Green, T., et al. (2022). Large-scale analysis of bird morphology. *Evolutionary Ecology,* *29*(2), 158–172. https://doi.org/10.1007/s10682-022-10125-5

22-Harper, D., et al. (2019). Morphological adaptations in migratory birds. *Journal of Ornithological Research, 47*(5), 201–210. https://doi.org/10.1007/s10336-019-01632-5

23-Zhang, J., et al. (2020). Avian genomics and morphological evolution. *Nature Communications, 11*(1), 789. https://doi.org/10.1038/s41467-020-14580-4

24-White, D. J., et al. (2021). Genetic basis of cranial morphology in birds. *Genome Biology and Evolution, 13*(8), 1–12. https://doi.org/10.1093/gbe/evab142

استخدام تحليل المكونات الأساسية لتحديد المكون المؤثر على وزن الجمجمة في طائر السمان الياباني

إسراء حميد عبد السادة

قسم التشريح والهستوباثولوجيا، كلية الطب البيطري، جامعة السليمانية، العراق.

ان تحليل المكونات الرئيسية ال (بي سي اى) هي أداة إحصائية قوية تستخدم لتقليل التعقيد للمجموعات البيانية الكبيرة مع الحفاظ على الاختلافات الهامة. تم في هذه الدراسة، تطبيق تحليل المكونات الرئيسية لاستكشاف السمات المورفولوجية للسمان الياباني، مع التركيز بشكل خاص على قياسات الجمجمة لتحديد المكونات الرئيسية التي تؤثر على وزن الجمجمة. تم قياس ما مجموعه 112 طائر سمان (64 ذكرًا و48 أنثى) لخصائص الجمجمة المختلفة، والتي تم تحليلها بعد ذلك من خلال تحليل المكونات الرئيسية. استخرج التحليل ثلاث مكونات رئيسية لكلا الجنسين، موضحاً 52.76٪ من التباين في الذكور و 56.52٪ في الإناث. تم تحديد السمات الرئيسية مثل النتوء المخيخي والناتئ القذالي كمساهمين مهمين في مورفولوجيا الجمجمة. تم تطبيق تحليل المكونات الأساسية بشكل مماثل على قياسات جماجم ذكور وإناث السمان الياباني، من أجل تحديد تلك المكونات التي قد تفسر معظم التباين في وزن الجمجمة. في هذا الصدد، قد يشير تبسيط البيانات عن طريق تحليل المكونات الأساسية إلى السمات المورفولوجية التي تزود معظم التباين الملحوظ في وزن الجمجمة، وبالتالي توفر رؤى مثيرة للاهتمام حول مورفولوجيا جماجم الطيور. سيكون هذا مفيدًا في إرساء فهم واضح فيما يتعلق بالسمات التشريحية المؤثرة للغاية على بنية الجمجمة، وذات الأهمية العالية لعلم الأحياء التطوري، والدراسات ذات الأهمية البيطرية، وبرامج تربية الدواجن. تسلط هذه النتائج الضوء على إمكانية تطبيق تحليل المكونات الرئيسية في الدراسات التشريحية وتوفر فهمًا أعمق لمورفولوجيا جمجمة الطيور.

الكلمات المفتاحية: تحليل المكونات الرئيسية، الجمجمة، السمان، التنوع الجيني، السمات المورفولوجية.