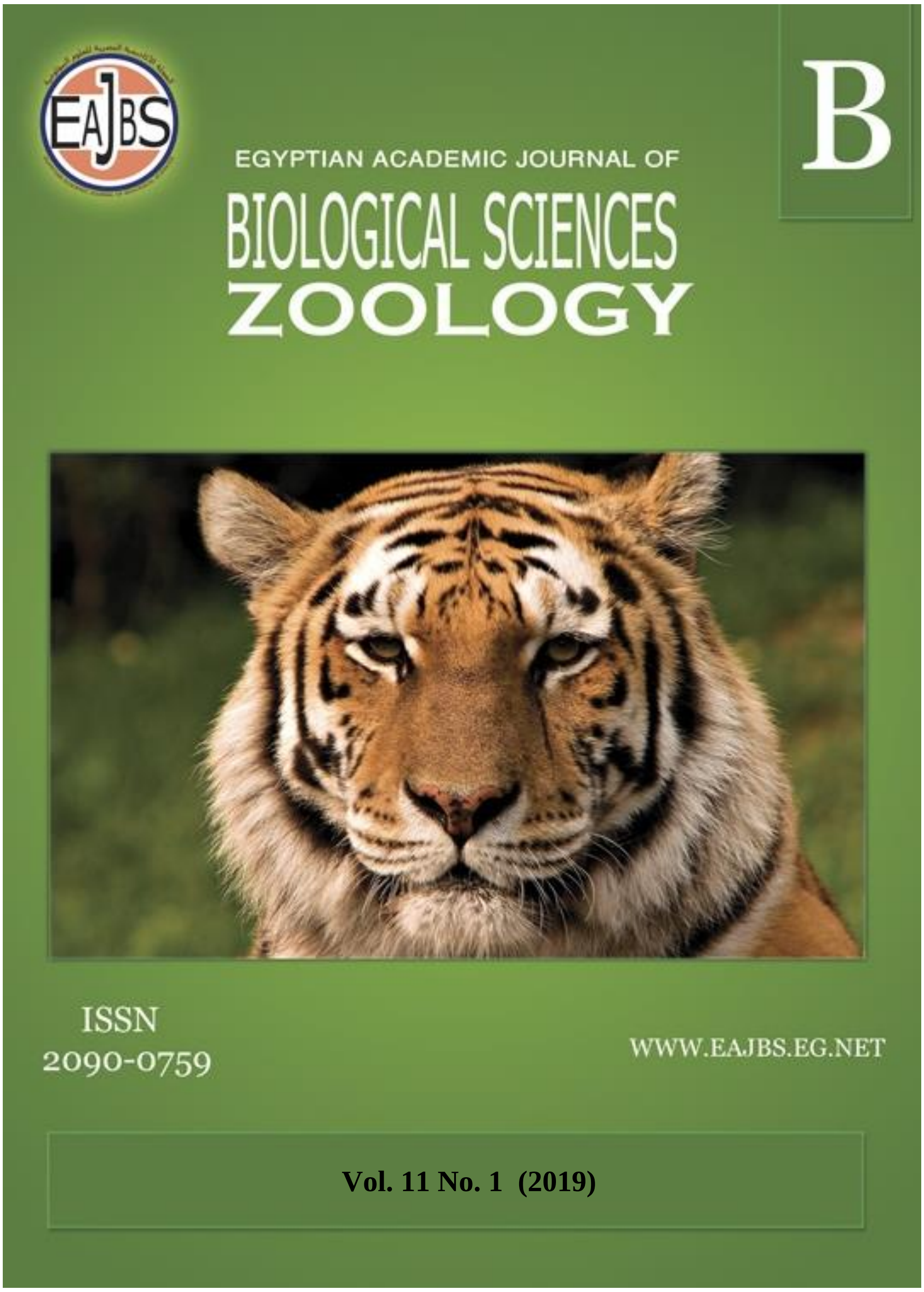

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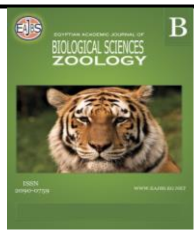

Comparative Morphometric Studies of the Cranium in the Three Types of Birds with Different Feeding Behaviors

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Kingfisher, Hoopoes, carnivorous, insectivore, Skull.

ABSTRACT

The present work was particularly designed to study the comparative anatomy of the skull of three different feeding Aves species inhibiting in Egypt. This study demonstrates that both size and shape are important components in the morphological differentiation of the skulls of carnivorous Kingfisher (*Halcyon smyrnensis*), insectivore Hoopoes (*Upupa epops*) and Omnivores Chicken (*Gallus gallus domesticus*) which clarify the relationship between size, shape of the skull and the type of feeding behavior. This paper presents a morphometric analysis of Kingfisher, Hoopoes and chicken skulls. Analyses are performed using traditional analytic and morphometric methods.

INTRODUCTION

All birds are adapted to their different environments with respect to food resources. Reflecting their different life styles, birds have different feeding behavior, with corresponding differences in the size and skull structure. The skeleton is important to zoologists and paleontologists for phylogenetic and taxonomic reasons. It is also important to veterinarians for economic reasons since skeletal disorders cause financial loss to the poultry industry (Suzer *et al.*, 2018). Birds possess one of the most highly specialized skulls among the living vertebrates (Bahadır, 2002; Suzer *et al.*, 2018). The avian skull is structurally and functionally composed of the rostrum, the orbits and the braincase (Morugán-Lobón and Buscalioni, 2006). The most distinctive feature of the avian skulls is that they have several shapes and variable dimensions (Zusi, 1993). Various studies have been carried out on the avian skull morphology. Some of these studies have been performed on different avian species, such as penguins (Acosta, 2009;Acosta and Tambussi, 2006) skuas (Acosta *et al.*, 2009) and Tinamidae (Degrange and Picasso, 2010) and some of them have been fulfilled using geometric morphometric methods (Acosta, 2009; Acosta and Tambussi, 2006; Degrange and Picasso, 2010; Morugán-Lobón and Buscalioni, 2006). In another study, the characteristics of the neurocranial shape variations of birds have been examined by using the advanced graphical imaging method (Morugán-Lobón and Buscalioni, 2009). The geometric, morphometric analysis on avian anatomy is rare (Degrange and

Picasso, 2010) and its use in morphological studies of birds is not common (Morugán-Lobón and Buscalioni, 2006).

Morphometrics are any quantitative analysis of morphological form, size and/or shape (Rohlf and Marcus, 1993; Webster and Sheets, 2010). There are three types of morphometric analyses: 1, traditional morphometrics use linear measurements along with multivariate statistics to compare shapes (Marcus, 1990; Webster and Sheets 2010), 2, geometric morphometric uses landmark configurations to summarize shape variations, and, 3, morphometric analysis is frequently used in biology to describe organisms (Gunduz *et al.*, 2007).

Therefore, the aim of the study is to evaluate the measurements of the skulls of Kingfisher, Hoopoes and Chicken to illustrate the adaptations of these species to their feeding habitats.

MATERIALS AND METHODS

Animals:

A total of 30 Healthy adult alive specimens, 10 samples of **White-throated kingfishers** have collected from their natural environments Nile delta; On the other hand, 10 samples of **Hoopoe** were collected from Abu-Rawash district near Giza governorate. While 10 samples of home **chicken** were collected from Egyptian Aldeshnawy Farms Service Center. These specimens were trapped alive from the previously mentioned areas. In the laboratory, the specimens were anesthetized with chloroform.

The skulls of the specimens were prepared by maceration and then were left in the sunlight to bleach; otherwise, some specimens were prepared by using NaOH (2-5%) and then were placed in hydrogen peroxide for 24 hours. The photographs of the skull were taken in various aspects to the skull under observation.

The skull measurement points were determined to identify the characteristics of the anatomical structure of birds skulls according to Pearson, 1901; Schmitt, 1966; Gusselkoo *et al.*, 2001; Hall *et al.*, 2009; Onar, 1999; Ino *et al.*, 2008. and Singh *et al.* 2015. Specified measurement points were named according to Nomina Anatomica Avium (NAA) (Baumell *et al.*, 1993).

Statistical Analysis:

Statistical analyses were performed with statistical software SPSS (SPSS, Version 23.0; Chicago, IL). Data were tested for normality distribution and variance homogeneity assumptions. Data were stated as mean±standard error of the mean

RESULTS

Morphological Studies:

The present study describes the skull followed from the caudal (Occipital), dorsal, lateral and ventral views, and data summarize at the Table (1).

The skull of Kingfishers (*Halcyon smyrnensis*):

Dorsal View (Fig 1A):

From the dorsal view according to the table number1, the present study measured and observed that the Jugal maximum distance (JMD) ranges between 26.3 – 28.1 mm with an average 27.33 ±0.53 of the total length of the skull. Inter orbital conscription (IOC) measures 9-10 mm (average 9.58±0.38). Nasal-hinge width (NHW) attains 11–13.3 mm (average 12.45±0.71) of the skull length. Premaxillar processes width (PMPW) measures 4.9–5.9 mm (average 5.52±0.32). Supraciliar process (SCP) attains 7.6 – 9.6 % (average 8.54±0.73).

Lateral View (Fig 1B):

From the lateral view, the skull length (SL) measured 89.7–94 mm (average 91.92±1.40). Bill (beak) length (BL) ranges between 60.7– 66.5 mm with an average 63.03± 2.38 of the total length of the skull. Orbito quadrate process (OQP) measures 9.9–13.4 mm (average 11.54±1.19).

Ventral View (Fig 1C):

From the ventral view, Basi temporal width (BTW) were measure and attains 7.2– 9.1 mm (average 0.64±0.67) of the skull length width. Intra pterygoid distance (IPD) measures 10.2–14 mm (average 12.19±1.08). Furthermore, Bill (beak) width (BW) of Kingfishers (*Halcyon smyrnensis*) measures 16.1–18.8 mm (average 17.5±0.91).

Occipital View (Fig 1D):

From the occipital view, all four components of the occipital bones surrounded the foramen magnum. A single occipital condyle is present at the posterior end of the skull, Furthermore, Postorbital processes distance (POD) ranges were measured and recorded between 21.9 – 23.1 mm with an average (22.77±0.56) of the total width of the skull.Temporal width (TW) measures 16.7– 18 mm (average 17.49±0.49). Skull width (SW) attains 20.6– 22.6 mm (average 21.81±0.61) of the skull length (SL). Skull height (SH) measures 16.5–19.1 mm (average17.87±0.95). Foramen magnum height (FMH) measures 3.8– 4.1 mm (average 3.89±0.09) of the total diameter of Foramen magnum. Foramen magnum width (FMW) represents 4.1–4.9 mm (average 4.48±0.27) of the total diameter of Foramen magnum.

Table (1): Summarize the morphometric characters skull of *H. smyrnensis, Upupa epops*, and *G. gallus*. Mean±SD

No.	character	*H. smyrnensis*	*Upupa epops*	*G. gallus*
1	JMD	27.33±0.53	17.78±0.36	30.29 ± 2.44
2	IOC	9.58±0.38	10.8±0.42	14.6± 2.27
3	NHW	12.45±0.71	13.16±0.94	12.88 ± 1.06
4	PMPW	5.52±0.32	2.6±0.23	2.42 ± 0.31
5	SCP	8.54±0.73	6.04±0.23	11.59 ± 1.74
6	SL	91.92±1.40	83.27±3.05	68.37 ± 4.49
7	BL	63.03±2.38	60.57±1.65	31.99 ± 4.49
8	OQP	11.54±1.19	6.62±0.41	11.29 ± 0.85
9	BTW	8.41±0.67	6.47±0.64	13.11 ±0.88
10	IPD	12.19±1.08	12.68±0.77	18.76 ±1.57
11	BW	17.5±0.91	10.42±1.12	11.36 ±2.38
12	POD	22.77±0.56	17.68±0.49	27.26 ±2.11
13	TW	17.49±0.49	16.3±0.32	22.24±1.91
14	SW	21.81±0.61	16.89±0.47	22.54 ±3.49
15	SH	17.87±0.95	14.88±0.17	22.17 ±0.47
16	FMH	3.89±0.09	3.94±0.25	6.41 ±0.49
17	FMW	4.48±0.27	4.51±0.27	7.46 ±0.55

The skull of Hoopoe (*Upupa epops*):

Dorsal View (Fig 2A):

On the other hand**,** from the dorsal view according to the table number1, the present study measured and observed that the Jugal maximum distance of *Upupa epops* ranges between 17.2 – 18.2 mm with an average 17.78±0.36 of the total length of the skull. Inter orbital conscription measures 10 – 11.4 mm (average 10.8±0.42). Nasal-hinge width attains 11.6– 14.6 mm (average 13.16±0.94) of the skull length. Premaxillar processes width measures 2.3 – 3.0 mm (average 2.6±0.23). Supraciliar process attains 5.6 – 6.3 mm (average 6.04±0.23).

Lateral View (Fig 2B):

From the lateral view, the present work recorded that, skull length measures 78 – 84.5 mm (average 83.27±3.05). Bill (beak) length ranges between 59.2 – 62.5 mm with an average 60.57±1.65 of the total length of the skull. Orbito quadrate process measures 6.0–7.2% (average 6.62±0.41). In addition to Bill (beak) width measured 9.1–11.5 mm (average 10.42±1.12).

Ventral View (Fig 2C):

From the ventral view, the present data observed that Basi temporal width attains 5.8– 7.1 mm (average 6.47±8.41) of the skull length width. Intra pterygoid distance measures 11.9–14.3 mm (average 12.68±0.77).

Occipital View (Fig 2D):

From the occipital view, the Postorbital processes distance were ranged between 17-18.4 with an average (17.68±0.49) of the total width of the skull. Temporal width measures 15.8-16.9 (average 16.3±0.32). Skull width attains 61.2-17.9 (average 22.54 ±3.49) of the skull length width. Skull height measures 14.5-15.2 (average 22.17 ±0.47). Foramen magnum height measures 3.4– 4.3 (average 6.41 ±0.49) of the total diameter of Foramen magnum. Foramen magnum width represents 4.0– 4.9 (average 7.46 ±0.55) of total diameter of Foramen magnum**.**

The skull of Chicken (*Gallus gallus*):

Dorsal View (Fig 3A):

From the dorsal view, the present study observed that the Jugal maximum distance of *Gallus gallus* were ranged between 26.1–34.3 mm with an average 30.29 ± 2.44 of the total length of the skull. Inter orbital conscription measures 11.9–18 mm (average 14.6± 2.27). Nasal-hinge width attains 11.2–14.4 mm (average 12.88 ± 1.06) of the skull length. Premaxillar processes width measures 2.0 – 2.9 mm (average 2.42 ± 0.31). Supraciliar process attains 9.3 – 13.2 mm (average 11.59 ± 1.74).

Lateral View (Fig 3B):

From the lateral view, the present data recorded that the Skull length was measured 64.9–73.7 mm (average 68.37 ± 4.49). Bill (beak) length ranges between 28.2 – 36.1 mm with an average 31.99 ± 4.49 of the total length of the skull. Orbito quadrate process measures 10.3–11.9 mm (average 11.29 ± 0.85).

Ventral View (Fig 3C):

From the ventral view, the present data observed that Basi temporal width attains 12.1–14.5 mm (average 13.11 ±0.88) of the skull length width. Intra pterygoid distance measures 16.5–19.7 mm (average 18.76 ±1.57).While Bill (beak) width of *Gallus gallus* measures 9.1–16.9 mm (average 11.36 ±2.38).

Occipital View (Fig 3D):

From the occipital view, the Postorbital processes distance were ranged between 26.5-31.3 with an average (27.26 ±2.11) of the total width of the skull. Temporal width measures 21.6-24 (average 22.24±1.91). Skull width attains 15.6.2-27 (average 22.54 ±3.49) of the skull length width. Skull height measures 21.7-22.7 (average 22.17 ±0.47). Foramen magnum height measures 5.9– 7.3 (average 6.41 ±0.49) of the total diameter of Foramen magnum. Foramen magnum width represents 6.9– 8 (average 7.46 ±0.55) of the total diameter of Foramen magnum**.**

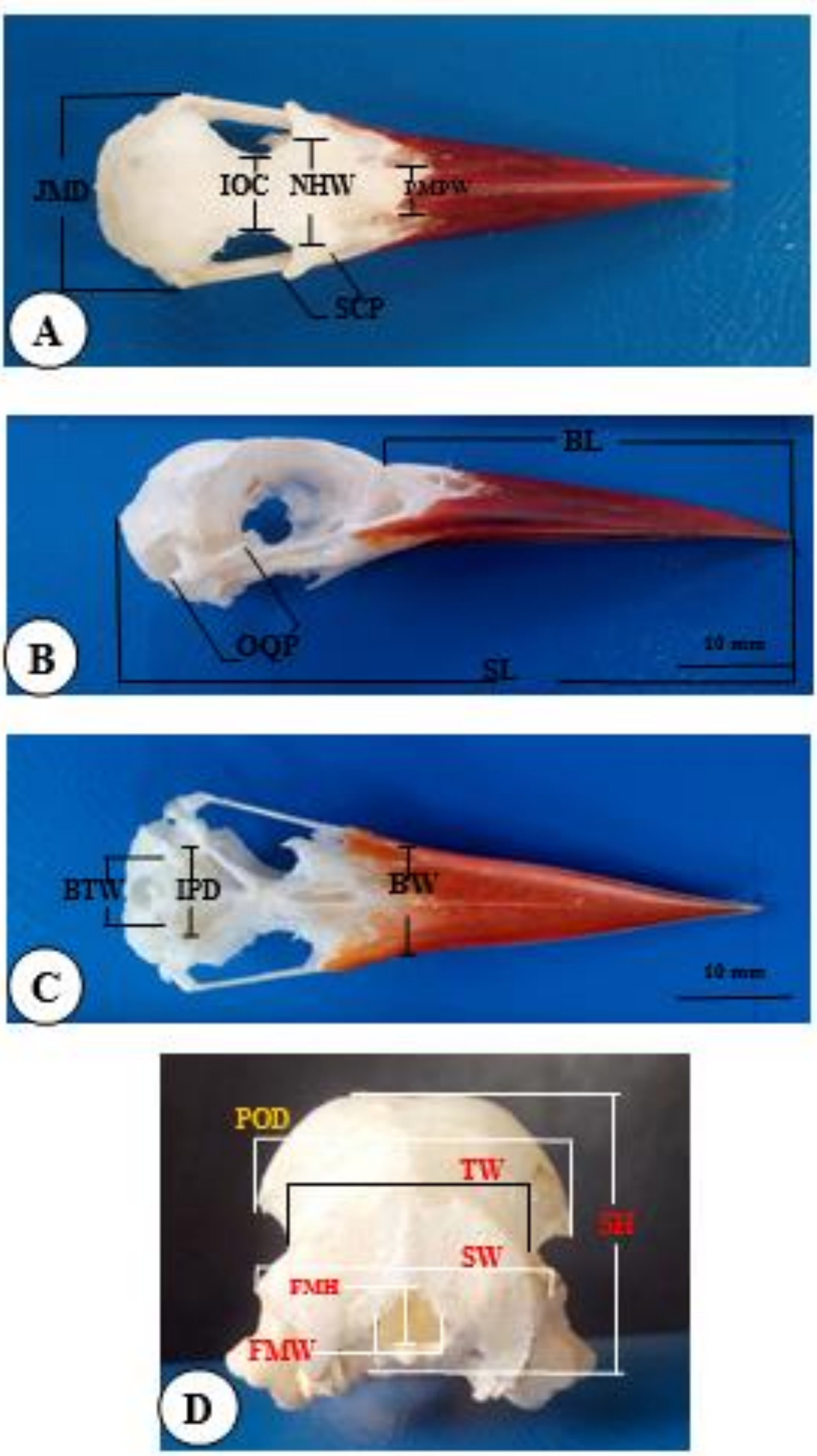

Fig. 1. Cranium of ***Halcyon smyrnensis***. Description of distances measured for the traditional morphometric analysis. **A**, dorsal view: **B**, lateral view, **C**, ventral view: **D**, caudal view: Scale bar: 10mm

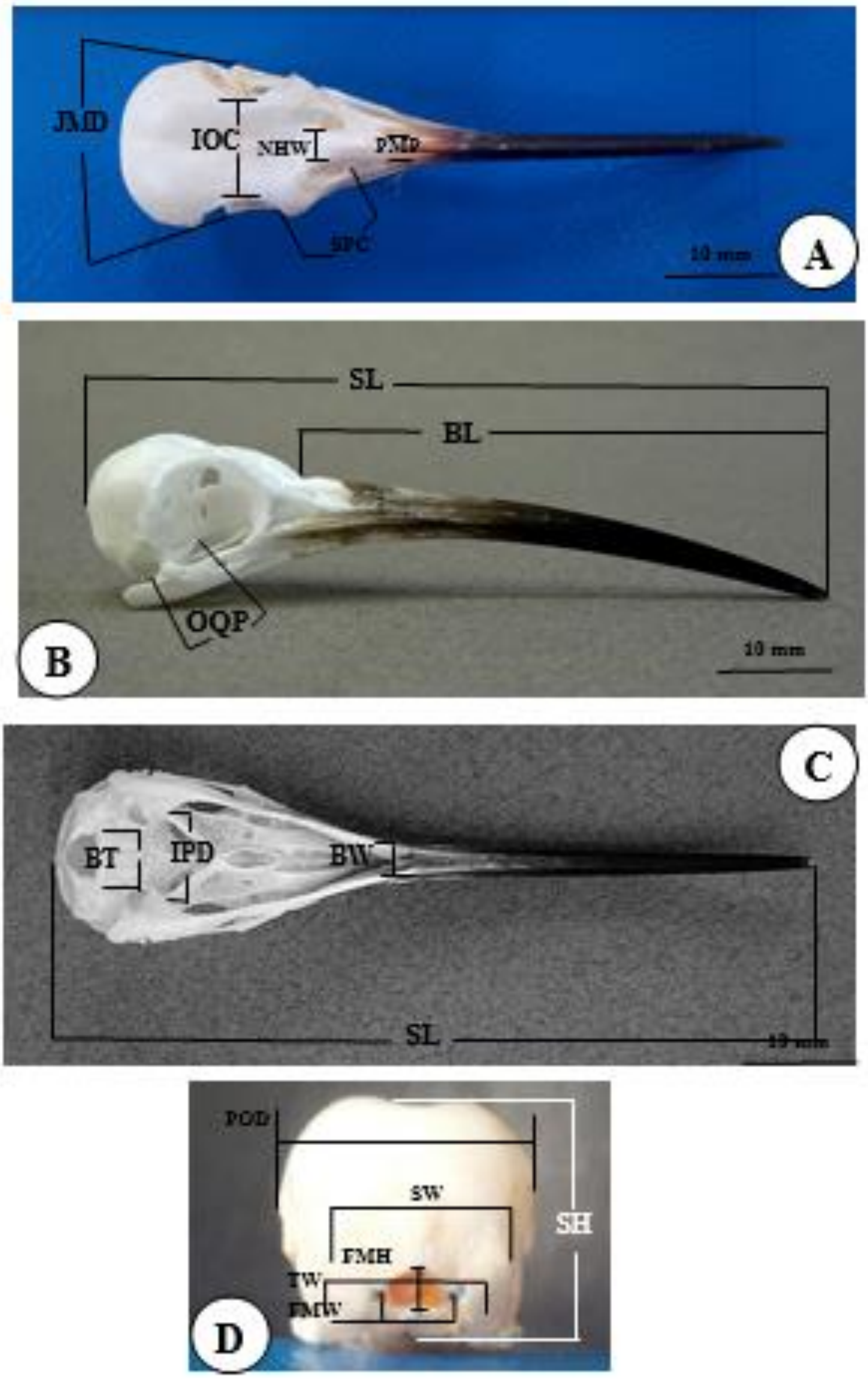

Fig. 2: Cranium of ***Upupa epops***. Description of distances measured for the traditional morphometric analysis. **A**, dorsal view: **B**, lateral view, **C,** ventral view: **D**, caudal view: Scale bar: 10mm

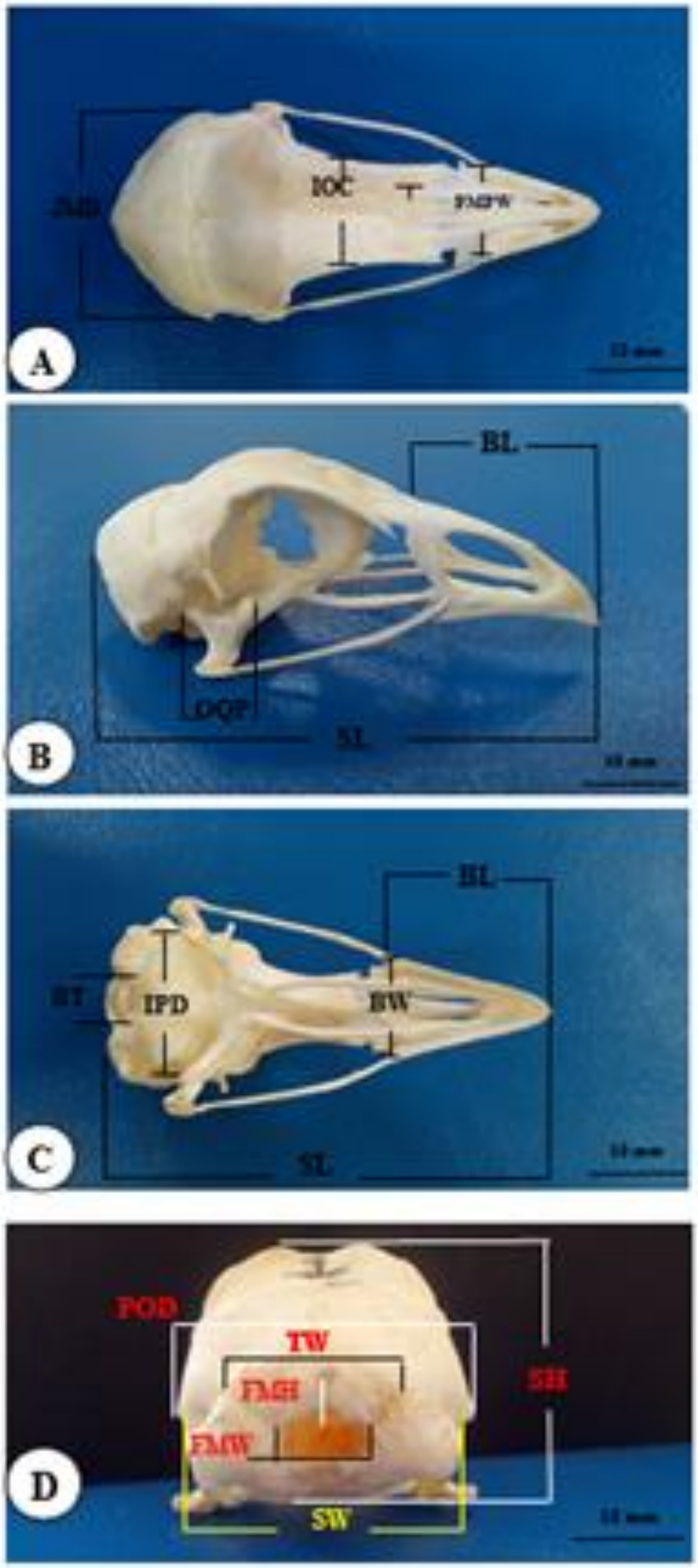

Fig. 3: Cranium of ***Gallus gallus***. Description of distances measured for the traditional morphometric analysis. **A**, dorsal view: **B**, lateral view, **C,** ventral view: **D**, caudal view: Scale bar: 10mm

List of abbreviations

Abbreviations	Definition
JMD	Jugal maximum distance
IOC	Interorbital conscription
NHW	Nasal-hinge width
PMPW	Pre maxilla processes width
SCP	Supra ciliar process
SL	Skull length
BL	Bill length
OQP	Orbito quadrate process
BTW	Basi temporal width
IPD	Intra pterigoid distance
BW	bill width
POD	Postorbital processes distance
TW	Temporal width
SW	Skull width
SH	Skull height
FMH	Foramen magnum height
FMW	Foramen magnum width

DISCUSSION

Morphometric Analysis:

According to the present results, the skull of Kingfisher, hoopoe and chicken shows some somatic differences involving also skull morphometry differences among this species for all Seventeen Characteristics (Table I). Morphometric analyses of avian anatomy are rare, and studies relating anatomical variations to ecological variables are even scarcer.

The species were studied here can be characterized and differentiated based on the morphometric shape of their skulls. The basic features for discrimination are bill length, length of the prenarial region, width and length of the neurocranium. Due to the paucity of sexed material, it was not possible to differentiate males from females at the intrageneric level. The major shape changes involve not only the bill (but the skull taken as a whole (Fry *et al.*, 1992; Slotow, 2000).

The analysis clearly separated the only available specimen of kingfisher from the specimens of booth hoopoe and chicken, these three species live in different environments, and there were differences between the mean skull shapes of halcyon, hoopoe and chicken**.** In other words, these species are distinguishable at a taxonomic level through an analysis of this kind. In the case of halcyon, hoopoe, and chicken the cranial morphological differences may reflect differences in their diet.

The variation found in the osseous anatomy of these skull regions might be related to the feeding mechanism, which is in turn linked to the degree of development of the jaw muscles. However, since these anatomical variations occur both between the halcyon and hoopoe, there are morpho-functional correlation seems to exist between feeding habits and skull shape.

From the current results, it was revealed that, there are differences between three species, the Jugal maximum distance of Kingfishers is larger than hoopoe and chicken, and this differences may due to the type of feeding of three species, in addition, no more different between halcyon and hoopoe species in inter orbital conscription (IOC) except in chicken the inter orbital conscription is bigger, but there are high differences in the skull length of kingfisher appeared longer than skull length of hoopoe and chicken to suitable of type feeding. This bird is well known for its versatile food and feeding habits (Ali and Ripley 1983; Mukherjee, 1975).

Bill size reflected differences in the nature of the bird's diet (Huxley, 1942; Lack, 1944; Kear, 1962; Grant, 1986; Smith, 1987).

The present data clearly have shown that culmen length is related to foraging behavior in the kingfishers. Both Kingfisher and Hoopoe bill length were approximately equaled, kingfisher usually dives into the water for their prey have the longest bills and those that dig in the soil for earthworms. While hoopoe captures the food by "gaping". During this operation, the bill is first kept closed then it is driven into the ground. Later the bill is opened against the resistance of earth and the insect food is captured (Rawal, 1968, Schutz, 2003). For gaping, if the bill is short the prey will escape deeper into the soil.

Bill (beak) width of Kingfishers (*Halcyon smyrnensis*) is broader and pointed in the anterior than beak width of the hoopoe and chicken, and this was suitable for grasping and catch the prey, this result agrees with Forshaw, (1983) stated that, noted that kingfishers had a laterally compressed, pointed bill which was suited for striking at and grasping prey while the broader. Hoopoes are almost completely insectivorous and use their long slender bill to probe into the ground for grubs and other invertebrates, and these results are agreed with (Kristin, 2001) who stated, the common hoopoe usually search for the prey on the ground but may sometimes make a short flight to catch their prey to insert its long slender bill into the ground with the hope of finding food, and then walking off in a different direction. In addition to the present results are agreed with (Sargatal *et al.*, 2001) stated that hoopoes are almost completely insectivorous and use their long bill to probe into the ground for grubs and other invertebrates.

On the other hand the present result noticed that, the skull hights and width of chicken larger than the skull of both halcyon and hoopoe, and these differences may duo to feeding behavior.

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ARABIC SUMMERY

دراسات مورفومترية مقارنة على جماجم ثلاثة أنواع من الطيور مختلفى الطبيعة الغذائية

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أجريت هذه الدراسة الحالية على جمجمة ثلاثة أنواع من الطيور مختلفى الطبيعة الغذاية وهم صياد السمك (*Halcyon smyrnensis*) والهدهد , و (*Upupa epops*) والدجاجة المنزلية (*Gallus gallus domesticus*) بجمهورية مصر العربية . بهدف أخذ قياسات مورفومترية للجماجم فى اتجاهاتها الأربعة (ظهرية- بطنية- جانبية- وخلفية).

وقد لوحظ أن الحيوانات محل الدراسة ذات علاقة وأرتباط وثيق بين نوع وسلوك التغذية وشكل وحجم عظام الجمجمة وذلك باستخدام الأساليب التحليلية والمورفومترية التقليدية.

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