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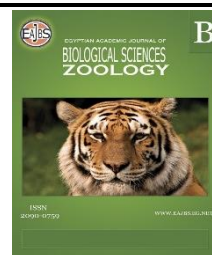


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## The Variation of the Skull and Sexual Dimorphism of Red Fox Sample from Egypt

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Numerous species of carnivores have been described, along with their cranial traits and sexual dimorphism. Despite the red fox's widespread distribution worldwide, very few studies have specifically addressed its cranial variations in Egypt. Despite the fact that many have focused on sexual dimorphism in carnivore skull size, other few studies have attempted to examine sexual dimorphism in skull shape in carnivores. In order to understand how shape and size relate to skull variability and differentiation, the current study analyses the morphometry of red fox sample skulls from Egypt. Multivariate statistical techniques were used to examine a total of 186 red fox skulls that had been collected around the whole country. All measurements were subjected to principal component analysis in order to categorize specimens according to size and shape. The skulls of red foxes exhibit significant individual variation. Age is related to the size and shape variations in red foxes. The size and shape of the skulls of sub-adult and adult red foxes largely overlap. Red fox skulls exhibit quietly pronounced sexual dimorphism, with older males being slightly larger than females. According to their cranial measurements, red foxes from the Western Mediterranean Coastal Desert and Western Desert Oases differ from those from the other regions of the country.

### INTRODUCTION

The population organization, diet accessibility, and size of the prey are all reflected in the skull morphology. Skulls have provided crucial evolutionary insights. Additionally, by examining an animal's skull, we may track changes that occur throughout its life or its ontogenetic development (Hartová-Nentvichová *et al.*, 2010).

For the most part, in carnivores, sexual dimorphism can occur to lessen male-female competition for prey. However, one of the primary factors promoting sexual dimorphism is sexual selection. Abiotic factors, including temperature and habitat resources, may also have an impact on sexual dimorphism (Serrat *et al.*, 2008).

According to Bergmann's rule, the size of some species can fluctuate along the lines of their geographic distribution, however, contrasting findings have been reported for mammalian carnivores. Differences in size between the sexes may also be explained by different mechanisms, such as slower growth in females due to higher energy expenditure

in post-reproductive females (Englund, 2006). Size may also be influenced by other variables, including age and the accessibility of human food (Yom-Tov *et al.*, 2007).

Animals that are warm-blooded should be smaller in warmer locations than in colder regions, according to Bergmann's rule. According to a Spanish study, only a small portion of the diversity in foxes' skull sizes may be attributed to latitude (Yom-Tov *et al.*, 2007). The body mass and length of foxes appear to be influenced by a variety of variables, including climate, latitude, population density, food availability, and genetics (Englund, 2006; Soulsbury *et al.*, 2008).

The proportion of juveniles and adults by sex may be used to assess trapping pressure and population trends. Sex identification is typically done using recent material from the main sex characters. Osteological remains, such as skulls or teeth are frequently used to determine the sex of carnivore species (Jenks *et al.*, 1984). On the basis of body mass and ratios (Wandeler and Lüps, 1993), tooth size, and dental forms (Nentvichová and Anděra, 2008), sexual dimorphism has been described in red foxes. Numerous authors have pointed out and validated the differences between the skulls of male and female red foxes (Lynch, 1996).

Two explanations are given for sexual size dimorphism by Thom *et al.* (2004): 1) Sexual selection, which can be viewed as mate competition. Due to the advantages of dominance and the consequent rise in mating opportunities, males may be selected for larger body sizes. The degree of male-biased sexual dimorphism may be interpreted as a sign of the level of rivalry for females within a species, according to Korablev *et al.* (2013). 2) Sexual dimorphism may be caused by inherent variations between the reproductive roles played by males and females. For instance, female mustelids may be smaller because they are more energetically efficient for reproduction (Moors, 1980). In order to reduce food rivalry between males and females, niche isolation between the sexes of various sizes may result in sexual dimorphism. Therefore, separate selection forces led to the optimal size for each sex (McDonald, 2002).

Numerous researchers have looked at the sex ratio of red fox populations (Wandeler and Lüps, 1993). Similarly, to this, numerous craniometric studies have detailed the age structure of red fox populations (Wandeler and Lüps, 1993; Younes and Basuony, 2015). To prevent false results by removing the effect of age, it must be separated into age groups and treated individually in morphological investigations. Understanding the age distribution of the population is important for this reason. It is crucial for determining the effectiveness of red fox hunting as a management tool as well (Younes and Basuony, 2015). The variations in red fox skulls have been examined in many countries, *e.g.*, Egypt (Younes and Basuony, 2015), Wales (Huson and Page, 1980), Switzerland (Lüps and Wandeler, 1983), and Germany (Ansorge, 1994).

The aim of the current study is to elucidate how shape and size relate to cranial variation and differentiation through an extensive examination of red fox skull morphometry in Egypt. Using recently developed statistical tools to analyze extensive morphometric data from red fox skulls, the following problems were investigated: How pronounced is the sexual dimorphism in skull shape and size? Are there age-related cranial differences? And is there a geographic variation in skull size and form among the red fox population in Egypt?

## MATERIALS AND METHODS

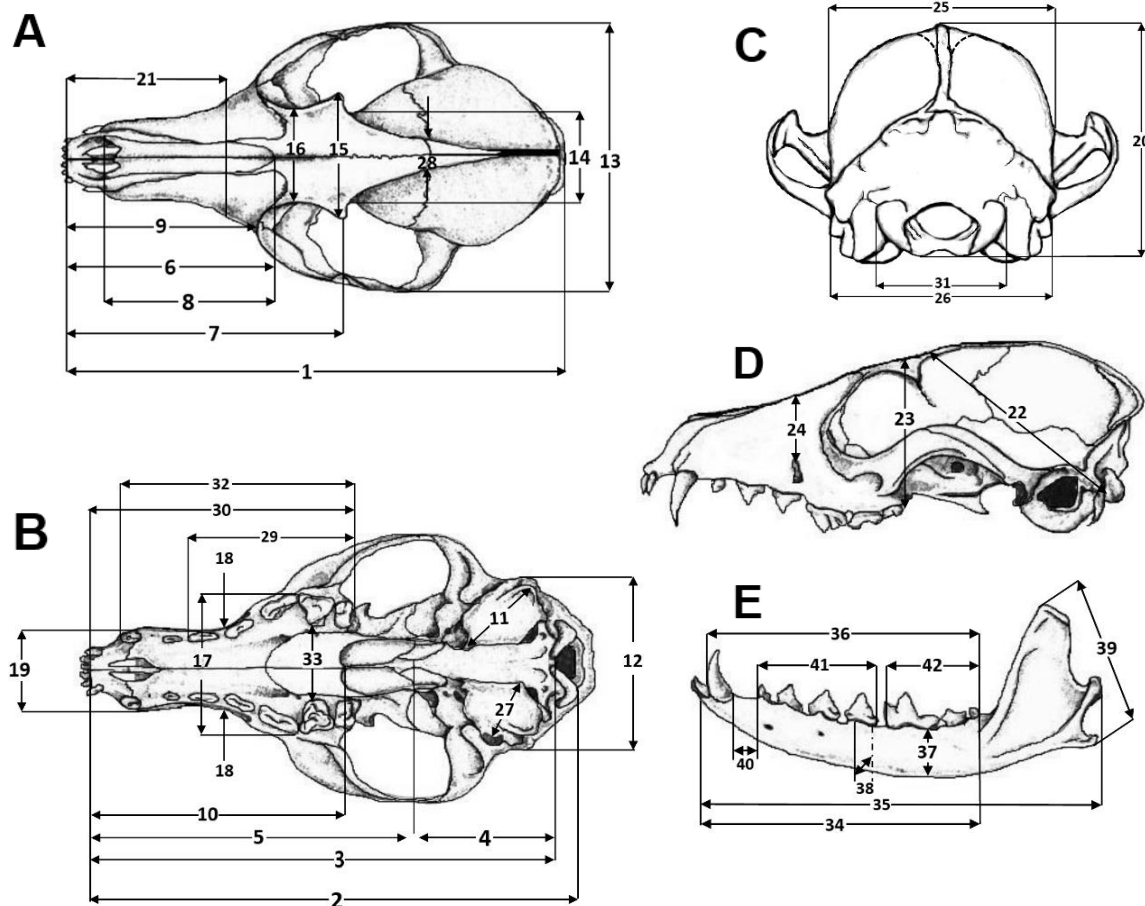
A total of 186 skulls of red fox, *V. vulpes*, deposited in the Al-Azhar University Zoological Collections at the Department of Zoology, Faculty of Science, Al-Azhar University, Cairo, Egypt, were analyzed. These skulls were collected from various parts of the country, including the Western Mediterranean Coastal Desert (WMCD), Qattara

Depression, Western Desert Oases (WDO), Nile Valley and Delta, Eastern Desert, and Sinai Peninsula, and covered both sexes between the ends of the 1990s and 2018. The red fox skulls of unknown sex were excluded from the study. According to Roulichova and Andera (2007), a widely used method for determining age involved counting the increment layers of secondary dental cement at the canine root. Sub-adults and adults were the two age groups into which the skulls were divided. The juvenile skulls, which were those older than a year, were not included in the current study. Individuals older than one year when they reach sexual maturity but younger than two years of age were classified as sub-adults, while those older than two years were classified as adults. An electronic movable calliper was used to determine 42 measurements of the cranium and mandible on each specimen (Table 1 and Fig. 1).

**Table 1.** Definition of cranial measurements used in the study.

No.	Abbreviation	Measurement description
1	GLS	The largest anteroposterior distance of the skull was measured dorsally from each extremity's most protruding point.
2	CBL	Measured ventrally from the occipital condyle to the premaxilla's anterior extremity.
3	BL	Measured ventrally from the junction of the two occipital condyles to the anterior extremity of a premaxilla.
4	BCL	Measured ventrally from the base of the presphenoid to the point between the two occipital condyles.
5	BFL	Measured ventrally from the anterior extremity of the skull to the base of the presphenoid.
6	VCL	Measured dorsally from the front extremity of the skull to the half-point between the two nasals.
7	FL	From the postorbital process to the anterior extremity of the skull, measured dorsally.
8	NL	Measurement is taken dorsally from the midpoint of two nasals to the tip of a nasal.
9	SL	From the front of the lacrimal bone to the front of the skull, measured dorsally.
10	PL	Measured ventrally from the anterior extremity of the cranium to the tip of a palatine.
11	ABL	The largest tympanic bulla measurement was obtained ventrally.
12	GBM	The greatest breadth was measured dorsally between the two mastoid processes.
13	ZB	The dorsally obtained measurement of the skull's largest width across the zygomatic arches.
14	PCW	The shortest distance dorsally measured between the two postorbital processes.
15	FPW	The longest distance dorsally measured between the two postorbital processes.
16	MnIW	The interorbital smallest width was measured dorsally.
17	MxPW	From the inside of the upper jaws, measured ventrally.
18	MnPW	The smallest snout width, measured ventrally.
19	CAW	The two canines' alveoli, measured ventrally, at their widest point.
20	DB	Measured laterally from the highest point dorsally to the deepest point ventrally on the cranium.
21	IF	Measured dorsally from the anterior extremity of the skull to the infraorbital foramen.
22	FM	The lateral measurement from the foramen magnum to the frontal midpoint.
23	PDT	Measured laterally from the tip of an upper jaw to the same point on the skull's roof.
24	DIF	Measured laterally from the infraorbital foramen to the point at the roof of the skull.
25	MxWB	The breadth of the braincase at the zygomatic arches' posterior roots.
26	WAM	The distance dorsally measured between the two external auditory meati.
27	WB	Width of the tympanic bulla at its widest point.
28	WS	When the parietal bones are viewed dorsally from the posterior edge.
29	MPU	Measured from the start of the upper jaw's first premolar PM <sup>1</sup> to the end of the last molar M <sup>2</sup> .
30	IM	Measured from the upper jaw's last molar to the base of the incisors.
31	WOC	The occipital condyles' widest point.
32	MXTR	Maxillary tooth row length measured from the front of the first upper canine to the rear of the last upper molar's crown.

No.	Abbreviation	Measurement description
33	MD	The upper M's' internal spacing, was measured ventrally from the palatine.
34	MT	Measured from a lower jaw's tip point to its last molar.
35	M	Measured from a lower jaw's tip point to the angular process.
36	MDTR	The distance along the mandibular tooth row from the back of the last lower molar's crown to the front of the lower canine.
37	MH	The maximum height of the mandible measured laterally from the lower jaw at the first molar's base.
38	JT	The largest thickness of the mandible is measured ventrally from the lower jaw at the first molar's base.
39	ACP	Angular - coronoid process
40	c-P <sub>1</sub>	The distance along the mandible from the first premolar to the lower canine.
41	P <sub>1</sub> -P <sub>4</sub>	The distance along the mandibular row from the lower premolar 1's front to the premolar 4's back.
42	M <sub>1</sub> -M <sub>3</sub>	The distance along the mandibular row from the third molar's back to the front of the lower first molar.



**Fig. 1.** Measurements of the skull used in the analysis. A. *Vulpes* cranium, dorsal view; B. *Vulpes* cranium, ventral view; C. *Vulpes* cranium, nuchal view; D. *Vulpes* cranium, left side view; E. *Vulpes* mandible, left side view.

### Statistical Analyses:

Shapiro-Wilk and QQ plots were used to check the normality of all measurements. The Kruskal-Wallis one-way analysis of variance (ANOVA) on ranks was used to examine differences in skull size between age groups. The Mann-Whitney test was used to determine whether the median differences between boys and females for each cranial measurement were statistically significant. To investigate the most significant variance in skull size and shape, multivariate analyses were used. According to Jolicoeur and Mosimann (1960), shape generally tends to convey more accurate information about an organism's morphology

than size. Because of its heavy reliance on ecological factors, size is frequently thought to be uncomfortable (McCoy *et al.*, 2006). However, it can be difficult to separate size from form in multivariate analyses of morphological data (Claude, 2008).

Using principal component analysis (PCA), this issue was solved. While the remaining principal components represent the shape space, the first principal component of PCA is typically thought of as a general size axis. It does, however, also contain shape information that is connected to size (Jolicoeur and Mosimann, 1960), and Jolicoeur (1963) recognized it as a multivariate allometric size axis. It is challenging to comprehend the remaining PCA components since the first component contains both size and size-related shape information. Finding the optimal ratios that distinguish between male and female skulls required applying the PCA ratio spectrum to the interpretation of the main components in shape space. The results of the PCA were validated using K-means cluster analysis. Using the "Factoextra" and "PCAtools" libraries, PCA and K-means were performed using the statistical language R.

#### **Ethics Statement:**

The skulls used in this study were taken from animals that were killed in car accidents, by natural causes, or as a result of ethical hunting. Additionally, specimens from Al-Azhar University Zoological Collection were collected by Dr. Mostafa Saleh, and Dr. Ali Basuony from Al-Azhar University and Dr. Walid Fathy from Ain Shams University. For the purpose of this research, no animals were killed.

## **RESULTS**

All measurements did not significantly vary from the normal distribution, as demonstrated by Shapiro-Wilk tests and QQ plots. It permitted the use of the one-way ANOVA and Mann-Whitney test. However, the assumption of normally distributed data is not strongly recommended for the majority of the statistical approaches that follow. According to the ANOVA results, sub-adult animals, or foxes between 1 and 2 years of age, varied from adult animals, or foxes older than 2 years, in the majority of skull measures. According to the findings, there are 86 males of *V. vulpes* (72 sub-adults between 1 and 2 years old and 14 adults older than 2 years) and 100 females (83 sub-adults between 1 and 2 years old and 17 adults older than 2 years) (Table 2). This collection's approximate ages varied from one to seven years. The majority of the collection's foxes are between one and two years old. With 83.33% of the animals in this sample being sub-adults younger than two years old, fox mortality appears to be considerable, leading to a life span that appears to be significantly shorter than the natural life expectancy.

The maximum width of the braincase (MxWB) measurement was the only area where sub-adult and adult specimens significantly differed. As a result, summary statistics of the skull measures for a joint group of sub-adult and adult foxes were determined. The Mann-Whitney test was used to investigate sexual dimorphism in skull size (Table 2). Male and female differences in almost all skull measures were statistically significant. However, because all of the features of the skull are highly overlapping, only the size of the skull can clearly distinguish between the sexes (Fig. 2). The large sample size is responsible for the extremely high level of statistical significance, as shown by the Mann-Whitney test.

The length of the upper and lower cheek tooth rows between males and females differs significantly, according to the data in Table 2, but the variance percentage is moderate in comparison to variations in other dimensions. On the other hand, males have substantially longer tooth rows and canines.

**Table 2.** Descriptive statistics of basic *V. vulpes* skull measurements and statistical significance of the differences examined by Mann-Whitney test.

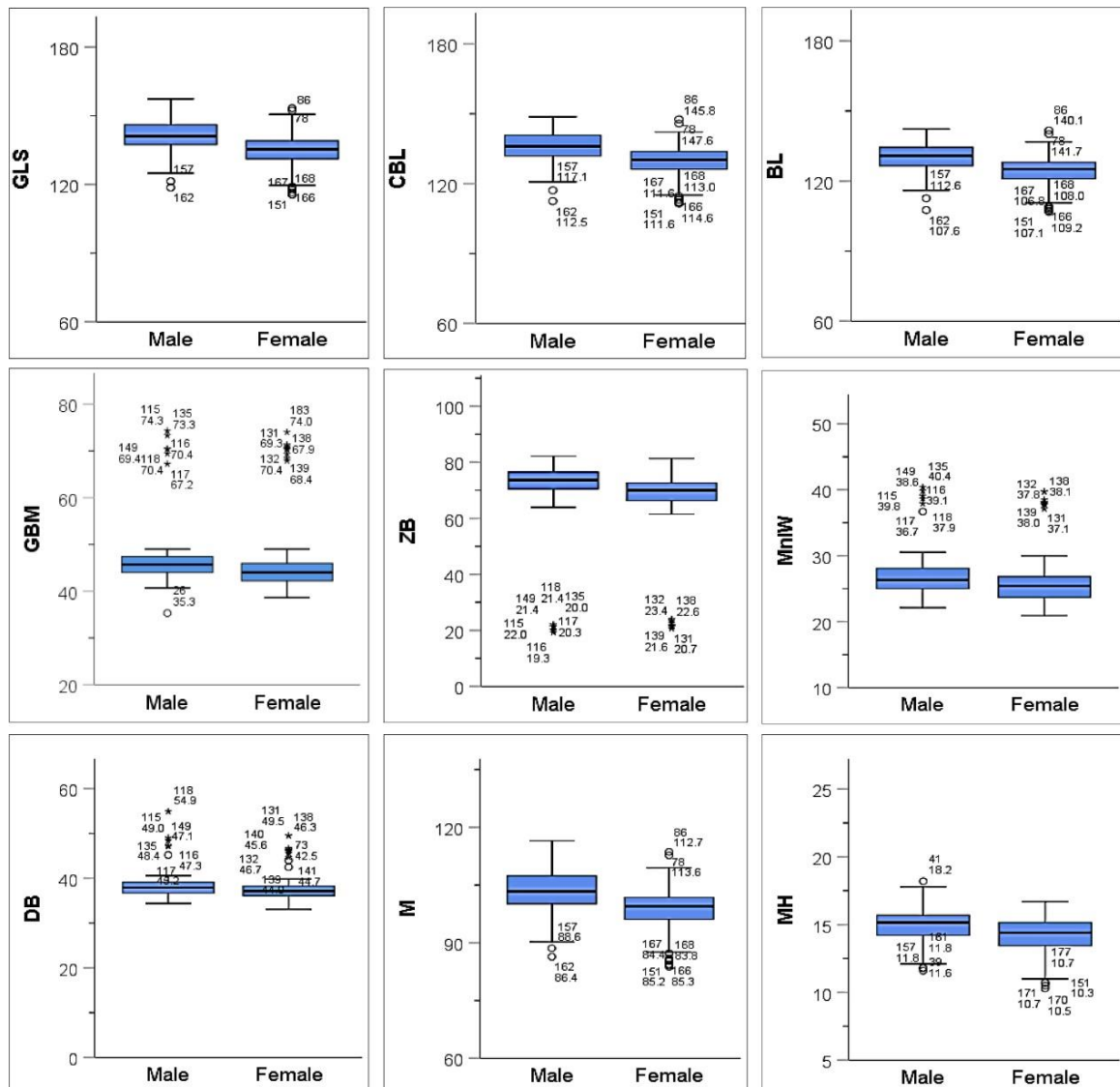
Abbreviation	Male (n=86)					Female (n=100)					P value
	Min	Q1	Median	Q3	Max	Min	Q1	Median	Q3	Max	
GLS	119	137	141	146	157	116	131	135	139	153	0.000**
CBL	113	132	136	141	149	112	126	130	134	148	0.000**
BL	108	126	131	135	142	107	121	125	128	142	0.000**
BCL	30	35	37	37	42	29	33	35	36	39	0.000**
BFL	77	91	93	97	104	76	87	90	93	104	0.000**
VCL	51	61	64	67	74	51	59	61	64	72	0.000**
FL	72	81	84	87	94	68	78	81	83	92	0.000**
NL	42	49	51	54	60	40	46	49	52	60	0.000**
SL	50	59	61	64	71	48	56	59	62	70	0.000**
PL	59	70	72	75	79	59	67	70	72	79	0.000**
ABL	19	21	22	23	24	18	20	21	22	24	0.000**
GBM	35	44	46	47	74	39	42	44	46	74	0.000**
ZB	19	71	74	77	82	21	66	70	73	81	0.000**
PCW	16	20	21	22	39	17	20	21	23	37	0.029**
FPW	24	32	35	37	41	24	31	33	35	41	0.001**
MnIW	22	25	26	28	40	21	24	25	27	40	0.005**
MxPW	19	37	39	41	44	18	35	38	39	43	0.000**
MnPW	16	19	20	21	25	14	18	19	20	24	0.003**
CAW	19	22	23	24	38	17	20	22	23	38	0.000**
DB	34	37	38	39	55	33	36	37	38	50	0.005**
IF	42	46	48	51	66	39	44	47	49	67	0.000**
FM	31	64	67	68	73	32	60	65	66	71	0.000**
PDT	18	33	34	35	46	18	31	33	34	37	0.000**
DIF	17	19	21	22	46	16	19	20	21	46	0.007**
MxWB	13	43	44	46	49	41	43	44	45	48	0.120
WAM	12	42	44	46	49	14	41	43	45	49	0.001**
WB	12	14	15	16	46	12	14	14	16	46	0.012**
WS	1	3	5	7	14	1	5	7	9	21	0.000**
MPU	44	50	52	53	56	41	47	50	51	55	0.000**
IM	63	72	73	76	80	60	68	71	73	79	0.000**
WOC	23	24	25	26	28	22	23	24	25	27	0.000**
MXTR	53	60	62	64	67	48	57	60	61	67	0.000**
MD	13	15	16	17	19	12	14	15	17	19	0.001**
MT	61	70	72	75	78	57	68	70	72	80	0.000**
M	86	100	103	107	117	84	96	100	102	114	0.000**
MDTR	59	67	69	72	75	56	64	67	69	74	0.000**
MH	12	14	15	16	18	10	13	14	15	17	0.001**
JT	4	6	6	6	7	4	5	6	6	7	0.000**
ACP	29	35	37	38	41	28	33	35	36	40	0.000**
c-P <sub>1</sub>	3	4	5	6	8	2	4	4	5	7	0.019**
P <sub>1</sub> -P <sub>4</sub>	26	31	32	33	35	26	30	31	32	35	0.000**
m <sub>1</sub> -m <sub>3</sub>	20	24	25	26	28	19	24	24	25	250	0.002**

Note: Level of statistical significance: \*\*  $p < 0.01$ , Q1= First Quartile Q3= Third Quartile.

The PCA was applied to specimens from all age groups. The first and second principal components in shape space accounted for 49.3% and 27.1 of the variance, respectively (Fig. 3). The sexual dimorphism in shape and size of the skull is not pronounced, and there is a large overlap between *V. vulpes* males and females (Figs. 3a and b). Differences are mainly in size but not in shape. Older males have bigger skulls, but this does not depend on their exact age. Most sub-adults and females could not be separated by the size and shape of their skulls.

All age groups of specimens were subjected to the PCA. In form space, the first and second principal components were 49.3% and 27.1, respectively, of the variation (Fig. 3). The sexual dimorphism in skull size and shape is not prominent in *V. vulpes*, and there is a large overlap between male and females (Figs. 3a and b). The main variations are in size rather than shape. Regardless of their actual age, older males have larger skulls on average.

The size and shape of the skull made it difficult to differentiate between most sub-adults and females.

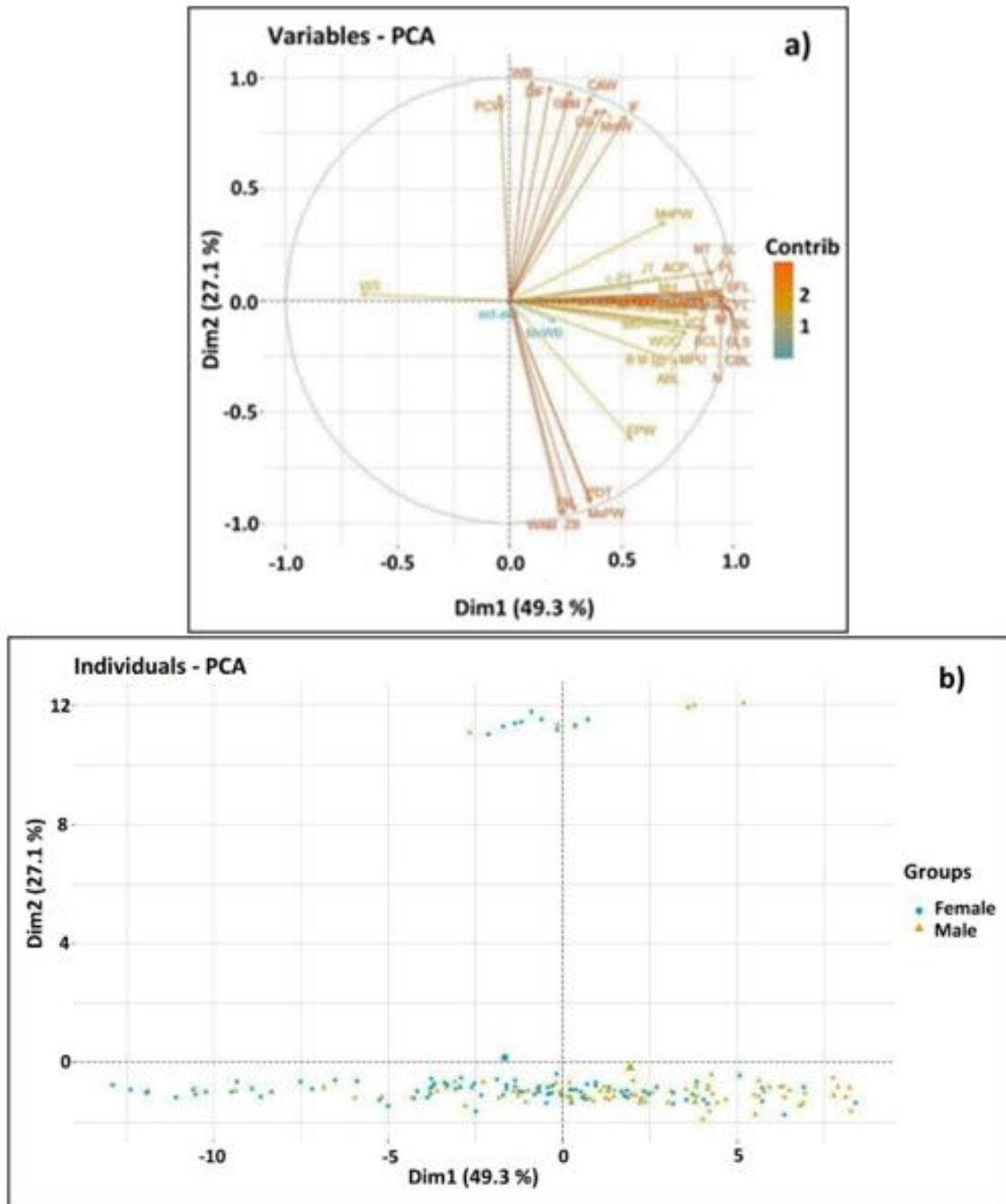


**Fig. 2:** Differences in basic cranial measurements between adult *V. vulpes* males and females.

Note: The numbers on the plot from 1 – 186 represent *V. vulpes* specimen's numbers.

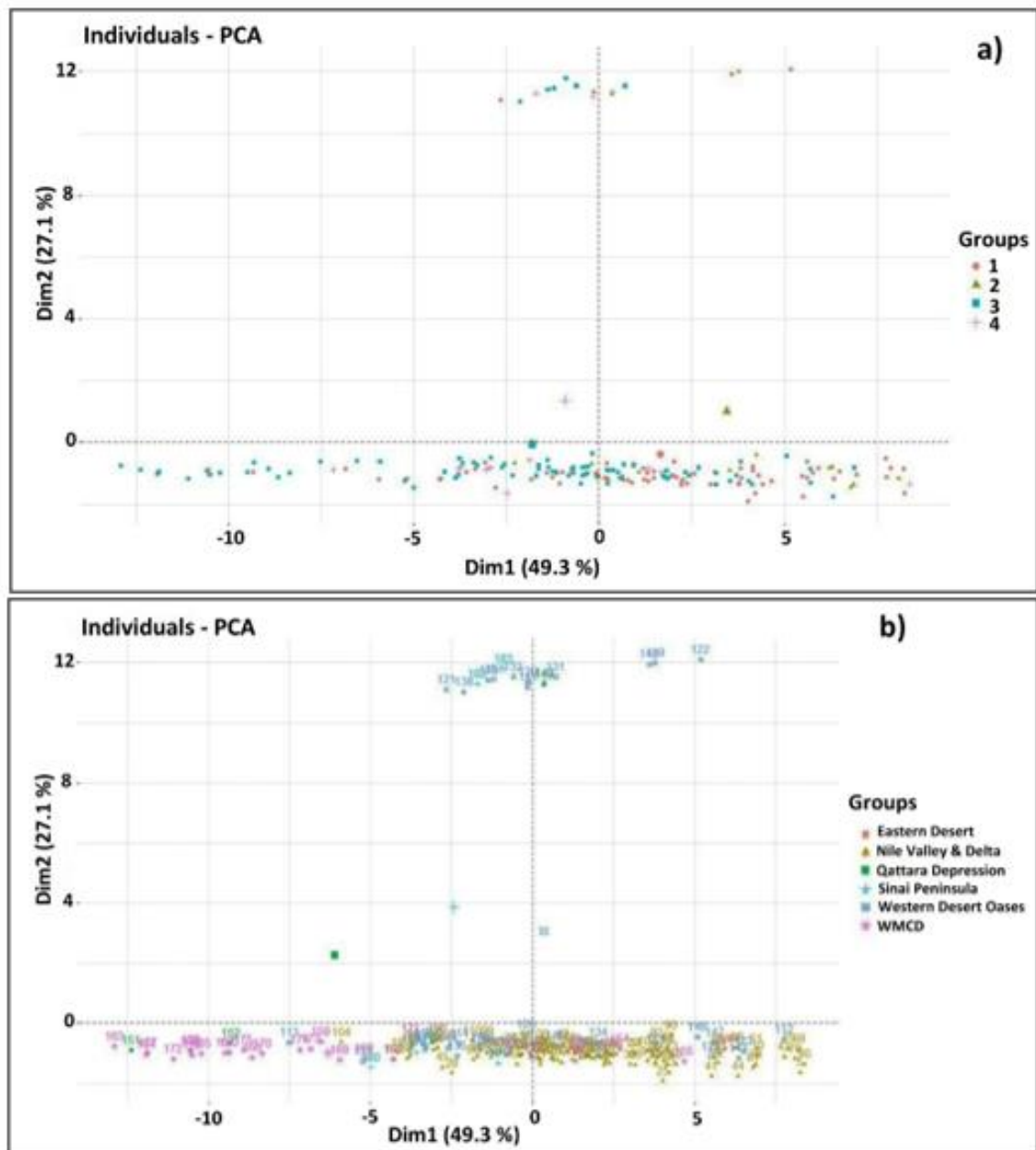
When the data are projected along the first and second principal components, only changes in skull form are visible. Only the first principal component could be used to identify the sub-adult foxes from the adults; however, there was a significant overlap between clusters. Males and females have identical-looking skull shapes (Fig. 4a). Geographical variances in cranium size and form might exist. With minor overlap, the red fox skulls from the Western Mediterranean Coastal Desert and Western Desert Oases were separated from the other skull regions (Fig. 4b).





**Fig. 3.** Principal component analysis. Projection of variables (a) and individuals (b) along first two principal components in shape space.

Principal components can be interpreted in shape space using the PCA ratio spectrum (Fig. 5). The current study applied the PCA ratio spectrum (Fig. 5) described in detail by Baur and Leuenberger (2011) for the interpretation of the two components. According to their explanation, a significant fraction of the variance of a shape PC can be explained by ratios calculated from characters that are far apart in the spectrum; in contrast, ratios from close characters make up a very small portion of the variance. The ratio of the width of the sagittal crest (WS) to the basal length (BL) dominated the shape PC1 according to the PCA ratio spectrum in Figure 5, but the ratio of the width across the auditory meatus (WAM) to the width of the bulla (WB) was recommended by the PCA ratio spectrum for the shape PC2.



**Fig. 4:** Principal component analysis. Projection of individual's age classes (a) and collection sites (b) along the first two principal components in shape space. Note: 1=Sub-adult males, 2=Adult males, 3=Sub-adult females and 4=Adult females  
Note: The numbers on the plot from 1 – 186 represent *V. vulpes* specimen's numbers.

As a result, the skulls of male foxes are generally large, elongate, and have thin post-orbital portions (Table 2). A few features that would make it simple and rapid to identify the majority of specimens might occasionally be useful for practical reasons, such as in fieldwork. One or two ratios would be ideal because they are simple to calculate and sometimes even allow for the estimation of proportional differences by sight (Reichenbach *et al.*, 2012).

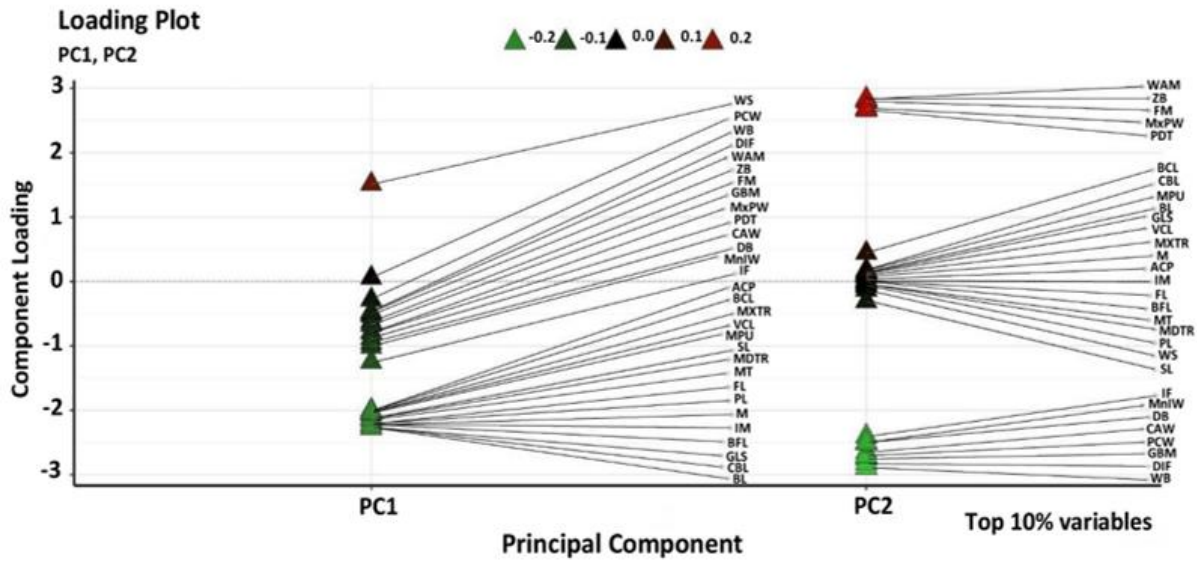


Fig. 5. PCA ratio spectrum for the first and second principal components in shape space.

A total of 186 *V. vulpes* specimens were partitioned and clustered for the first and second principal components in shape space (Fig. 6). There were four clusters that appeared; clusters 1 and 2 contained a variety of individuals from the Sinai Peninsula, the Eastern Desert, the Nile Valley, and the Delta. Cluster 3, including 13 specimens, represents the Western Desert Oases plus 2 specimens from the Sinai Peninsula. Cluster 4, including 17 specimens, represents the Western Mediterranean Coastal Desert (Fig. 6).

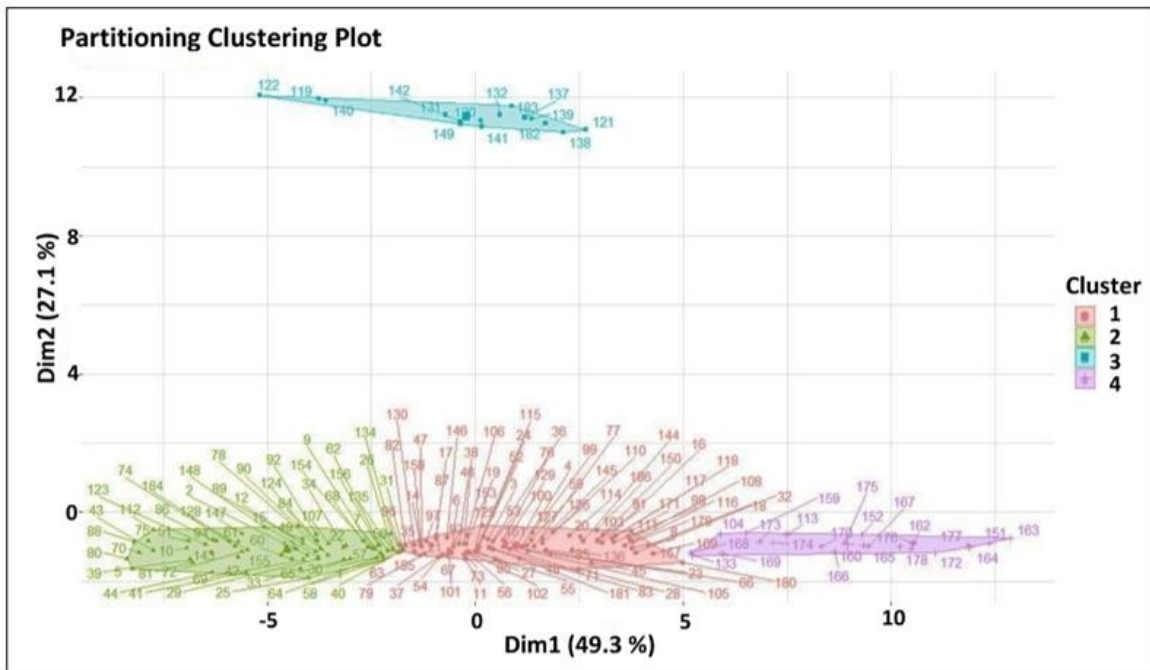


Fig. 6. Partitioning clustering for the first and second principal components in shape space. Note: The numbers on the plot from 1 – 186 represent *V. vulpes* specimen's numbers.

## DISCUSSION

With 83.33% of the animals in this collection, the red fox, *V. vulpes*, seems to have a life expectancy that is substantially shorter than the natural life expectancy in Egypt. Similar findings were reported by Younes and Basuony (2015), who made the assumption

that the sample of red foxes actually reflects the age structure of the population and that the vast majority of red foxes pass away before their second year of age.

In the current collection, the average age of the males is younger than that of the females. The lower average male rate could point to one aspect of this species' sexual dimorphism if the sample accurately reflects the wild population. It might also mean that younger foxes are simpler to catch than older ones. The red fox appears to be able to withstand intense hunting because there are so many young foxes in the population and because of its high rate of reproduction. The current findings are compatible with those of Younes and Basuony (2015).

Red fox males and females can be distinguished by their different skull shapes, which is true for all age classes. The differences in skull size and form that are often stated by many authors can be seen in the ratio of means of specific variables between males and females (Ansorge, 1994; Lynch, 1996). The postorbital constriction is narrower and significantly longer in male red foxes. Sedláková (2005), who dealt with red fox skulls from the Czech Republic, confirmed that red fox females had a postorbital constriction that is comparatively greater. On the other hand, Lüps and Wandeler (1983) found no difference in the ratios of length to width between sexes.

Similar to Ansorge's (1994) sample, the present study described the considerably larger skull and its sagittal crest in males. This trait is even more pronounced in older individuals. In addition, males in all age groups had a considerably large zygomatic breadth. The narrower postorbital constriction is one of the adaptations for compensating for the smaller area for masseter muscle insertion (Ansorge (1994). Additionally, it is made up for by a larger sagittal crest, which results in a higher skull height in male fox skulls as well as a wider zygomatic width. On the other hand, Churcher (1960) discovered no variations in the length and width of the sagittal crest between sexes in North American foxes.

The present results suggest that both male and female foxes change their width dimensions across their lives rather than their length dimensions. Furthermore, for most of those width dimensions, we were able to verify that older foxes had skulls with larger widths than the younger foxes, as also referred to by other studies (Huson and Page, 1980; Ansorge, 1994; Englund, 2006). The skull breadth is hypothesized to be one of the most important features when foxes compete with each other (Englund, 2006).

The present findings imply that age is a factor in the variations in the size and shape of red fox skulls that have been found. According to Larter *et al.* (2012), the growth of the skull slows down and eventually stops in the majority of canine species. Many species continue to grow over their whole lives, making the oldest individuals in the population generally the largest. Even after the foxes achieve sexual maturity, the skull breadth continues to increase. Only the zygomatic width and the least width between the orbits distinguish sub-adults from adults. Typically, healthier and more viable individuals live into old age, but smaller animals typically die young and live only from 2–3 years of age (Stoyanov, 2013).

Sexual selection and a decline in male-female competitiveness are two proposed explanations for sexual dimorphism (Lynch, 1996). Competition between males manifested as hostile behaviour and threat displays, is likely to have been a significant factor in the evolution of sexual dimorphism in carnivores (Meiri *et al.*, 2005). The reduction of intraspecific eating rivalry between male and female red foxes may be facilitated by sexual size dimorphism in red foxes, which may lead to a partial separation of the food niche. The region for muscle insertion is expanded by the significantly narrower postorbital constriction and the longer sagittal crest, strengthening the male jaw. Therefore, it is possible that male foxes can handle relatively larger prey. In some carnivorous species, the nutritional differences between males and females of the stone marten *Martes foina* were validated by Loy *et al.* (2004). These differences were attributed to males' smaller

postorbital constriction and, consequently, to their greater anterior part of the temporalis muscle. According to Abramov and Puzachenko (2005), dietary differences between males and females are not likely causes of sexual dimorphism in skull size in omnivorous animals. According to Iossa *et al.* (2008), sexual dimorphism in foxes may enable male foxes to benefit from polygynous mating. This could help explain some of the variance in mating systems. In monogamous species like raccoon dogs, *Nyctereutes procyonoides* (Kauhala, 1998), and crab-eating foxes, *Cerdocyon thous* (Macdonald and Courtenay, 1996), sexual dimorphism is either negligible or absent. Although research on wolves from Egypt (Younes and Fouad, 2016) and the Balkan Peninsula (Trbojević and Ćirović, 2016) demonstrated significant sexual dimorphism in adult individuals, sexual dimorphism in Canidae is generally small, with males being somewhat larger than females.

Despite the statistical significance of the variations in mean values of all measurements between males and females, the sexual dimorphism in red fox skull size was not particularly noticeable. Other research (Markov *et al.*, 2017; Krendl *et al.*, 2018) also supported the same findings. The Mann-Whitney test showed a high level of statistical significance, which may have been misleading given the large sample size. However, there is a significant overlap between males and females in all characteristics of the skull, making it difficult to distinguish them just based on the skull size (Fig. 2).

Only a few studies have previously examined the width of the postorbital constriction in the Pampean fox, *Dusicyon gymnocercus* (Prevosti and Lamas, 2006), and although it is a distinct species, no sexual dimorphism has been discovered for this character either. However, in eastern German red foxes, the postorbital constriction was discovered to be 4% larger in females (Ansorge, 1994), and in several other carnivores (Meiri *et al.*, 2005), the postorbital constriction had also been analyzed and differences between the sexes had been reported, being also larger in males (Stronen *et al.*, 2010).

Although the sample size included in the analyses was relatively large, the projected data formed a homogenous cluster with large individual variability. Figure 4b shows some differentiation among the shapes of red fox skulls from WMCD, WDO, and the other collecting regions, contrary to the results of Stoyanov (2019), who observed jackals from various parts of the country scarcely showed any changes in the morphology of their skulls. Based on red fox population demographics and differences in the reproductive value of sub-adult and adult individuals, the entire red fox collection was split into two age groups. Even multivariate analyses, meanwhile, were unable to effectively distinguish between sub-adults and adults. In Figure 4a, there was considerable overlap between the two groups. Despite the relatively large sample size used in the analysis, the projected data show a homogeneous cluster with high individual variability. Contrary to the findings of Stoyanov (2019), who claimed that there could rarely be observed changes in skull shape between jackals, Figure 4b shows some differentiation among the shapes of red fox skulls from WMCD, WDO, and the other collecting regions. Partitioning clustering for all the red fox specimens that were tested in this study is shown in Figure 6. The tested fox skulls from the Western Mediterranean Coastal Desert (WMCD), cluster 4, often have less elongated skulls and are wider, with expanded zygomata, a more inflated and rounder cranium, and a significantly wider post-orbital constriction than the foxes from other regions.

The current study was confirmed by Walid (2011) and Basuony (2015), who reported that in foxes of the Nile Valley and Delta, the snout is parallel-sided anteriorly, abruptly expanding at the level of the PM<sup>3</sup>. In foxes of the WMCD, the expansion of the snout is gradual, with its sides never being parallel. The snout of the WMCD fox is much more pointed than in other regions. The frontoparietal, sagittal, and lambdoidal ridges are clearly less developed in the WMCD foxes than in the Nile Valley and Delta foxes. The superior edge of the lambdoidal ridge extends considerably beyond the level of the occipital condyle in foxes of the Nile Valley and Delta, while it barely does so in those of the WMCD.

## Conclusion

The red fox, *V. vulpes*, skulls in Egypt exhibit significant individual variation and intrapopulation differences. Age is a factor in the red foxes' variations in size and morphology. The size and shape of the skulls of sub-adult and adult red foxes largely overlap. Red fox skulls exhibit slightly pronounced sexual dimorphism, with older males having a little bigger head than females. Based on cranial measurements, red foxes from the WMCD and WDO differ from those from other parts of the country.

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## ARABIC SUMMARY

## تباين الجمجمة وإزدواج الشكل الجنسي لعينة الثعلب الأحمر من مصر

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تم وصف العديد من أنواع الحيوانات آكلة اللحوم، من حيث سمات جماجمها وإزدواج الشكل الجنسي لها. وعلى الرغم من توزيع الثعلب الأحمر على نطاق واسع في جميع أنحاء العالم، فقد تناولت أعداد قليلة من الدراسات في مصر الاختلافات في شكل الجمجمة لهذا النوع. وعلى الرغم من أن الكثيرين ركزوا على فحص إزدواج الشكل الجنسي في حجم الجمجمة في آكلات اللحوم، حاولت دراسات قليلة أخرى فحص إزدواج الشكل الجنسي من شكل الجمجمة لتلك الحيوانات. ومن أجل معرفة كيف يرتبط الشكل والحجم بتغير وتمايز الجمجمة، تحلل الدراسة الحالية قياس التشكل في جماجم عينة الثعلب الأحمر من مصر. تم استخدام التقنيات الإحصائية متعددة المتغيرات لفحص 186 جمجمة لنوع الثعلب الأحمر التي تم جمعها في جميع أماكن تواجده في البلاد. خضعت جميع القياسات لتحليل المكون الرئيسي من أجل تقسيم العينات وفقاً للحجم والشكل. وأوضحت النتائج أن جماجم الثعلب الأحمر تظهر تباين كبير على مستوع الأفراد. كما أنه يرتبط العمر باختلافات الحجم والشكل. وأيضاً يتداخل حجم وشكل جماجم الثعالب الحمراء شبه البالغة والثعالب البالغة بشكل كبير. وتظهر جماجم الثعلب الأحمر إزدواج الشكل الجنسي بشكل واضح، حيث وجد أن الذكور الأكبر سناً أكبر قليلاً من الإناث. وخلصت الدراسة أيضاً أنه تختلف الثعالب الحمراء من الصحراء الساحلية لغرب البحر الأبيض المتوسط ووحدات الصحراء الغربية عن تلك الموجودة في المناطق الأخرى من البلاد تبعاً لقياسات الجماجم.