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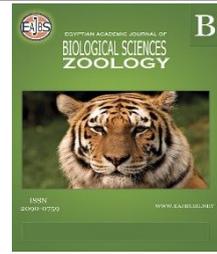
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The Nile Delta and Valley as An Ecological Barrier for Desert Mammals: With Special Reference To The Cairo Spiny Mouse, *Acomys cahirinus*

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ABSTRACT

The Nile Delta and Valley act as an important natural ecological barrier that the animals of the Western and Eastern Deserts cannot cross. For historical biogeographic reconstructions of arid habitats, the genus *Acomys* is an excellent model. Barriers that restrict the movement of animals allow for geographic isolation. In the present study, to investigate the evolutionary forces driving the differentiation of the Cairo spiny mice, *Acomys cahirinus*, particularly as related to the biogeographical relationship between the Western and Eastern Deserts of Egypt, thirty-eight skulls of male specimens of the Cairo spiny mouse from four different regions of Egypt that were kept in Al-Azhar University Zoological Collection in Cairo, Egypt were examined. Five of these skulls came from Bahariya Oasis, seven from Dakhla Oasis, five from Helwan region, and twenty-one came from Eastern Desert. Based on sixteen absolute cranial and dental measurements and seventeen ratios used here, *A. c. helmyi* from Dakhla Oasis differ greatly from those from Bahariya Oasis (*A. c. cahirinus*), Helwan region (*A. c. cahirinus*), and Eastern Desert (*A. c. hunteri*) populations. There were many cranial and dental characteristics correlated with each other. Most of these characteristics are highly positively correlated with body mass, condyloincisive length, and mastoid width. Despite the presence of this natural ecological barrier (the Nile Delta and Valley), a great similarity was found between the Cairo spiny mouse populations from Bahariya Oasis (Western Desert) and from Eastern Desert, noting the great difference between the Cairo spiny mouse populations from Dakhla Oasis (Western Desert) from the other populations in the present study.

INTRODUCTION

Mayer (1963) who was the first used the term allopatric speciation to describe divergence that takes place in many locations. Geographic isolation between sexually reproducing populations will mostly or completely stop the gene flow between them. Barriers that restrict the movement of organisms allow for geographic isolation. The younger populations will differ from each other due to genetic differences developed by the original population as a result of natural selection or genetic drift, while some gene flow preserves the original genes. The gene flow will be fully cut off and the populations will turn into independent evolutionary units if the populations are completely isolated and their

dispersal stops (Brown and Lomolino, 1998).

Sympatric speciation refers to speciation where the original species is not geographically isolated. Although sympatric speciation proved to be more widespread than previously believed, allopatric speciation is still thought to be the most plausible pathway for speciation. Numerous theoretical analyses have been prompted by the increased interest in sympatric speciation mechanisms (Higashi *et al.*, 1999). According to Rosenzweig (1978), such disruptive selection that operates along an environmental gradient may gradually increase clinal variation until the original population splits into two or more species.

Studies in a variety of fields, including behavior (Pillay, 2000), ecology (Kessing, 1998), and functional morphology (Satoh, 1999), have focused on various species of muroid rodents. Studies of the ecology and phylogeny of muroid species are of immediate interest because many of these species act as viral reservoirs and disease vectors in humans (Heyman *et al.*, 2002). Despite improvements in the systematic study of muroid rodents (Musser and Carleton, 1993; Michaux *et al.*, 2001), many elements of the field, including species identification and evolutionary relationships within and among lineages, are still poorly understood.

At least eight species of spiny mice belonging to the Murinae family are included in the genus *Acomys* (Carleton and Musser, 1984). Based on a few specimens brought from Cairo, Egypt, Desmarest identified the Cairo spiny mouse, *Acomys cahirinus*, as *Mus cahirinus* in 1819 (Rosevear, 1969). Due to its dorsal bristles, the genus *Acomys*, often known as a spiny mouse, is widely distributed throughout Africa, the Levant, Western Asia, and even some Mediterranean islands (Haughton *et al.*, 2016; Renaud *et al.*, 2020).

The spiny mouse *Acomys* was placed in the Murinae because it shares a unique and complex tooth pattern with the Murinae (Carleton and Musser, 1984). Jacobs *et al.* (1990) defined the Murinae by the presence of two additional lingual cusps on the first upper molar (M^1), a derived character also found in *Acomys*. However, the spiny mice were also characterized by the structure of their third upper molar (M^3), and this morphological pattern, also found in two other African genera of murids, is not present in most fossil and living murines.

Because of its distinctive and complex tooth pattern, the spiny mouse *Acomys* was classified as a member of the Murinae (Carleton and Musser, 1984). The presence of two extra lingual cusps on the first upper molar (M^1), a derived characteristic also present in *Acomys*, was used by Jacobs *et al.* (1990) to define the Murinae. However, the spiny mice were also distinguished by the shape of their third upper molar (M^3). Two evolutionary studies based on cladistic analyses of morphological features revealed that *Acomys* was either a murine or an early murine offshoot in response to the challenge of the immunological findings (Wilson *et al.*, 1987). *Acomys* was found to be more closely connected to the Murinae than to the other subfamilies examined, according to a taxonomy study of muroid rodents using isozyme electrophoresis (Bonhomme *et al.*, 1985).

If the monophyly of the genus *Acomys* is accepted, the arrangement of its current species is very debatable and has been changed numerous times since *Acomys* was initially described as "*Mus cahirinus*" by Desmarest in 1819. The majority of the taxonomic uncertainty in the genus stems from conflicting interpretations of confusing morphological data, which has prompted researchers to suggest multiple iterative revisions of *Acomys* species (Musser and Carleton, 1993). The aim of this study was to investigate the evolutionary forces driving the differentiation of the Cairo spiny mice, particularly as related to the biogeographical relationship between the Western and Eastern Deserts of Egypt via investigation and analysis of the cranial measurements of the Cairo spiny mice skulls collected from four different regions in Egypt.

MATERIALS AND METHODS

The Study Animals and Areas:

Thirty-eight skulls of male specimens of the Cairo spiny mouse, *A. cahirinus*, from four different regions of Egypt that were kept in Al-Azhar University Zoological Collection (AUZC) in Cairo, Egypt were examined. These samples were collected between November 2013 and December 2015. Table 1 lists the locations where these specimens were collected, their museum numbers, and their coordinates. Five of these skulls came from Bahariya Oasis (Western Desert), seven from Dakhla Oasis (Western Desert), five from Helwan region, and twenty-one came from the Eastern Desert (Table 1 and Figure 1). The samples of the Eastern Desert *A. cahirinus* population were collected from four regions (Table 1 and Figure 1), geographically far apart, but according to Osborn and Helmy (1980) and Walid (2000) this population sitting under one subspecies *A. c. hunteri*.

Table 1: Collection localities and museum numbers of the Cairo spiny mouse, *A. cahirinus*, specimens used in this study.

Collecting region (Year)	Site	Museum number	Coordinates
Bahariya Oasis (2014)	Bawiti, near Gabal El Maghrafa	m005211	28°24'28.0"N, 28°53'28.7"E
		m005212	28°24'28.0"N, 28°53'28.7"E
		m005213	28°24'28.0"N, 28°53'28.7"E
		m005214	28°24'28.0"N, 28°53'28.7"E
		m005215	28°24'28.0"N, 28°53'28.7"E
Dakhla Oasis (2014)	Near El Mawhoub Village	m005243	25°42'18.3"N, 28°48'09.9"E
		m005244	25°42'18.3"N, 28°48'09.9"E
		m005245	25°42'18.3"N, 28°48'09.9"E
		m005246	25°42'18.3"N, 28°48'09.9"E
		m005247	25°42'18.3"N, 28°48'09.9"E
		m005248	25°42'18.3"N, 28°48'09.9"E
Helwan region (2015)	Near Helwan Cement Company	m005250	29°49'24.9"N, 31°18'07.6"E
		m005251	29°49'24.9"N, 31°18'07.6"E
		m005252	29°49'24.9"N, 31°18'07.6"E
		m005253	29°49'24.9"N, 31°18'07.6"E
		m005254	29°49'24.9"N, 31°18'07.6"E
Eastern Desert (2013-2015)	Wadi Nakhil - Qusair	m005228	26°08'51.7"N, 34°07'08.9"E
		m005231	26°08'51.7"N, 34°07'08.9"E
	Wadi Hulous - Hamata	m005232	24°22'38.7"N, 34°42'19.7"E
		m005234	24°22'38.7"N, 34°42'19.7"E
	Wadi Khodaa - near Berenice	m005162	23°40'00.2"N, 35°16'00.8"E
		m005163	23°40'00.2"N, 35°16'00.8"E
		m005164	23°40'00.2"N, 35°16'00.8"E
		m005165	23°40'00.2"N, 35°16'00.8"E
		m005166	23°40'00.2"N, 35°16'00.8"E
		m005167	23°40'00.2"N, 35°16'00.8"E
		m005168	23°40'00.2"N, 35°16'00.8"E
		m005169	23°40'00.2"N, 35°16'00.8"E
		m005170	23°40'00.2"N, 35°16'00.8"E
		m005171	23°40'00.2"N, 35°16'00.8"E
		m005172	23°40'00.2"N, 35°16'00.8"E
		m005173	23°40'00.2"N, 35°16'00.8"E
		m005174	23°40'00.2"N, 35°16'00.8"E
		m005175	23°40'00.2"N, 35°16'00.8"E
	m005176	23°40'00.2"N, 35°16'00.8"E	
	Near Ras Hadarbah	m005235	22°03'28.1"N, 36°42'00.4"E
		m005255	22°03'28.1"N, 36°42'00.4"E



Fig. 1: Map of Egypt showing the collecting localities of *A. cahirinus* (red dots) in the present study.

The Morphological and Cranial Measurements:

For each specimen, the standard external body measurements were taken: the distance between the tip of the nose and the base of the tail is known as head and body length (HBL). Tail length (TL) is the whole length of the tail, not including the tail tuft, measured from its root to tip. The measurement of the hind foot length (HFL) is taken from the heel to the end of the longest toe. The length of the ear, measured from the notch to the tip, is known as the ear pinna length (EL). The ear is extended to its utmost straightness without being stretched. The body mass (BM) was measured in grams.

The thirty-eight rodent skulls were examined for taxonomic purposes, and 10 cranial measurements were taken with an electronic digital caliper to the nearest 0.01 mm. According to Osborn and Helmy (1980), Harrison and Bates (1991), and Walid (2000) these measures were as follows: the skull length (SL) is the maximum horizontal length of the cranium including the mastoid bullae in some cases. The longest horizontal measurement from the supraoccipital to the nasals' most anterior edge is called the occipitonasal length (ONL). The longest distance between the anterior-most surface of the incisors and the posterior borders of the occipital condyles is known as the condyloincisive length (CIL). The largest width across the zygomatic arches is called zygomatic breadth (ZB). Interorbital constriction (IOC) is the narrowest width across the interorbital region. The width of the braincase measured at the posterior ends of the zygomatic arches is known as the braincase

width (BCW). The breadth of the braincase measured at the two auditory meati is called the mastoid width (MW). The length of the upper tooth row (TRL). The bullar length (BL) is the largest horizontal distance between its anterior-most surface and its point of contact with the paraoccipital process on its posterior-most surface. The height of the skull (SH), including the incisors and bullae, was measured from its highest point to the underside of a plate of a specified thickness. The real measurement is then obtained by subtracting the plate thickness.

The Statistical Analysis:

Using the SPSS computer software package, version 25, the obtained data were statistically analyzed and the dendrogram was done. One-way ANOVA with Duncan post hoc test, *P-value* is set at 0.05 level, and Pearson's coefficient correlation analysis, *P-value* is set at 0.01 level, were applied to test the reliability and correlation between characters used in the present study, respectively.

RESULTS

Description of *A. cahirinus* skull:

Figure 2 shows dorsal and ventral views, and ventral view of the lower jaw of the Cairo spiny mouse, *A. cahirinus*, from the four studied regions adjusted to the same skull length. The braincase of *A. cahirinus* is broad and noticeably convex dorsally, as shown in Figure 2. Well-developed supraorbital and temporoparietal ridges, the latter of which is low on the braincase and curves outward. Prominent medial supraoccipital ridge. Very big and semicircular interparietal. After the cranial ridge, there is a temporoparietal suture. Posterior nasal margin split. The zygomatic plate is quite large, gradually rounded above, and masseteric tuberosity is barely noticeable on the lower border. The incising foramen is long and extends to the level of the medial root of m^1 . Minute palatine foramen (Figure 2). Exceptionally long, wide, and shallow parapterygoid fossa. The basisphenoid-presphenoid suture is anterior to the level of the shelf formed by the palatines and closes the mesopterygoid fossa. Mildly enlarged tympanic bulla; mastoid ossified. The occipital condyle does not protrude above the supraoccipital processes. Very tiny coronoid and alveolar processes on the mandible. Compressed upper incisor with opisthodont, smooth anterior surface, and normal cutting edge. The crown of M^1 has three roots and is shorter than M^2 and M^3 . An extra, temporary anterolateral cusp on the M^2 . Two laminae in M^3 (Fig. 2).

Data in Table 2 shows significant differences $P < 0.05$ between the studied regions for HFL, SL, CIL, ONL, and MW measurements. The Cairo spiny mice from Dakhla Oasis recorded the largest dimensions in these five parameters presented in Table 2. The Cairo spiny mice from the Eastern Desert recorded a significant decrease in four parameters (Table 2). The minimum value of HFL was recorded for Eastern Desert mice 17.96 ± 1.34 mm and the maximum one was recorded for Dakhla Oasis mice 21.14 ± 1.46 mm. The minimum value of SL was recorded for Eastern Desert mice 29.21 ± 1.18 mm and the maximum one was recorded for Dakhla Oasis mice 31.50 ± 0.62 mm. The minimum value of CIL was recorded for Eastern Desert mice 27.61 ± 1.14 mm and the maximum one was recorded for Dakhla Oasis mice 30.16 ± 0.60 mm. The minimum value of ONL was recorded for Eastern Desert mice 29.21 ± 1.18 mm and the maximum one was recorded for Dakhla Oasis mice 31.50 ± 0.62 mm. The minimum value of MW was recorded for Helwan region mice 11.52 ± 0.07 mm and the maximum one was recorded for Dakhla Oasis mice 12.43 ± 0.37 mm (Table 2).

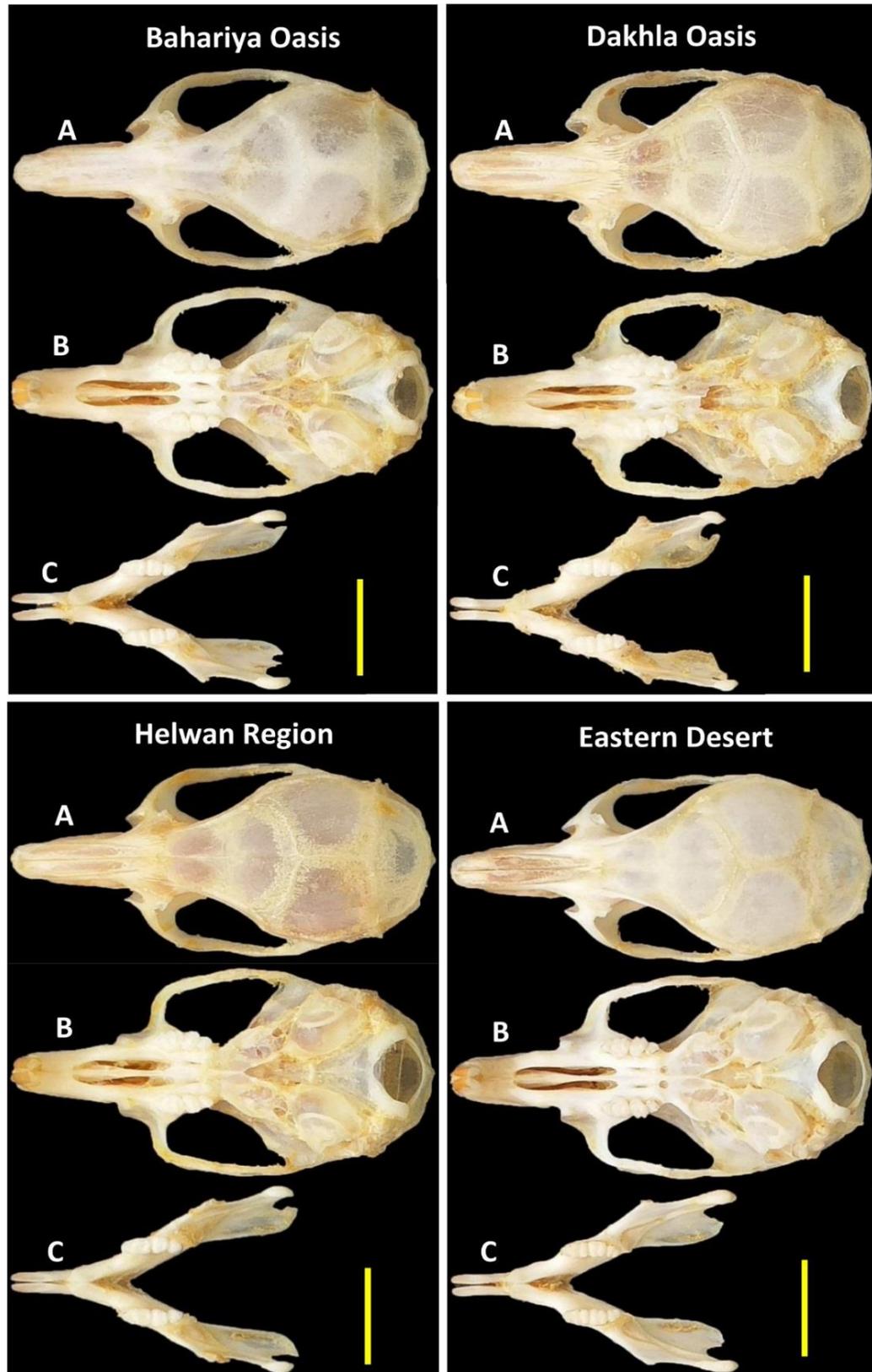


Fig. 2: Skull dorsal (A) and ventral (B) views, and ventral view of the lower jaw (C) of the Cairo spiny mouse, *A. cahirinus*, from the four studied regions. The scale equal 10 mm.

Table 2: Mean \pm SD of the Cairo spiny mouse, *A. cahirinus*, morphological measurements collected from the four studied areas. All measurements are in mm. Means with the same letter are not significantly different from each other.

Character	The Studied Regions			
	Bahariya Oasis	Dakhla Oasis	Helwan Region	Eastern Desert
TL	116.65 \pm 1.91	108.0 \pm 8.66	118.80 \pm 10.21	107.50 \pm 15.83
HFL*	18.90 ^{bc} \pm 0.58	21.14^a\pm1.46	19.60 ^b \pm 0.55	17.96 ^c \pm 1.34
SL*	30.24 ^b \pm 0.38	31.50^a\pm0.62	29.65 ^b \pm 0.53	29.21 ^b \pm 1.18
CIL*	28.75 ^b \pm 0.51	30.16^a\pm0.60	28.46 ^b \pm 0.48	27.61 ^b \pm 1.14
ONL*	30.24 ^b \pm 0.38	31.50^a\pm0.62	29.65 ^b \pm 0.53	29.21 ^b \pm 1.18
IOC	4.80 \pm 0.10	5.11 \pm 0.16	4.73 \pm 0.10	4.65 \pm 0.19
MW*	11.81 ^b \pm 0.01	12.43^a\pm0.37	11.52 ^b \pm 0.07	11.59 ^b \pm 0.32
RW	4.41 \pm 0.46	5.46 \pm 3.38	3.92 \pm 0.01	3.86 \pm 0.30

The largest skull appears in their dimensions in Figures 3 and 4. The four BM, HBL, ZB, and BCW parameters recorded a significant increase in Dakhla Oasis specimens and EL, BL, and SH parameters recorded a significant increase in Eastern Desert specimens (Figures 3 and 4). Figures 3 and 4 show that Eastern Desert specimens recorded the smallest values in BM, ZB, and TRL. Whereas, Bahariya Oasis specimens recorded the smallest values in HBL, EL, and BL. The smallest BCW and SH values were recorded for Helwan region specimens. The minimum body mass (BM) was recorded for Eastern Desert mice 30.55 \pm 5.16 g and the maximum one was recorded for Dakhla Oasis mice 52.18 \pm 7.50 g. The minimum HBL was recorded for Bahariya Oasis specimens 94.95 \pm 1.10 mm and the maximum one was recorded for Dakhla Oasis specimens 114.16 \pm 5.04 mm. The minimum EL was recorded for Bahariya Oasis specimens 18.70 \pm 0.34 mm and the maximum one was recorded for Eastern Desert specimens 20.78 \pm 1.82 mm. The minimum ZB was recorded for Eastern Desert specimens 13.64 \pm 0.54 mm and the maximum one was recorded for Dakhla Oasis specimens 15.21 \pm 0.62 mm (Figure 3). The minimum BCW was recorded for Helwan region specimens 12.01 \pm 0.22 mm and the maximum one was recorded for Dakhla Oasis specimens 12.88 \pm 0.40 mm. The minimum BL was recorded for Bahariya Oasis specimens 6.45 \pm 0.32 mm and the maximum one was recorded for Dakhla Oasis specimens 6.87 \pm 0.10 mm. The minimum SH was recorded for Helwan region specimens 9.79 \pm 0.11 mm and the maximum one was recorded for Dakhla Oasis specimens 10.25 \pm 0.27 mm. The minimum TRL was recorded for Eastern Desert specimens at 4.22 \pm 0.24 mm and the maximum one was recorded for Dakhla Oasis specimens at 4.49 \pm 0.16 mm (Fig. 4).

Data in Table 3 show eleven significant differences $P < 0.05$ of ratios between the four studied regions. Six of which (EL/HBL, BCW/SL, BCW/ZB, MW/ZB, BL/ZB, and SH/ZB) were the ratios recorded significantly increased $P < 0.05$ in Eastern Desert specimens when compared with the other three studied specimens. Bahariya Oasis specimens recorded a significant increase $P < 0.05$ in TL/HBL and HFL/HBL ratios. While Dakhla Oasis specimens recorded a significant increase $P < 0.05$ in HFL/TL and RW/SL ratios. Finally, Helwan region specimens recorded a significant increase $P < 0.05$ in IOC/SL ratio only (Table 3).

Based on the data presented in Tables 2 and 3 and Figures 3 and 4, the dissimilarity between the four studied regions is shown in Figure 5. Sixteen absolute morphological measurements and seventeen ratios were used to make the dendrogram shown in Figure 5. Eastern Desert and Bahariya Oasis specimens are close to each other and placed in one cluster. Whereas, Helwan region specimens were close somewhat to the Eastern Desert/Bahariya Oasis cluster. Dakhla Oasis specimens are differ from the other studied regions and placed in one cluster. So, the Cairo spiny mouse, *A. cahirinus*, from Dakhla Oasis differs from that from Bahariya Oasis, Helwan region and the Eastern Desert.

When using Pearson correlation (2-tailed) between the sixteen studied absolute measurements, there were a lot of these characters correlated with each other. BM was correlated with nine (9/16) of the tested parameters. The strong correlation of BM was with SL (0.743, $P < 0.01$) and with ZB (0.836, $P < 0.01$) (Figure 6). CIL was correlated with eleven (11/16) of the tested parameters. The strong correlation of CIL was with SL (0.977, $P < 0.01$) and with HBL (0.791, $P < 0.01$) (Figure 6). MW was correlated with twelve (12/16) of the tested parameters. The strong correlation of MW was with BM (0.764, $P < 0.01$), SL (0.695, $P < 0.01$), CIL (0.760, $P < 0.01$), and ONL (0.840, $P < 0.01$) (Figure 6).

Table 3: Mean \pm SD of the Cairo spiny mouse, *A. cahirinus*, ratios of morphological measurements from the four studied areas. Means with the same letter are not significantly different from each other.

Ratio	The Studied Regions			
	Bahariya Oasis	Dakhla Oasis	Helwan Region	Eastern Desert
TL/HBL	1.23^a\pm0.01	0.93 ^c \pm 0.06	1.05 ^{bc} \pm 0.05	1.09 ^b \pm 0.13
EL/HBL	0.19 ^{ab} \pm 0.01	0.17 ^b \pm 0.01	0.17 ^b \pm 0.02	0.21^a\pm0.03
HFL/HB	0.20^a\pm0.01	0.18 ^{ab} \pm 0.02	0.17 ^b \pm 0.02	0.18 ^{ab} \pm 0.02
HFL/TL	0.16 ^b \pm 0.01	0.20^a\pm0.01	0.17 ^{ab} \pm 0.02	0.17 ^{ab} \pm 0.03
ZB/SL	0.48 \pm 0.01	0.49 \pm 0.02	0.48 \pm 0.01	0.47 \pm 0.01
IOC/SL*	0.16 ^{ab} \pm 0.01	0.15 ^b \pm 0.01	0.16^a\pm0.01	0.15 ^{ab} \pm 0.01
IOC/ZB	0.33 \pm 0.01	0.33 \pm 0.01	0.33 \pm 0.01	0.34 \pm 0.01
BCW/SL	0.42 ^{ab} \pm 0.01	0.42 ^{ab} \pm 0.01	0.41 ^b \pm 0.01	0.43^a\pm0.02
BCW/ZB	0.89 ^b \pm 0.02	0.85 ^c \pm 0.03	0.85 ^c \pm 0.03	0.91^a\pm0.03
MW/SL	0.39 \pm 0.01	0.39 \pm 0.01	0.39 \pm 0.01	0.40 \pm 0.01
MW/ZB	0.82 ^b \pm 0.01	0.81 ^c \pm 0.02	0.81 ^c \pm 0.01	0.84^a\pm0.02
TRL/SL	0.14 \pm 0.01	0.14 \pm 0.01	0.14 \pm 0.01	0.15 \pm 0.01
RW/SL*	0.15 ^b \pm 0.02	0.17^a\pm0.11	0.13 ^c \pm 0.01	0.13 ^c \pm 0.01
BL/SL	0.21 \pm 0.01	0.22 \pm 0.01	0.23 \pm 0.01	0.23 \pm 0.01
BL/ZB*	0.45 ^c \pm 0.03	0.45 ^c \pm 0.02	0.47 ^b \pm 0.03	0.48^a\pm0.02
SH/SL	0.33 \pm 0.01	0.33 \pm 0.01	0.33 \pm 0.01	0.34 \pm 0.01
SH/ZB*	0.68 ^{bc} \pm 0.02	0.67 ^c \pm 0.02	0.69 ^b \pm 0.01	0.72^a\pm0.02

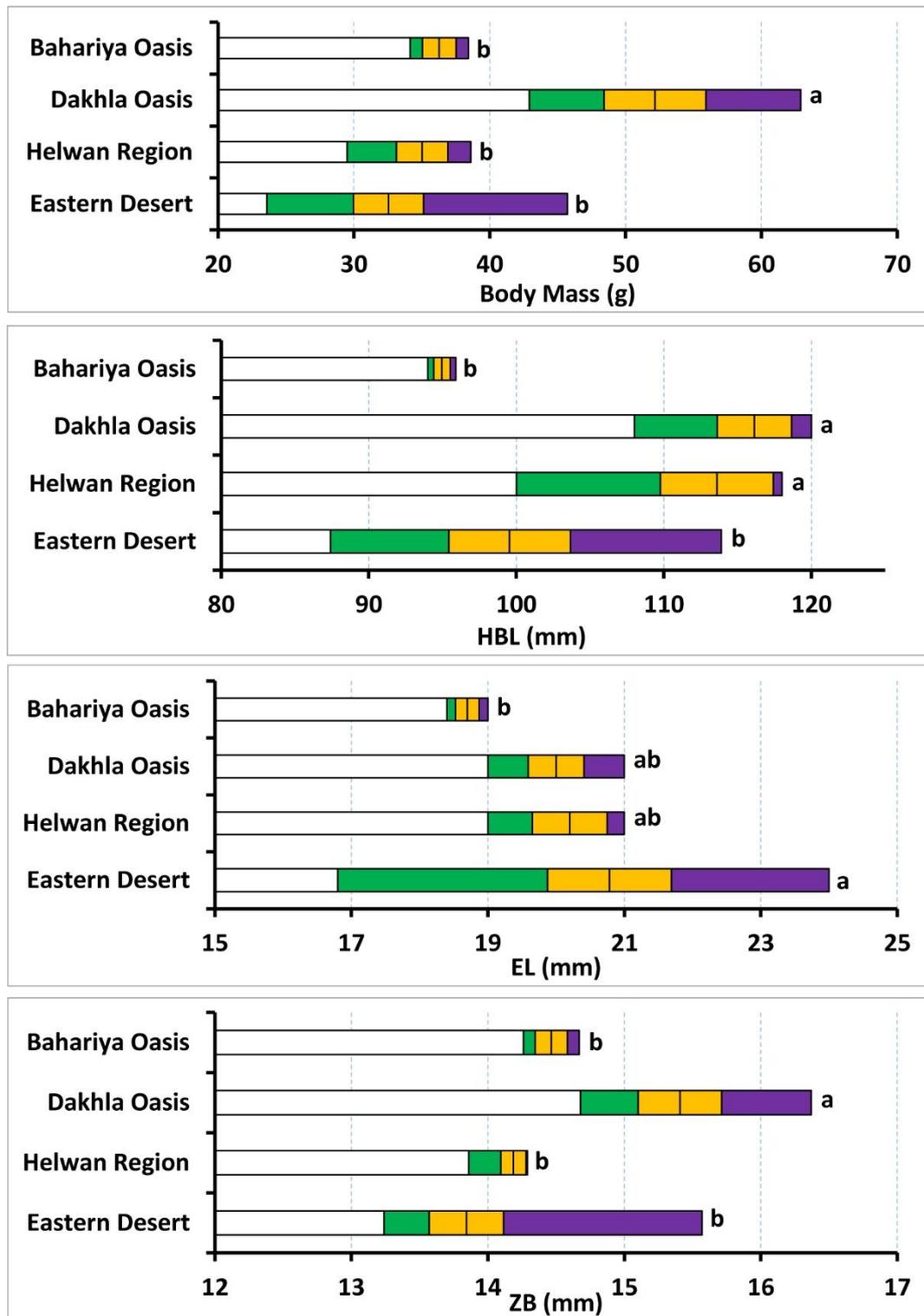


Fig. 3: Body mass (BM), head and body length (HBL), ear length (EL), and zygomatic breadth (ZB) of the Cairo spiny mouse, *A. cahirinus*, from the four studied regions. At the end of white color is the minimum values, green color is the mean values, yellow color = standard deviation, and mauve color is the maximum values. Means with the same letter are not significantly different from each other.

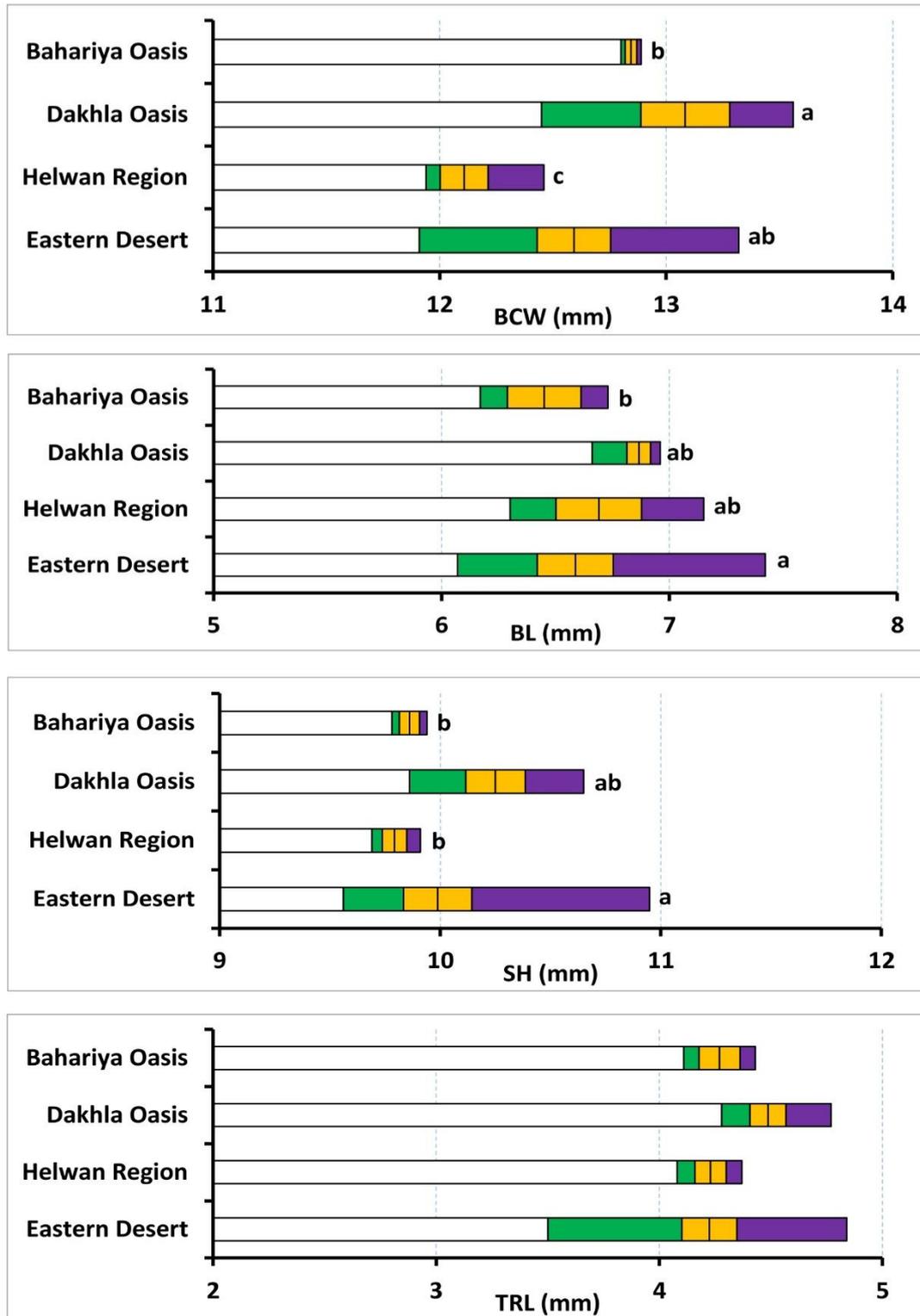


Fig. 4: Braincase width (BCW), bullar length (BL), skull height (SH), and upper tooth row length (TRL) of the Cairo spiny mouse, *A. cahirinus*, from the four studied regions. At the end of white color is the minimum values, green color is the mean values, yellow color = standard deviation, and mauve color is the maximum values. Means with the same letter are not significantly different from each other.

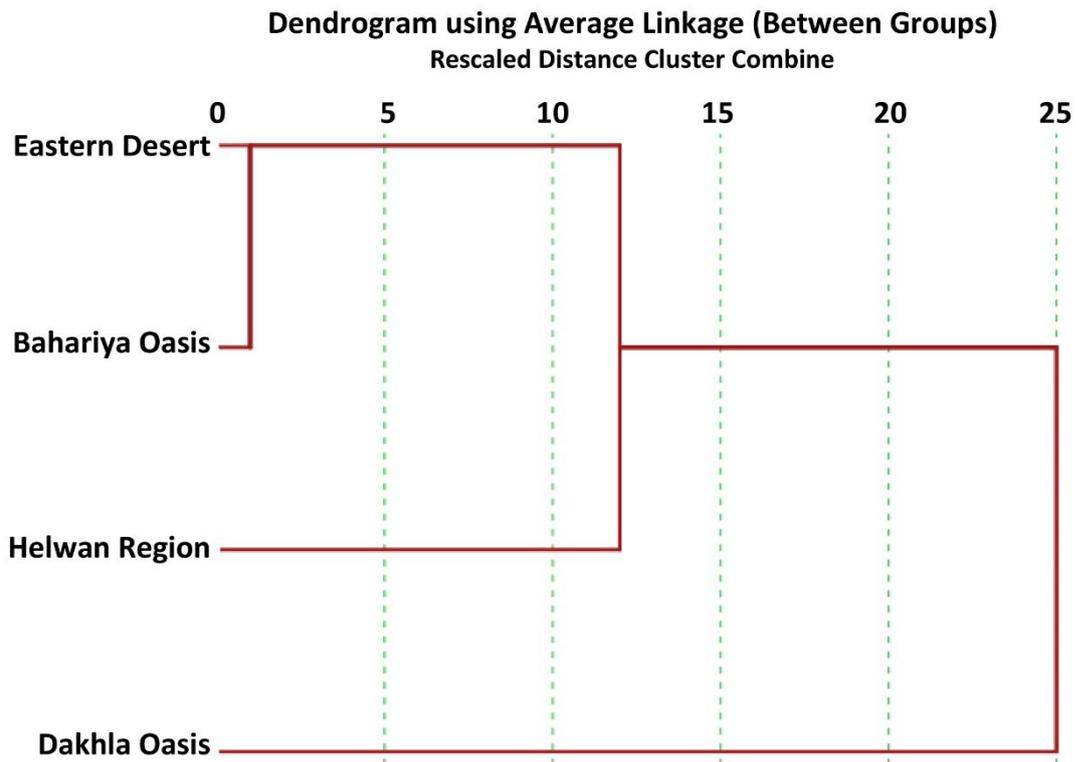


Fig. 5: Dendrogram showing dissimilarity between the Cairo spiny mice, *A. cahirinus*, from the four studied regions.

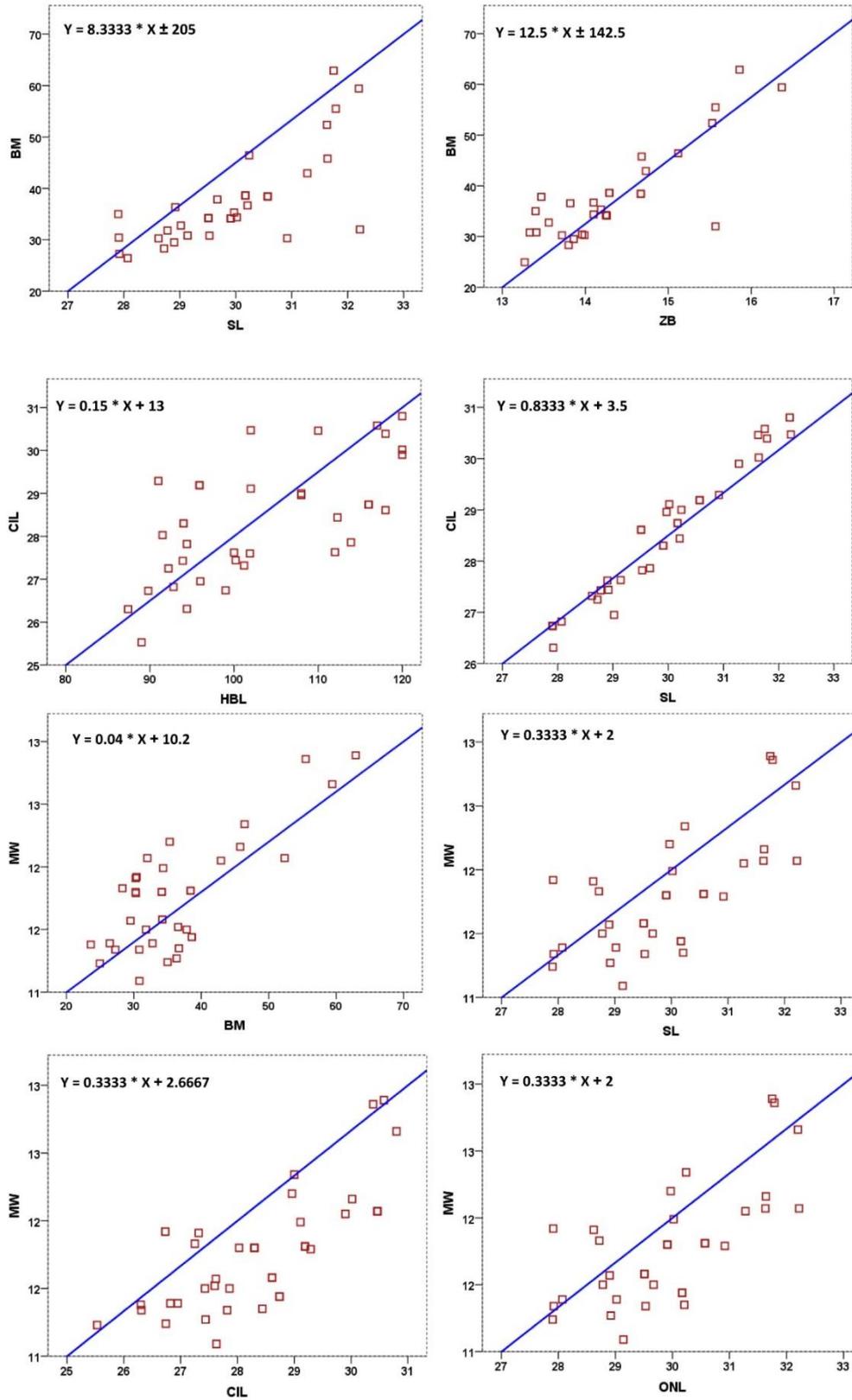


Fig. 6: Pearson correlation between some morphological characters of the Cairo spiny mice, *A. cahirinus*, used in the current study.

DISCUSSION

According to Saleh and Basuony (2014), the current Egypt's land fauna is represented by components with varying biogeographical histories. The ecological diversity in the country's recent geological and geomorphological evolution, as well as in its climatic and biogeographical past, has had a significant role in determining the composition and distribution of the country's fauna. The Western Desert Oases are separated from one another, from the Nile Valley, and from habitable areas in Egypt by hundreds of kilometers of hyper-arid desert. This tremendous barrier appears to be difficult for animals with little mobility to pass. Some animals don't seem to be able to disperse over great distances because of ecological barriers. The majority of species seem to have systems for choosing their habitats, and the capacity to identify and react suitably to favorable environments. These characteristics are so well-developed in some animals that they severely restrict active dispersal. As their ecological patches undergo succession and become inappropriate, species suited to successional habitats must constantly move to new areas. Therefore, compared to species that are constrained to relatively stable settings, such species are considerably more likely to break through barriers and effectively disperse over great distances (Crisci *et al.*, 2009).

The desert may act as a complete barrier for many small terrestrial mammals and other animals that must move much more slowly on foot (Brown and Lomolino, 1998). These animals probably settled in the most isolated areas when, during the Pleistocene, they were linked by bridges of suitable habitat (Patterson, 1984). Ecological risks like competition and predation that might reduce local species abundances and thwart successful dispersal must also be overcome by dispersing animals in addition to the physiological challenges imposed by the ecosystems they travel through (Brown and Lomolino, 1998). According to Crisci *et al.* (2009), species with Asian ancestry likely spread throughout northeastern Africa at that time, settling in the eastern Sahara and other suitable habitats like the then-evolving Nile Valley and the great hollow to the west, which now includes the oases of the Egyptian Western Desert. During that time, Afro-tropical species were also able to spread into southwest Asia and perhaps even the rest of the Palearctic.

There are two different types of ecological barriers that mammals must overcome in order to move between the Levant and Africa today and in the past. Both the highly vegetated and frequently marshy environments of the Nile Delta or Valley and the desert of the Sinai Peninsula fall under this category. A species' capacity to overcome these ecological barriers depends on the physiological adaptations that it has acquired. The mesic biological conditions of the Nile Delta and Valley are an impassable barrier for a species that is acclimated to the desert. Likewise, animals physiologically accustomed to mesic ecosystems face a significant hurdle in the desert. Water conservation adaptations that distinguish desert species are a crucial group of traits that define desert animals apart from their mesic environment counterparts. The past biogeography of the species in question has a direct bearing on the scope of these adaptations (Crisci *et al.*, 2009).

Many mammalian taxa of mesic habitats appear to have responded to Quaternary cyclical climatic changes by expanding their ranges during pluvial periods, which improved population connectivity, and then contracting their ranges during dry periods, which decreased connectivity and caused population fragmentation, according to Saleh and Basuony (2014). It is anticipated that this cycle of isolation and colonization will give rise to a number of spatially constrained lineages that diverged due to random genetic drift or natural selection, regularly allowing for speciation (Hewitt, 2000).

According to Musser and Carleton (1993), certain aspects of the systematics of the spiny mouse, *Acomys*, are still debatable, especially with regard to the species composition, the boundaries of their range, and their evolutionary affinities. *A. cahirinus* is a native of

the Middle East's rocky landscape. It is a member of the Murinae subfamily, which also includes common mice and rats (Ellerman, 1949). The prevailing color of the soil in their habitat has a significant impact on the coloring of spiny mice. This element may be crucial in dry regions, such as Egypt's Western and Eastern Deserts, where scant vegetation covers the desert topography, exposing the soil surface to a lot of sunlight.

Following Setzer (1959), Atallah (1967) identified *A. cahirinus* as a separate species, citing cranial shape and nasal length as the distinguishing characteristics. *A. cahirinus* is a small-to medium-sized murid with conspicuous pigmented ears, according to Osborn and Helmy (1980). Spinous dorsal pelage. V-shaped in cross-section are the spines. Bristles and broad, noticeable annulations alternate on the tail.

Osborn and Helmy (1980) refer *A. cahirinus* as six subspecies from Egypt. They referred to the population of the Nile Delta and Valley to Aswan and Bahariya Oasis as *A. c. cahirinus*, that of Farafra, Dakhla and Kharga Oases as *A. c. helmyi*, that of southern Sinai Peninsula as *A. c. dimidiatus*, that of the northern part of Eastern Desert to Wadi Araba as *A. c. megalodus*, that of Eastern Desert south of Wadi Araba, Nile Valley south of Aswan as *A. c. hunteri*, and that of Gebel Uweinat and possibly El Gilf El Kebir as *A. c. viator*.

So, the populations of the Cairo spiny mouse, *A. cahirinus*, from Bahariya Oasis and Helwan region are known as *A. c. cahirinus*. Usually, the melanistic or slate color and the absence or fuzziness of the tail's bicolor mark allow *A. c. cahirinus* to be identified from other subspecies. Dimensions of *A. c. cahirinus* are alike *A. c. hunteri*, but the average size is much less than in *A. c. helmyi*. *A. c. hunteri* is somewhat equal in dimensions to *A. c. cahirinus*, but does not exhibit the strong melanistic features, such as a dark blackish back and brownish or greyish sides, that nonmelanistic *A. c. cahirinus*. These results are agreed with Osborn and Helmy (1980) and Walid (2000).

The present study confirmed the close similarity between *A. cahirinus* populations from Eastern Desert (*A. c. hunteri*) and Bahariya Oasis (*A. c. cahirinus*) (Figure 5). Also, *A. cahirinus* population from the Helwan region (*A. c. cahirinus*) is similar to the Bahariya Oasis/Eastern Desert cluster (Figure 5). According to Osborn and Helmy (1980), a sample of *A. c. hunteri* from buildings resembles *A. c. cahirinus* in that it has greyish sides and a belly. *A. c. cahirinus* specimens from nearby hills resemble typical *A. c. hunteri*. The first cluster, as depicted in Figure 5, encompasses the *A. c. hunteri* and *A. c. cahirinus* subspecies from the Eastern Desert and Bahariya Oasis, respectively, based only on geography and the differences in *A. cahirinus* habitats. The *A. c. cahirinus* subspecies is represented by the second cluster, which is close to the first cluster. There is a distinct separate cluster for the Dakhla Oasis population, which according to (Osborn and Helmy, 1980), belongs to the subspecies *A. c. helmyi*.

With regard to measurements, data in Tables 2 and 3 indicate considerable geographical variation in dimensions in *A. cahirinus*. There are gradations in dimensions among all populations of this species. Table 2 and figures 2, 3, and 4 show that the skulls with the largest dimensions are of subspecies *A. c. helmyi* from Dakhla Oasis in the Western Desert. The current findings are in agreement with those reported by Osborn and Helmy (1980) who noticed that isolated samples of *A. c. helmyi* from Farafra Oasis in the Western Desert are pale dorsally and the dimensions of *A. cahirinus* subspecies vary greatly.

According to Setzer (1959), the melanistic *A. c. cahirinus* is the most prevalent mouse in buildings and houses and is thought to be almost entirely commensal in the Nile Delta and Valley. Some of these mice were taken from cliffs, steep hills, date palm groves, and gardens. This subspecies is widely distributed in tombs and temples, where melanism, incidentally, tends to become lighter in color.

Walid (2000) reported the desert subspecies of the Cairo spiny mice typically live in steep canyons, cliffs, and hillsides, but they can also be seen coexisting with humans in villages and traditional homes. The Eastern and Western Deserts both have areas where the

Cairo spiny mice are particularly found near date palms. Distribution doesn't seem to be impacted by altitude as long as food is available. In the southeast of Egypt, burrows in the sand have been home to the Cairo spiny mice (Hoogstraal *et al.*, 1957). Although active at all times of the day, *A. cahirinus* is most frequently observed in the early morning and late afternoon. Extremely agile, difficult to handle, and quick to bite, spiny mice constitute a threat to humans (Hoogstraal *et al.*, 1957).

According to Abou Egla *et al.* (2008), correlations between an animal's morphology and ecological factors like habitat characteristics highlight the close connection between phenotype and environment. However, these correlations are frequently difficult to interpret because the functional significance of morphological variations is frequently unknown. Numerous cranial and dental characteristics were associated with the current investigation (Figure 6). On the other hand, the majority of these traits have strong positive correlations with body weight, condyloincisive length, and mastoid width.

Younes and Mohallal (2023) noticed that the most of cranial and dental characters of the Egyptian weasel, *Mustela subpalmata*, were highly positively correlated with each other at about 0.9 $P < 0.01$. The present findings, together with other previous ones on different animals somewhat emphasized the relationships between cranial and dental measurements. Finally, from a geographical perspective, the line separating Western and Eastern Deserts fauna is the Nile Valley and Delta. This distributional break is most pronounced at the Nile Valley and Delta separates the Eastern Desert from Western Desert *A. cahirinus* populations.

CONCLUSION

The mesic biological conditions of the Nile Delta and Valley are an impassable barrier for a species that is acclimated to the desert. *A. cahirinus* of the deserts to the east and west is separated from its populations and genetic exchange between these separated populations by the Nile Valley and Delta, which have extremely distinct environmental conditions. Based on sixteen absolute cranial and dental measurements and seventeen ratios used here, the *A. c. helmyi* from Dakhla Oasis differ greatly from those Bahariya Oasis (*A. c. cahirinus*), Helwan (*A. c. cahirinus*), and Eastern Desert (*A. c. hunteri*) populations. There were many cranial and dental characteristics correlated with each other. Most of these characteristics are highly positively correlated with body mass, condyloincisive length, and mastoid width.

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Declarations:

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ARABIC SUMMARY

دلتا وادي النيل كحاجز بيئي أمام الثدييات الصحراوية: مع إشارة خاصة إلى فأر القاهرة الشوكي، *Acomys cahirinus*

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تعتبر دلتا وادي النيل بمثابة حاجز بيئي طبيعي مهم لا تستطيع حيوانات الصحاري الغربية والشرقية عبوره. بالنسبة لإعادة هيكلة الجغرافيا الحيوية التاريخية للموائل القاحلة، ويُعد جنس *Acomys* نموذجًا ممتازًا لهذه الهيكلة. تسمح الحواجز التي تقيد حركة الحيوانات بالعزلة الجغرافية. في الدراسة الحالية، لفحص القوى التطورية الدافعة للتمايز بين عشائر فأر القاهرة الشوكي، *Acomys cahirinus*، خاصة فيما يتعلق بالعلاقة الجغرافية الحيوية بين الصحاري الغربية والشرقية في مصر، تم استخدام ثمانية وثلاثون جمجمة لعينات ذكور من فأر القاهرة الشوكي من أربع مناطق مختلفة من مصر ضمن المجموعة المرجعية الحيوانية لجامعة الأزهر في القاهرة، مصر. خمس من هذه الجمجم تم تجميعها من الواحات البحرية، وسبع من الواحات الداخلة، وخمس من منطقة حلوان، وواحدة وعشرون جمجمة من جنوب الصحراء الشرقية. واستنادًا إلى ستة عشر قياسًا مطلقًا لهذه الجمجم وسبعة عشر نسبة، وجد أن عشائر *A. c. helmyi* من الواحات الداخلة تختلف بشكل كبير عن عشائر الواحات البحرية (*A. c. cahirinus*)، ومنطقة حلوان (*A. c. cahirinus*)، والصحراء الشرقية (*A. c. hunteri*). كما أوضحت النتائج أنه يوجد العديد من قياسات الجمجمة والأسنان مرتبطة ببعضها البعض ارتباطًا كبيرًا. كما ترتبط معظم هذه القياسات للغاية بكتلة الجسم (BM) وطول الجمجمة من اللقمة الفذالية إلى مقدمة الأسنان (CIL) وعرض الجمجمة من عند فتحتي صماخ الأذن (MW). وبالرغم من وجود الحاجز البيئي الطبيعي (دلتا وادي النيل) إلا أنه وُجد تشابه كبير بين عشائر فأر القاهرة الشوكي من الواحات البحرية (الصحراء الغربية) ومن الصحراء الشرقية مع ملاحظة اختلاف عشائر فأر القاهرة الشوكي من الواحات الداخلة (الصحراء الغربية) عن باقي العشائر محل الدراسة.