Egyptian Journal of Zoology (EJZ)
Publisher: The Zoological Society of A. R. Egypt
DOI: 10.21608/ejz.2023.197104.1095

p-ISSN: 1110-6344
e-ISSN: 2682-3160

RESEARCH ARTICLE

STRUCTURAL AND FUNCTIONAL CHANGES IN THE KIDNEYS IN AN ISOLATED POPULATION OF *GERBILLUS GERBILLUS* IN THE EGYPTIAN NILE DELTA

Mahmoud I. Younes*; Mohamed M. Ghalwash; Mahmoud M. Salem

Zoology Department, Faculty of Science, Al-Azhar University, Cairo, Egypt

Article History:
Received: 28 February 2023
Revised: 6 April 2023
Accepted: 15 April 2023

Published Online:
8 June 2023

Keywords:
Desert adaptation
Egypt
Gerbillus gerbillus
Kidney
Nile Delta

***Correspondence:**
Mahmoud Younes
Zoology Department
Faculty of Science
Al-Azhar University
Cairo, Egypt
E-mail:
myounes@azhar.edu.eg

ABSTRACT

A recently-discovered population of the lesser Egyptian gerbil "*Gerbillus gerbillus*", a rodent of extreme desert habitats inhabits an isolated area in the well-watered Nile Delta. The population has been isolated in this atypical habitat since the formation of the modern Nile Delta in the late Pleistocene-early Holocene and has since been subjected to environmental conditions that are very different from those of their typical extreme desert habitats. This study examined the renal morphology and a suite of hematological and biochemical parameters in 57 Egyptian gerbils to assess whether this isolation has resulted in any detectable structural and/or functional changes in the Nile Delta population compared with the other populations. Significant morphological changes in the kidney structure were detected among the groups, and included higher relative medullary thickness and fewer but larger cortical and juxtamedullary glomeruli with higher relative glomerular blood volume. These changes may reflect adaptive morphological and physiological changes developed following the isolation of the northern Nile Delta population that began with the encroaching mesic and estuarine conditions of the northern fringes of the Nile Delta some 12000 years before the present. Such changes appear to be related to the need to excrete excess salts associated with feeding on halophytic plant material of the northern Nile Delta habitat. The changes detected in some of the tested hematological and biochemical parameters are difficult to be explained and may be secondary to the development of the ability to get rid of excessive salt load or as an adaptation to different environments.

INTRODUCTION

The lesser Egyptian gerbil, *Gerbillus gerbillus* (Olivier, 1801), is a widespread small rodent of arid and hyper-arid habitats in the Sahara and the Middle East. In Egypt, the species occurs in the arid Mediterranean coastal desert, the vegetated depressions in the hyper-arid Western Desert hinterland, and throughout the hyper-arid Eastern Desert and the Sinai Peninsula[1,2]. A small population occurs in a narrow belt of coastal dunes in the north-central region of the Nile Delta (unpublished data). Surrounded by the mesic habitats of the Nile Delta, these isolated desert patches and their associated desert fauna seem to represent a relict biodiversity of the time before the formation of the Nile Delta. The nearest *G. gerbillus* population occurring in a more typical habitat, is found in the Mediterranean coastal dunes of northern Sinai[1,2].

Geological evidence shows that the modern Nile and its Delta were formed some 12000 years before the present. This implies that the northern Nile Delta, Faiyum, Western Mediterranean Coastal Desert (WMCD), and Sinai populations have been separated from each other for at least 12000 years[3-5]. It is not known, however, if the long isolation of the northern Nile Delta population in their atypical, less arid habitat, has affected the internal morphological of physiological features in these animals.

The mammalian kidney has a prevalent role in controlling the volume and concentration of body fluids. The prevalence of nephrons with long loops of Henle is reflected in extended renal papillae[6,7] and is directly proportional to the medullary thickness[8]. Sperber[9] was the first to show a relationship between the renal papilla length and the availability of drinking water in the natural habitat of an animal. Specifically, mammals living in arid and semiarid habitats tended to have exceptionally long loops of Henle, as compared with mammals living in mesic habitats. Sperber[9] proposed the relative medullary thickness (RMT) as an index for quantifying the relative length of the longest loops of Henle. He found that mammals from arid habitats had higher values of RMT and produce more concentrated urine than those from more mesic habitats.

Both RMT and urine concentration scaled negatively with body mass. When considering the effect of habitat (with body mass as a covariate), mammals from arid habitats tended to have higher urine concentration and greater RMT, as compared with those living in mesic habitats. The medullary thickness gave similar results when tested across habitats. Hence, allometric relationships for urine concentrating ability and RMT have been developed for mammals living in xeric[8,10] and those living in mesic environments[8].

The current study aimed to investigate whether the relatively short period of isolation, in evolutionary terms, has resulted in any adaptive changes in kidney functional and structural aspects, as well as in a set of hematological and biochemical parameters in the isolated *G. gerbillus* populations of northern Nile Delta and Faiyum, when compared with those of the more typical, hyper-arid habitats of WMCD and northern Sinai.

MATERIAL AND METHODS

Collection of gerbils

A total of 57 specimens of the lesser Egyptian gerbil, *G. gerbillus*, of both sexes, were legally trapped from the four different regions between November 2020 to August 2021. These regions were Al-Dabaah, Western Mediterranean Coastal region (14 specimens: 13 males and one female), Kom O'shim, Faiyum region (13 male specimens), Baltim in the northern region of the Nile Delta (13 specimens: 12 males and 1 female), and Bir El-Abd, North Sinai (17 specimens: 15 males and 2 females) (Figure 1). After trapping, all animals were identified, weighed, and taken to the laboratory. Rodents were trapped, treated, and investigated in accordance with the guidelines of the Ethical Committee of Desert Research Center for animal use, El Matareya, Cairo, Egypt (approval number: ACUC-APPD-APPRD-DRC-38).

The study areas

The northern fringes of the Nile Delta consist of a flat expanse of sandy plain, locally known as *Barari* (wasteland) extending for up to about 10 km inland, with scattered dunes, and numerous sand mounds stabilized by wild vegetation (phytogenic mounds). Dune types vary from simple barchans with horns pointing southward, to complex and deformed barchans, and small linear dunes. Maximum

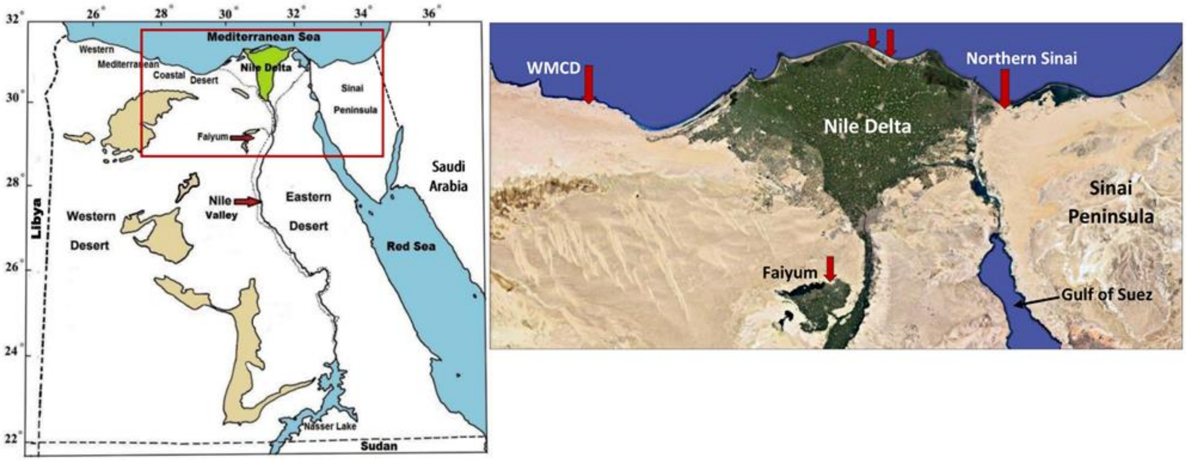

Figure 1: Map of Egypt (left) showing *G. gerbillus* collection localities (right) in Western Mediterranean Coastal Desert (WMCD), Faiyum, northern Nile Delta, and northern Sinai (red arrows).

height is about 20 m, but the most common height is 2-3 m[11]. The WMCD (Figure 2A) and northern Sinai (Figure 2D) samples were collected from typical desert habitats of barren dunes and other sandy areas with sparsely vegetated, low-lying areas with a variety of xerophytic vegetation. This sandy zone extends southwards to form the Mediterranean coast for close to 50 km in places. No permanent freshwater streams of any kind are found in that sector. The Faiyum samples were collected from an area of partly vegetated, uninhabited, and has some dunes (Figure 2B). The northern Nile Delta samples were collected from an area of partly vegetated, dunes, and elevated patches of sand sheets between the cultivated and the Mediterranean coastline. The area is characterized by a relatively dense vegetation cover, reaching up to 35%, extending over the area from just above the supratidal marine zone, southwards for up to about 5 km in places. The plant cover is dominated by *Zygophyllum album*, which is a very common succulent desert plant in the region (Figure 2C).

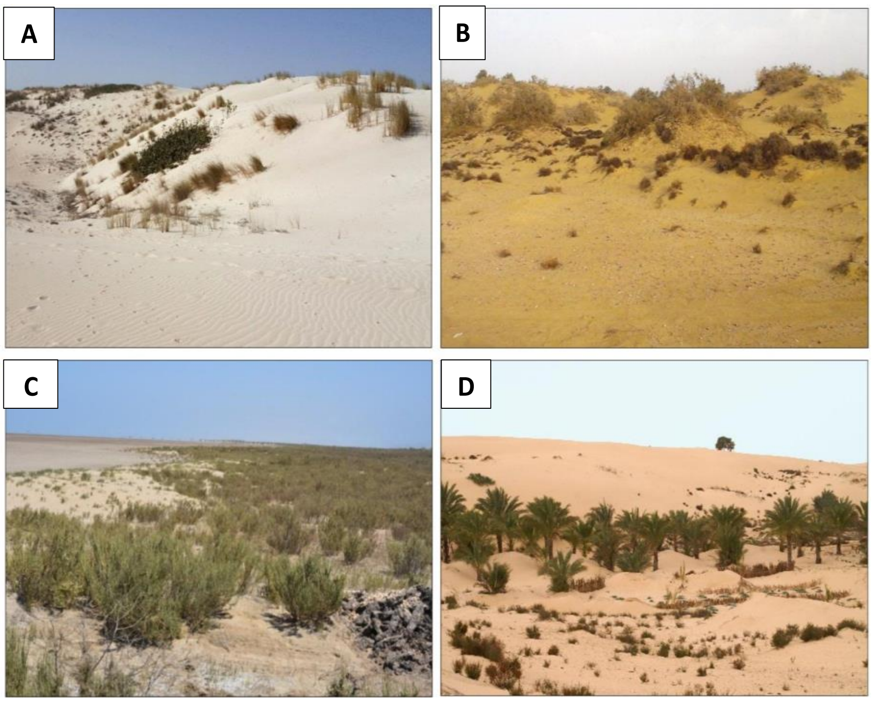

Figure 2: *G. gerbillus* collection localities in Western Mediterranean Coastal Desert (A), Faiyum (B), northern Nile Delta (C), and northern Sinai (D).

Blood and tissue sampling

In the laboratory, blood samples were taken in capillary tubes from the retro-orbital venous plexus. Part of the blood sample was mixed with EDTA for measuring the hematological parameters and collecting the plasma samples. The rest of the sample was allowed to clot to collect serum. Samples were then centrifuged to separate plasma and sera and stored at −20°C until analyzed for measuring the biochemical parameters. The animals were then sacrificed and the kidneys of each animal were carefully removed and weighed to calculate the kidney-to-body ratio (KBR). One kidney of each animal was embedded in paraffin for light microscopy investigation.

Hematological and biochemical Analyses

Red blood corpuscles (RBCs), while blood cells (WBCs), and platelet counts were carried out using a hemocytometer "Neubauer chamber". Hemoglobin (Hb) content, hematocrit (Hct) value, and RBC indices [mean cell volume (MCV), mean cell Hb (MCH), mean cell Hb concentration (MCHC)] were also determined. Serum urea, uric acid, and creatinine concentrations were determined colorimetrically as described previously [12]. Cholesterol and triglycerides levels were assessed using commercial kits supplied by Spinreact Company (Girona, Spain). Potassium, sodium, chloride, phosphorous [$(PO_4)^{-3}$], and calcium (total and ionized) levels were determined using Spectrum Diagnostics (Cairo, Egypt) commercial kits. Magnesium values were measured using Biomed Diagnostics (White City, OR, USA) kit.

Histological examinations

One kidney was fixed in 10% formalin and then sectioned at 5 µm. Sections were stained with hematoxylin and eosin[13]. The renal tissue sections were microscopically examined and the cortical, as well as outer and inner medullary thickness of the kidney was measured using a calibrated eyepiece. The total number of glomeruli in a longitudinal mid-sagittal section was also estimated. To avoid the variation in animal size, these measurements were factorized by kidney weight according to Altaschuler *et al.*[14]. The ratio of medullary to cortical thickness is one indicator of the species' urine-concentrating capacity[15]. The glomerular diameter (D) was calculated as $D = (L+B) / 2$, where, L is the long glomerular axis and B is the short glomerular axis. The glomerular volume was calculated using the formula $GV = \pi / 6(LB)^{3/2}$, where GV is the glomerular volume, π is a constant equal to 3.14, L is the long glomerular axis, and B is the short glomerular axis. The relative glomerular blood volume (RGBV) was calculated as described by Palkovits and Zolani[16] using the formula $RGBV = GV \times N$, where N is the average number of glomeruli. Relative medullary thickness (RMT) was calculated according to the method of Sperber[9] as $RMT = 10(\text{medullary thickness}) / (\text{kidney volume})^{1/3}$, where kidney volume is the product of the dimensions of the kidney.

Statistical analysis

The results are expressed as the mean ± standard deviation. Comparison between the four studied regions was carried out using one-way ANOVA with Duncan post hoc test. The *P* values less than 0.05 were considered to be statistical significance. All statistical analyses were performed using SPSS statistical version 20.0 software package (SPSS® Inc., Chicago, IL, USA).

RESULTS

Figure "3" showed transverse sections in kidneys of *G. gerbillus* collected from Western Mediterranean Coastal Desert (A-C), Faiyum (D-F), northern Nile Delta (G-I), and northern Sinai (J-L). Data presented in Table "1" showed the average body and kidney weights and the KBW ratio of the lesser Egyptian gerbil, *G. gerbillus*, from the studied regions. All of these tested parameters were significantly different ($P<0.05$). The largest body weight was found in gerbils from northern Sinai (35.04±5.07 g) and the smallest one was recorded in gerbils from Faiyum (18.32±3.63 g).

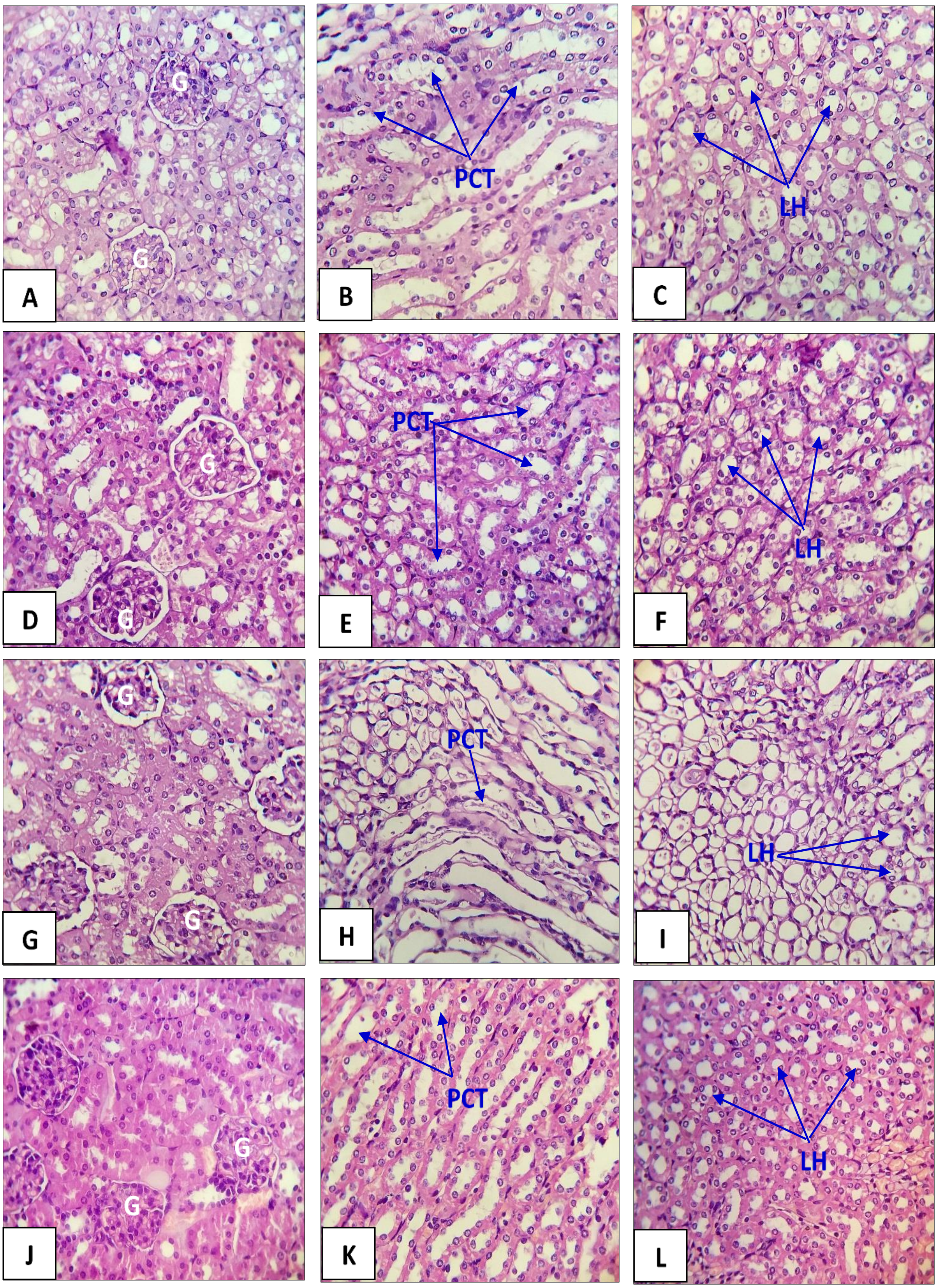

Figure 3: Transverse sections in *G. gerbillus* kidney from Western Mediterranean Coastal Desert (A-C), Faiyum (D-F), northern Nile Delta (G-I), and northern Sinai (J-L). Each row involving Cortex, outer medulla, and inner medulla, respectively (stain: hematoxylin and eosin; magnification: 400×). Where, G = glomerulus, PCT = proximal convoluted tubules, and LH = loop of Henle.

Table 1: Body and kidney weights of *G. gerbillus* from WMCD, Faiyum, northern Nile Delta, and northern Sinai regions.

	WMCD	Faiyum	Northern Nile Delta	Northern Sinai
Body weight (g)	27.34±3.69^{b}	18.32±3.63^{c}	31.03±2.43^{b}	35.04±5.07^{a}
Kidney weight (g)	0.11±0.01^{bc}	0.09±0.01^{c}	0.14±0.01^{a}	0.12±0.03^{b}
Kidney weight/body weight (%) × 10^{-3}	4.02±0.56^{bc}	4.91±0.15^{a}	4.47±0.04^{b}	3.42±0.05^{c}

Displayed data as mean ± standard deviation. Means in the same row having the same superscript letter are not significantly different. Data of Western Mediterranean Coastal Desert (WMCD) and Faiyum regions were quoted from Ghalwash *et al*.[17].

Changes in the renal histology of gerbils collected from different populations

The collected gerbils from the northern Nile Delta were significantly higher (P<0.05) in most of the tested kidney parameters (9 from 13 parameters as shown in Table 2). The minimum values of RMT, cortical glomerular diameters and volumes, and cortical RGBV were recorded in gerbils collected from the northern Sinai region. The minimum values of juxtamedullary diameters and juxtamedullary RGBV were recorded in gerbils from the Faiyum region. The minimum value of juxtamedullary glomerular volumes was recorded form the WMCD region. The maximum values of the above-mentioned kidney parameters were recorded in gerbils from the northern Nile Delta region (Table 2).

Table 2: Kidney parameters of *G. gerbillus* from WMCD, Faiyum, northern Nile Delta and northern Sinai regions.

	WMCD	Faiyum	Northern Nile Delta	Northern Sinai
Kidney volume (mm^3)	209.25±67.70^{b}	174.00±52.19^{bc}	133.88±39.99^{c}	372.25±35.42^{a}
Cortical thickness (mm)	1.02±0.14^{a}	0.69±0.09^{c}	0.99±0.11^{ab}	0.86±0.17^{b}
Outer medullary thickness (mm)	0.43±0.01^{b}	0.42±0.02^{b}	0.61±0.07^{a}	0.43±0.07^{b}
Inner medullary thickness (mm)	0.68±0.13	0.63±0.07	0.78±0.10	0.80±0.23
Relative medullary thickness (RMT)	2.31±0.25^{a}	1.92±0.23^{b}	2.78±0.44^{a}	1.71±0.33^{b}
Cortical glomerular number	102.50±6.61^{ab}	93.75±4.80^{bc}	85.25±15.27^{c}	108.25±5.28^{a}
Cortical glomerular diameter (µm)	60.75±8.63^{a}	51.89±7.59^{b}	64.83±5.64^{a}	49.50±3.99^{b}
Cortical glomerular volume × 10^4 (μ^3)	11.29±4.21^{a}	7.34±3.14^{b}	14.20±3.81^{a}	6.06±1.48^{b}
Cortical RGBV × 10^6	11.49±4.13^{a}	7.39±3.18^{b}	12.21±4.03^{a}	6.56±1.71^{b}
Juxtamedullary glomerular number	72.50±4.14^{a}	52.13±5.79^{b}	57.13±8.69^{b}	73.00±5.55^{a}
Juxtamedullary glomerular diameter (µm)	73.55±8.84^{c}	72.90±7.36^{c}	94.22±9.33^{a}	82.69±6.33^{b}
Juxtamedullary glomerular volume × 10^4 (μ^3)	20.13±6.43^{b}	20.29±6.43^{b}	43.68±13.38^{a}	29.45±7.27^{b}
Juxtamedullary RGBV × 10^6	14.69±5.13^{b}	10.79±4.50^{b}	24.95±7.97^{a}	21.52±5.76^{a}

Displayed data as mean ± standard deviation. Means in the same row having the same superscript letter are not significantly different. Data of Western Mediterranean Coastal Desert (WMCD) and Faiyum regions were quoted from Ghalwash *et al*.[17].

Changes in the hematological measurements of gerbils collected from different populations

RBCs, WBCs, and platelets counts, Hb content, Hct value, MCV, MCH, and MCHC were significantly different ($P<0.05$) between groups. The minimum values of RBCs were recorded in gerbils from WMCD ($3.89\pm0.35 \times 10^6/mm^3$) and the maximum values were recorded in gerbils from the Faiyum region ($5.46\pm0.48 \times 10^6/mm^3$). The minimum values of WBCs were recorded in gerbils from the northern Sinai region ($1.55\pm0.77 \times 10^3/mm^3$) and the maximum values were recorded in gerbils from the WMCD region ($3.50\pm1.49 \times 10^3/mm^3$). The minimum values of platelets were recorded in gerbils from the northern Sinai region ($195.25\pm51.10 \times 10^3/mm^3$) and the maximum values were recorded in gerbils from the Faiyum region ($291.25\pm56.09 \times 10^3/mm^3$). The minimum values of Hb content were recorded in gerbils from the northern Nile Delta region (8.86±0.91 g/dL) and the maximum values were recorded in gerbils from the northern Sinai region (12.81±0.91 g/dL). The minimum values of Hct value were recorded in gerbils from the northern Nile Delta region (27.79±2.29%) and the maximum values were recorded in gerbils from the Faiyum region (37.96±6.34%). The minimum values of MCV were recorded in gerbils from the northern Sinai region (71.00±9.67 fL) and the maximum values were recorded in gerbils from the WMCD region (91.51±3.58 fL). The minimum values of MCH were recorded in gerbils from the northern Nile Delta region (25.33±5.0 pg) and the maximum values were recorded in gerbils from the WMCD region (31.38±1.35 pg). The minimum values of MCHC were recorded in gerbils from the Faiyum region (30.23±1.08 g/dL) and the maximum values were recorded in gerbils from the northern Sinai region (36.04±2.23 g/dL) as shown in Table "3".

When comparing the studied regions it is noted that the gerbils collected from WMCD recorded the highest values of WBCs, MCV, and MCH, but recorded the lowest value of RBCs only. The gerbils collected from the Faiyum region recorded the highest values of RBCs, platelets, and Hct, but recorded the lowest value of MCHC only. The gerbils collected from the northern Nile Delta region didn't record any highest values in the hematological parameters and recorded the lowest values of Hb, Hct, and MCH. Finally, the gerbils collected from the northern Sinai region recorded the highest values of Hb and MCHC, but recorded the lowest values of WBCs, platelets, and MCV (Table 3).

Table 3: Hematological parameters of *G. gerbillus* from WMCD, Faiyum, northern Nile Delta and northern Sinai regions.

	WMCD	Faiyum	Northern Nile Delta	Northern Sinai
RBCs × $10^6/mm^3$	3.89±0.35^{b}	5.46±0.48^{a}	4.04±0.67^{b}	5.42±0.91^{a}
WBCs × $10^3/mm^3$	3.50±1.49^{a}	2.38±0.89^{ab}	3.35±1.28^{a}	1.55±0.77^{b}
Platelets × $10^3/mm^3$	285.25±104.77^{a}	291.25±56.09^{a}	209.63±90.0^{b}	195.25±51.10^{b}
Hb (g/dL)	11.83±1.32^{ab}	10.85±1.69^{b}	8.86±0.91^{c}	12.81±0.91^{a}
Hct (%)	37.66±3.94^{a}	37.96±6.34^{a}	27.79±2.29^{b}	35.48±0.66^{a}
MCV (fL)	91.51±3.58^{a}	85.05±4.05^{b}	85.28±2.44^{b}	71.00±9.67^{c}
MCH (pg)	31.38±1.35^{a}	30.56±1.45^{a}	25.33±5.0^{b}	25.41±1.85^{b}
MCHC (g/dL)	33.05±1.26^{b}	30.23±1.08^{c}	30.38±3.55^{c}	36.04±2.23^{a}

Displayed data as mean ± standard deviation. Means in the same row having the same superscript letter are not significantly different. Data of Western Mediterranean Coastal Desert (WMCD) and Faiyum regions were quoted from Ghalwash *et al*.[17].

Changes in the biochemical measurements of gerbils collected from different populations

All tested biochemical parameters were significantly different ($P<0.05$) in the four *G. gerbillus* populations, except for serum creatinine, uric acid, and potassium. Cholesterol, triglycerides, and total and ionized calcium were lower in gerbils from the northern Sinai region, but sodium, chloride, and magnesium were higher in gerbils from the northern Sinai region. The gerbils from the northern Nile Delta region recorded the lowest values of urea, chloride, and magnesium, but the highest values for triglycerides and total calcium. The gerbils collected from WMCD recorded the highest value of creatinine only, but recorded the lowest values of phosphorous only. The gerbils from the Faiyum region recorded the lowest value for sodium only and the highest values for urea, cholesterol, ionized calcium, and phosphorous (Table 4).

Table 4: Biochemical parameters of *G. gerbillus* from WMCD, Faiyum, northern Nile Delta and northern Sinai regions.

	WMCD	Faiyum	Northern Nile Delta	Northern Sinai
Urea (mg/dL)	54.26±5.15^{b}	67.38±10.57^{a}	44.88±3.23^{b}	66.50±9.17^{a}
Creatinine (mg/dL)	1.54±0.33	1.34±0.03	0.71±0.19	0.73±0.06
Uric acid (mg/dL)	2.41±0.68	3.26±0.13	1.56±0.33	2.25±0.39
Cholesterol (mg/dL)	157.50±14.51^{b}	218.25±43.91^{a}	165.88±15.11^{b}	105.75±11.54^{c}
Triglycerides (mg/dL)	157.38±16.48^{c}	206.88±32.05^{b}	271.13±72.78^{a}	129.25±27.62^{c}
Potassium (K) (mmol/L)	6.55±0.19	6.79±0.14	6.78±0.14	6.45±0.37
Sodium (Na) (mmol/L)	154.76±1.17^{b}	143.25±1.28^{d}	146.13±1.89^{c}	163.73±4.40^{a}
Chloride (Cl) (mmol/L)	113.46±1.16^{b}	110.13±1.96^{c}	103.63±1.30^{d}	122.19±2.95^{a}
Total calcium (mg/dL)	7.90±0.08^{c}	10.31±0.09^{b}	10.79±0.10^{a}	5.67±0.09^{d}
Ionized calcium (mg/dL)	3.42±0.10^{c}	5.20±0.20^{a}	5.08±0.07^{b}	2.87±0.04^{d}
Phosphorous (mg/dL)	12.25±1.16^{c}	17.49±1.43^{a}	12.51±0.32^{c}	15.00±1.85^{b}
Magnesium (mg/dL)	4.19±0.08^{c}	4.63±0.13^{b}	3.51±0.24^{d}	5.13±0.33^{a}

Displayed data as mean ± standard deviation. Means in the same row having the same superscript letter are not significantly different. Data of Western Mediterranean Coastal Desert (WMCD) and Faiyum regions were quoted from Ghalwash *et al*.[17].

DISCUSSION

G. gerbillus is a widespread rodent, typical of arid and hyper-arid habitats of North Africa and the Middle East[1,18]. The distribution of this typical desert rodent across its vast range is interrupted by the local mesic conditions created in the flood plain and Delta of the Nile River, which cut across the eastern Sahara from south to north. With its drastically different ecological conditions, the Nile River and its Delta create a mesic ecological barrier separating populations of many desert species to the east of the Nile from those to the West[1]. Small pockets of desert remain, however, in the northern fringes of the Nile Delta close to the climatically arid, Mediterranean coast and are surrounded by extensive areas of well-watered habitats created by the vast network of river distributaries. These isolated pockets of the desert still retain some of their original desert fauna that inhabited the area before the formation of the Nile Delta. The recently discovered *G. gerbillus* population in the northern Nile Delta (unpublished data) is separated from their nearest conspecific population in the extremely arid northern Sinai and WMCD by the extensive estuaries of the Nile[1]. It may be assumed that this northern Nile Delta population has been genetically isolated into their relict pockets of desert habitats, at least since the formation of the Modern Nile in the late Pleistocene, some 12000 years ago[3-5].

Our results showed that the numbers of the females in the collected specimens are not enough for the statistical analysis. On the other hand, there were a significant difference between gerbils' body and kidney weights of the studied regions. In WMCD, Faiyum, northern Nile Delta, and northern Sinai populations, the cortical glomeruli were more abundant than the juxta-medullary glomeruli (1.41:1, 1.78:1, 1.49:1 and 1.48:1, respectively). This is contrary to the assumption that the long-loop, juxta-medullary nephrons, which allow the production of more concentrated urine, are more abundant in desert mammals[19]. However, the results also showed that juxtamedullary glomeruli were 1.21, 1.40, 1.45, and 1.67 times larger in average diameter and 1.78, 2.76, 3.08, and 4.89 in average volume than cortical glomeruli in the four gerbil populations of WMCD, Faiyum, northern Nile Delta, and northern Sinai regions, respectively. Similarly, the relative glomerular blood volume (RGBV) is 1.28, 1.46, 2.04, and 3.28 times larger in the juxtamedullary glomeruli than in the cortical glomeruli in the WMCD, Faiyum northern Nile Delta, and northern Sinai populations, respectively. Similar observations have been reported in several desert mammalian species[15,20,21].

The larger volume of the juxtamedullary glomeruli presents a larger glomerular filtration surface in comparison with cortical glomeruli and may make up for the smaller number resulting in an overall higher glomerular filtration rate through juxtamedullary glomeruli. Dickinson *et al.*[22] reported that glomeruli in the kidney of the desert rodent *Acomys cahirinus* were fewer in number and larger in volume than those in that of the laboratory mouse of similar size. Hanssen[20] stated that the glomerular filtration rate of the juxtamedullary nephron was approximately eight times higher than that of the nephron from the outer cortex. Accordingly, the mere variation in the number of glomeruli in the kidney does not directly affect the ability to produce concentrated urine. The kidney of *Psammomys obesus*, a desert rodent that feeds on salt-loaded halophytic plants and produces a high output of highly concentrated urine, contains 66% short (cortical glomeruli) and 34% long-looped (juxtamedullary glomeruli) nephrons[23]. The juxtamedullary glomeruli, however, are considerably larger than the cortical glomeruli[23]. The larger volume of the juxtamedullary glomeruli may thus lead to preferential filtration in these long-looped nephrons, resulting in higher urine concentration capacity.

Significant differences occur, however, in most of the kidney's histological characteristics. The kidney of gerbils from the northern Nile Delta has a significantly thicker medulla (higher RMT), which is an adaptation correlated to the improved capacity to produce concentrated urine[24,25]. Sperber[9] stated that urine concentrating ability is correlated directly to the lengths of the Henle's loop and collecting ducts that traverse the renal medulla. Schmidt-Nielsen and O'Dell[24] were the first to elucidate a quantitative correlation between the relative length of the longest loops of Henle (as reflected by RMT) and the maximum urine concentration in mammals. RMT is inversely related to body mass; which means that the larger-bodied gerbils (northern Sinai = 35.04±5.07 g) generally have lower values for RMT (1.71±0.33) and a relatively smaller ratio of the kidney to body weight (3.42×10^{-3}±0.05). These findings with agreement with Beuchat[26] and Al-Kahtani *et al*.[27].

The juxtamedullary glomeruli are fewer in number and considerably larger in volume in gerbils of the northern Nile Delta than those from the other studied regions. Relative glomerular blood volume (RGBV) in both cortical and juxtamedullary glomeruli is higher in the gerbil's kidney of the northern Nile Delta than in the other studied populations. These significant differences between the four gerbil populations may reflect adaptive morphological and physiological changes developed following the isolation of the northern Nile Delta population began with the encroaching mesic and estuarine conditions of the northern fringes of the Nile Delta some 12000 years before the present. All of the observed changes are likely to have been driven by certain adaptive pressures imposed by features of the atypical habitat of *G. gerbillus* in the northern Nile Delta. Such changes appear to be related to the ability to excrete a high salt load rather than to conserve water and are somewhat analogous to features in the kidney of *Psammomys obesus*. In that species, unique renal characteristics have evolved primarily to allow getting rid of excess salt ingested with its diet of halophytic plant tissue[23]. These include fewer, but larger cortical and juxtamedullary glomeruli, as well as larger RGBV, which are features, also observed in gerbils of the northern Nile Delta. It is worth noting that *G. gerbillus* in our northern Nile Delta study area shares this habitat with a population of *Psammomys obesus*, the only such a population in the northern Nile Delta region[1].

In the northern Nile Delta, *G. gerbillus* occupies habitats dominated by halophytic plants and salt marsh vegetation. The food of *G. gerbillus* is typically seeds, leaves, and buds of a variety of plants and possibly some insects[1,21]. Only on very few, elevated spots, occur non-halophytic plants, which may be considered the more typical *G. gerbillus* diet. Although the exact food composition and salt contents of the diets of the gerbils in this habitat are not known, one can safely assume that higher salt loads are ingested by these gerbils than are taken by animals occupying more typical desert habitats. It may be further assumed that, since their early Holocene isolation in their atypical habitat, and for the approximately 12000 years that followed, animals of this population were subjected to a selective evolutionary pressure to feed on high salt content diet and excrete excess ingested salt. Although brief in evolutionary terms, this isolation period was sufficient for adaptive morphologic and physiologic changes to evolve, allowing this highly adaptable, fast-reproducing desert rodent to continue to survive. It may thus be assumed that the observed changes appear to be more directed towards the evolved ability to excrete the excessive salt load rather than to conserve water.

Our results also show that gerbils from the WMCD region have significantly higher WBCs, MCV, and MCH and lower RBCs than the other studied regions. The gerbils from the Faiyum region have significantly higher RBCs, platelets, and Hct, and lower MCHC, than the other studied regions. The gerbils from the northern Nile Delta region recorded the lowest values of Hb, Hct, and MCH. The gerbils from the northern Sinai region recorded the highest values of Hb and MCHC and the lowest values of WBCs, platelets, and MCV. Interspecific differences in hematological characters in three species of Australian murid desert rodents, however, are reported to be minor[28], although the age of an animal can affect the levels of some hematological and biochemical parameters[29]. On the other hand, all tested biochemical parameters were significantly different in the four *G. gerbillus* populations, except for serum creatinine, uric acid, and potassium. Serum chloride and sodium values in particular were either similar or higher than those reported for several other mammalian species, including rodents[30-32]. The observed hematologic and biochemical differences between gerbils of WMCD, Faiyum, northern Nile Delta, and northern Sinai regions are difficult to explain. One possible explanation is that such changes are related to adaptive changes in response to the drastically different habitat attributes and resource use pressures affecting those populations, particularly those associated with feeding on a high salt content diet[33,34].

In conclusion, the current study detected significant morphological changes in the kidney structure of the northern Nile Delta when compared with WMCD, Faiyum, and northern Sinai populations. The changes include higher relative medullary thickness and fewer but larger for both cortical and juxtamedullary glomeruli with higher RGBV. These findings may reflect adaptive morphological and physiological changes developed following the isolation of the northern Nile Delta population that began from 12000 years before the present. The changes appear to be related to the need to excrete excess salts associated with feeding on halophytic plant material of the northern Nile Delta habitat.

ACKNOWLEDGMENTS

Authors express their gratitude to Prof. Dr. Mostafa A. Saleh (Zoology Department, Faculty of Science, Al-Azhar University, Cairo, Egypt) for his helpful and continuous advice. Dr. M. Saleh gave us detailed feedback on the manuscript. Also authors thank Dr. Eman Mohalla (Desert Animal Ecology Unit, Desert Research Center, El Matareya, Cairo, Egypt) for helping us to collect the northern Sinai gerbils.

FUNDING SOURCE DISCLOSURE

No funding was received to assist with the preparation of this manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

[1] Osborn, D. J. and Helmy, I. (1980). The Contemporary Land Mammals of Egypt (Including Sinai), Fieldiana Zoology, new series, number 5. Field Museum of Natural History, Chicago, IL, USA.

[2] Ayyad, M. A.; Kassas, M.; Springuel, I. *et al*. (1993). Habitat Diversity: Egypt. National Biodiversity Unit, Cairo, Egypt.

[3] Said, R. (1990). The Geology of Egypt. Routledge, London, UK.

[4] Saleh, M. A. (1997). Amphibians and Reptiles of Egypt. National Biodiversity Unit, Number 6, Cairo, Egypt.

[5] Hamimi, Z.; El-Barkooky, A.; Frías, J. M., *et al*. (2020). The Geology of Egypt. Springer Nature Switzerland AG, Switzerland.

[6] Folk, G. E. (1974). Textbook of Environmental Physiology, 2nd Edition. Lea & Febiger, Philadelphia, PA, USA.

[7] Bankir, L. and de Rouffignac, C. (1985). Urinary concentrating ability: insights from comparative anatomy. Am J Physiol, 249(Pt 2): R643-R666.

[8] Beuchat, C. A. (1996). Structure and concentrating ability of the mammalian kidney: correlations with habitat. Am J Physiol, 271 (1 Pt 2): R157-R179.

[9] Sperber, I. (1944). Studies on the mammalian kidney. Zool Bidrag Uppsala, 22: 249-431.

[10] Calder 3rd, W. A. and Braun, E. J. (1983). Scaling of osmotic regulation in mammals and birds. Am J Physiol, 244(5): R601-R606.

[11] Zaghloul E. A. (2013). Physical Geology and Historical Settlement in North Western Nile Delta Region, Egypt, R & D Project Report. National Authority for Remote Sensing and Space Sciences (NARSS), Cairo, Egypt.

[12] Wu, A. (2006). Tietz Clinical Guide to Laboratory Tests, 4th Edition. W.B. Saunders Co, Philadelphia, PA, USA.

[13] Bancroft, J. D. and Cook, H. C. (1994). Manual of Histological Techniques and Their Diagnostic Application. Churchill Livingstone, Edinburgh, UK.

[14] Altaschuler, E. M.; Nagla, R. B.; Braun, E. J. *et al.* (1979). Morphological study of the desert heteromyid kidney with emphasis on the genus *Perognathus*. Anat Rec, 194(3): 461-468.

[15] Munkacsi, I. and Palkovits, M. (1965). Volumetric analysis of glomerular size in kidneys of mammals living in desert, semidesert or water–rich environment in the Sudan. Circ Res, 17(4): 303-311.

[16] Palkovits, M. and Zolani, B. (1963). [Glomerulometric studies. I. Quantitative-histological methods for the statistical study of the volume of the kidney glomeruli and their percentage ratio in the kidney cortex]. Z Wiss Mikrosk, 65:342-56.

[17] Ghalwash, M. M.; Salem, M. M. and Younes, M. I. (2022). Kidney function and structure, oxidative stress and immunohistochemical expression of *Gerbillus* from two different habitats in Egypt. Egypt Acad J Biol Sci, B. Zoology, 14: 85-99.

[18] Harrison, D. L. and Bates, P. J. J. (1991). The Mammals of Arabia, 2nd Edition. Harrison Zoological Museum, Kent, UK.

[19] Ichii, O.; Yabuki, A.; Ojima, T. *et al.* (2006). Species specific differences in the ratio of short to long loop nephrons in the kidneys of laboratory rodents. Exp Anim, 55(5): 473-476.

[20] Hanssen, O. E. (1961). The frequency of temporarily inactive glomeruli in mice under physiologic condition. Acta Pathol Microbiol Scand, 53: 253-264.

[21] Basuony, M. I. (1997). Ecological variability and kidney structure of eight desert rodents. Egypt J Histol, 20(2): 417-434.

[22] Dickinson, H.; Moritz, K.; Wintour, E. M. *et al.* (2007). A comparative study of renal function in the desert-adapted spiny mouse and the laboratory-adapted C57BL/6 mouse: response to dietary salt load. Am J Physiol Renal Physiol., 293(4): F1093-F1098.

[23] Kaissling, B.; de Rouffignac, C.; Barrett, J. M. *et al.* (1975). The structural organization of the kidney of the desert rodent *Psammomys obesus.* Anat Embryol (Berl), 148(2): 121-143.

[24] Schmidt-Nielsen, B. and O'Dell, R. (1961). Structure and concentrating mechanism in the mammalian kidneys. Am J Physiol, 200(6): 1119-1124.

[25] Marsh, D. J. and Segel, L. A. (1971). Analysis of countercurrent diffusion exchange in blood vessels of the renal medulla. Am J Physiol, 221(3): 817-828.

[26] Beuchat, C. A. (1990). Body size, medullary thickness, and urine concentrating ability in mammals. Am J Physiol, 258(2 Pt 2): R298-R308.

[27] Al-Kahtani, M. A.; Zuleta, C.; Caviedes-Vidal, E. *et al.* (2004). Kidney mass and relative medullary thickness of rodents in relation to habitat, body size, and phylogeny. Physiol Biochem Zool, 77(3): 346-365.

[28] Old, J. M.; Connelly, L.; Francis, J. *et al.* (2005). Hematology and serum biochemistry of three Australian desert murids: the plains rat (*Pseudomys australis*), the spinifex hopping-mouse (*Notomys alexis*) and the central rock-rat (*Zyzomys pedunculatus*). Comp Clin Pathol, 14: 130-137.

[29] Riviello, M. C. and Wirz, A. (2001). Haematology and blood chemistry of *Cebus apella* in relation to sex and age. J Med Primatol, 30(6): 308-312.

[30] Weber, D. K.; Danielson, K.; Wright, S. *et al*. (2002). Hematology and serum biochemistry values of dusky-footed wood rat (*Neotoma fuscipes*). J Wildl Dis, 38(3): 576-582.

[31] Moreau, B.; Vie, J. C.; Cotellon, P. *et al.* (2003). Hematologic and serum biochemistry values in two species of free-ranging porcupines (*Coendou prehensilis, Coendou melanurus*) in French guiana. J Zoo Wildl Med, 34(2): 159-162.

[32] Aroch, I.; King, R. and Baneth, G. (2007). Hematology and serum biochemistry values of trapped, healthy, free-ranging rock hyraxes (*Procavia capensis*) and their association with age, sex, and gestational status. Vet Clin Pathol, 36: 40-48.

[33] Baverstock, P. R. and Watts, C. H. (1974). Water balance and kidney function in some rodents native to Australia. Lab Anim Sci, 24(5): 743-751.

[34] Baverstock, P. R. and Green, B. (1975). Water recycling in lactation. Science, 187(4177): 657-658.

التغييرات التركيبية والوظيفية في الكُلى لعشائر معزولة من الجربوع الصغير "*GERBILLUS GERBILLUS*" في دلتا النيل المصرية

محمود إبراهيم يونس، محمد ممدوح غلوش، محمود محمد محمد سالم

قسم علم الحيوان، كلية العلوم، جامعة الأزهر، القاهرة، جمهورية مصر العربية

تم اكتشاف مجموعة من الجربوع المصري الصغير "*Gerbillus gerbillus*"، وهي قوارض من موائل الصحراء القاحلة تقطن منطقة معزولة في دلتا النيل وفيرة المياه. لقد تم انعزال عشائر الجربوع المصري الصغير في هذا الموئل غير النمطي منذ تكوين دلتا النيل الحديثة في أواخر العصر الجليدي وأوائل عصر الهولوسين، ومنذ ذلك الحين تعرضت هذه العشائر لظروف بيئية مختلفة تمامًا عن موائلها الصحراوية القاسية النموذجية. فحصت الدراسة الحالية مورفولوجيا الكُلى ومجموعة من المعايير الدموية والكيميائية الحيوية في 57 جربوع مصري صغير لتقييم ما إذا كانت هذه العزلة قد أدت إلى أية تغييرات تركيبية و/ أو وظيفية يمكن اكتشافها في عشائر دلتا النيل مقارنة بالعشائر في مناطق أخرى. تم الكشف عن تغيرات مورفولوجية كبيرة في بنية الكُلى بين مجموعات الجرابيع تضمنت زيادة سمك النخاع نسبيًا، وعدد أقل ولكن أكبر من الكبيبات القشرية والمجاورة مع حجم دم كبيبي أعلى نسبيًا. وقد تعكس هذه التغييرات الاختلافات المورفولوجية والفزيولوجية التكيفية التي تطورت بعد انعزال عشائر الجرابيع في شمال دلتا النيل الذي بدأ مع اعتدال الظروف المناخية وزحف مصبات الأنهار في الأطراف الشمالية لدلتا النيل منذ حوالي 12000 عام قبل الوقت الحاضر. ويبدو أن هذه التغييرات مرتبطة بالحاجة إلى إفراز الأملاح الزائدة المرتبطة بالتغذية على الأجزاء النباتية الملحية في موئل شمال دلتا النيل. ويصعب تفسير التغييرات المكتشفة في بعض المعايير الدموية والكيميائية الحيوية المختبرة التي قد تكون ثانوية لتغير القدرة على التخلص من حمل الملح الزائد أو كتكيف مع بيئات مختلفة.