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RESEARCH ARTICLE **Open access**

Interspecific variation within the genus *Ophiomorus* Duméril & Bibron, 1839 (Sauria: Scincidae) in Iran based on morphological characters

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Abstract
Many studies conducted on range of animals showed that morphology is related to habitat. In the present study, we aimed to examine the morphological characteristics of species assigned to the genus *Ophiomorus* in Iran. Seventy-one specimens from throughout the range of distribution in the central plateau of Iran were investigated. Eleven morphometric and four meristic variables were analyzed independently. Multivariate analyses were performed using canonical variate analysis (CVA) and principal component analysis (PCA). The results showed that there is significant morphological differentiation between three species groups *brevipes*, *tridactylus*, and *punctatissimus* in this genus in relation to habitat choice. ANOVA results showed that 14 morphological characters (SVL, HL, HW, HH, SL, LF, LA, LFL, LFH, LHF, NSL, NDSB, NMC, and NIL; 10 metric and four Meristic) were significantly different among all *Ophiomorus* species, which based on this, TL did not show a significant difference among species. Finally, we assigned three species groups based on limb reduction (especially fingers), and habitat surface (comparison based on habitat observations) for all *Ophiomorus* species in Iran. In addition, using newly applied morphological characteristics we proposed an updated identification key for the genus.

Key words: *Adaptation, Biogeography, Morphology, Ophiomorus, Iranian Plateau, Snake Skinks*

INTRODUCTION

Traditional taxonomy based on morphological diagnostics and the morphological species concept, is important to use accurate characteristics to determine the species (Mayr, 2000; Sites & Marshall, 2003; Bauer et al., 2011; Kornilios et al., 2018). However, it should be highlighted that each species may show geographic variation in morphology, and then in this case, the integrated taxonomic study will help the evaluation (Padial et al., 2010; Ford, 2018; Cicero et al., 2021)**.** Reptiles are one of the ancient animal groups that live more than 300 million years on the earth, during this time adapted to different habitats and most diversified (Organ et al., 2008). Due to the low mobility of reptiles and select the microchabitat area as special habitat in some taxa, strict adaptations can be found in these types of animals (Cloudsley-Thompson, 1991). The Family Scincidae in Iran consists of six genera, one of which is the genus

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Ophiomorus, which occurs in most parts of the central Iranian plateau (Nabizadeh et al., 2022). The recent molecular phylogenetic study showed that the genus *Ophiomorus* has a sister relationship with the genus *Mesoscincus* from Central America, which belongs to the Scincidae family (Pyron et al., 2013; Andrade et al., 2016). The genus *Ophiomorus* has 12 species, which show a considerable amount of morphological and ecological diversity. Three species of the genus inhabited the west of the Palearctic, namely in southeastern Europe, the Middle East, and the eastern Mediterranean region, and nine of them are distributed in south and southwest Asia (Nabizadeh et al., 2022). Seven species including endemic and non-endemic species are present in the Iranian plateau (Nabizadeh et al., 2022) (Fig. 1). Iranian endemic species comprise *Ophiomorus maranjabensis*, *Ophiomorus nuchalis*, *Ophiomorus persicus*, and *Ophiomorus streeti* (Anderson, 1999; Nabizadeh et al., 2022) (Fig. 2). Recently, two species of the genus *Ophiomorus* have been described. *Ophiomorus maranjabensis* and *Ophiomorus kardesi* were described in Iran in 2011 and southern Turkey in 2018, respectively (Kazemi et al., 2011; ŠMÍD et al., 2014; Eskandarzadeh et al., 2018; Kornilios et al., 2018). The genus dwells in different types of habitats and surfaces. The results obtained from the morphological studies showed that *O. maranjabensis*, *O. streeti*, and *O. tridactylus* are only distributed in completely sandy habitats or sand dunes, but *O. persicus* lives in hard and stony grounds. In addition, *O. nuchalis*, *O. brevipes*, and *O. blanfordii* live in habitats where the hard ground is a mixture of sand and gravel (Anderson, 1999; Nabizadeh et al., 2022) (Fig. 3). One of the main characteristics of skink members is the short limbs or no limbs, which means that this genus is a monophyletic group taxon (Pyron et al., 2013). Identification of all members of this genus except *Ophiomorus kardesi* was mainly based on morphological traits (Kornilios et al., 2018). The members of this genus choose different habitats based on their morphological characteristics (Greer & Wilson, 2001) and accordingly, Anderson and Leviton (1966) divided the members of this genus into three species groups, *brevipes*, *tridactylus*, and *punctatissimus*. These characters were defined based on their tendency to limb reduction (especially fingers) (Anderson & Leviton, 1966). Anderson (1999) divided the genus *Ophiomorus* into two western and eastern groups based on habitat preferences. The western group have a very cylindrical and long body and a conical snout, and they choose hard surfaces, such as under rocks or hard soils, as habitats which include *Ophiomorus punctatissimus*, *Ophiomorus latastii*, and *Ophiomorus persicus*. The eastern group consists of *Ophiomorus chernovi*, *Ophiomorus brevipes*, *Ophiomorus blanfordii*, *Ophiomorus nuchalis*, *Ophiomorus streeti*, *Ophiomorus raithmai*, and *Ophiomorus maranjabensis* that are dwelling in loose sand and sand dune regions. Due to the nocturnal activity and nest under the surface or being cryptic, the genus *Ophiomorus* has not been studied thoroughly. In the present study, we aimed to examine the morphological characteristics of species of the genus *Ophiomorus* from the Iranian Plateau. Meanwhile, the main goal of this study was to investigate the validity of the morphological characteristics of the *Ophiomorus* species in the Iranian Plateau.

MATERIAL AND METHODS

SAMPLING AND DEPOSITION

Ninety specimens of the genus *Ophiomorus* were collected during fieldwork in Central Iran from April 2019 to September 2021 (Table 1). Finally, we selected 71 male specimens belonging to eight taxonomic operational units (OTUs). The locality addresses of the collected population and their geographic coordinates are provided in Table 1. Elevation was obtained using a Garmin eTrex 30 GPS receiver. Specimens were photographed and then euthanized, and all specimens were preserved in 75% ethanol and deposited in the Sabzevar University Herpetological Collection (SUHC). The approval (no. 14968) for the study was provided by the ethical committee of Razi University of Kermanshah, Kermanshah, Iran.

MORPHOLOGY

Morphological characters were examined as body size and body shape, meristic characters of pholidosis, and the description of color patterns of adult specimens. All measurements were taken using digital calipers with 0.01 mm accuracy under the light loop. Furthermore, the heads of all species were drawn to compare the scales of the head. Morphometric and morphological descriptions followed Anderson (1999), Rastegar-Pouyani et al. (2001, 2007), Kazemi et al. (2011) and Nasrabadi et al. (2017).

FIGURE 1. Sampling localities of collected specimens of *Ophiomorus* in Iran.

For morphometric analysis, the following standard characters were used: SVL—snout-vent length (from snout to vent); TL—tail length (from the posterior edge of the cloaca to the tip of the tail); HL—head length (from the end of the snout to the angle of the jaw); HW—head width (at the widest point of the head); HH—head height (from lower edge infralabial to the tip of supraocular); SL—Snout Length (from the tip of snout to the anterior corner of the eye); LF—Length of femur; LA—Length of arm; LFL—Length of forelimb; LFH—Length of hindlimb; LHF—Length between hindlimb and forelimb. The following meristic characters were examined: NSL (R/L)—Number of supralabials; NIL (R/L)—Number of infralabials; NDSB—Number of dorsal scales around the body; NMC—Number of scales from mental to anterior edge of the cloaca. In addition to the characters mentioned above, we added body coloration and patterns for the specimen description.

MULTIVARIATE AND UNIVARIATE ANALYSES

The 11 morphometric and four meristic variables were analyzed independently (Table 2). Statistical analyses were used to investigate differences in shape and size among all *Ophiomorus* species and OTU (*Ophiomorus* cf. *nuchalis*) present in Iran.

FIGURE 2. Photos of the endemic species of the genus *Ophiomorus* in Iran, *O. streeti* (A), *O. maranjabensis* (B), *O. nuchalis* (C), *O. persicus* (D) and Non-endemic species *O. brevipes* (E), *O. blanfordii* (F), *O. tridactylus* (G).

SPSS Statistics V.26. was used for statistical analyses, and data normality was checked before analyses. Analysis was carried out separately for morphometric and meristic characters. All morphometric characters were $\log_{10}$-transformed to obtain data normality and increase the homogeneity of variance. After getting the normality test, a one-way analysis of variance (ANOVA) was used among the species. Multivariate analyses have been done using two popular approaches in morphological studies: Canonical Variate Analysis (CVA) and Principal Component Analysis (PCA). These multivariate approaches were done on the significant characters identified by ANOVA. Based on significant characters, the PCA was used to assess the variation among populations. Based on the population grouping, the CVA was used to determine the correct classification.

RESULTS

COLOR AND PATTERN

Based on data from all specimens examined, the color pattern in *Ophiomorus* is variable and may depend on ground color (pers. obs.). The members of the *tridactylus* group living in a completely sandy habitat have a light color (canary yellow color, cream or bright brown in preservative, sandy-beige in life) on the dorsal surface (Fig. 2 (A-B-G)). However, the dorsal color is cream or pale brown in the members of the *brevipes* group (Fig. 2 (C-E-F)).

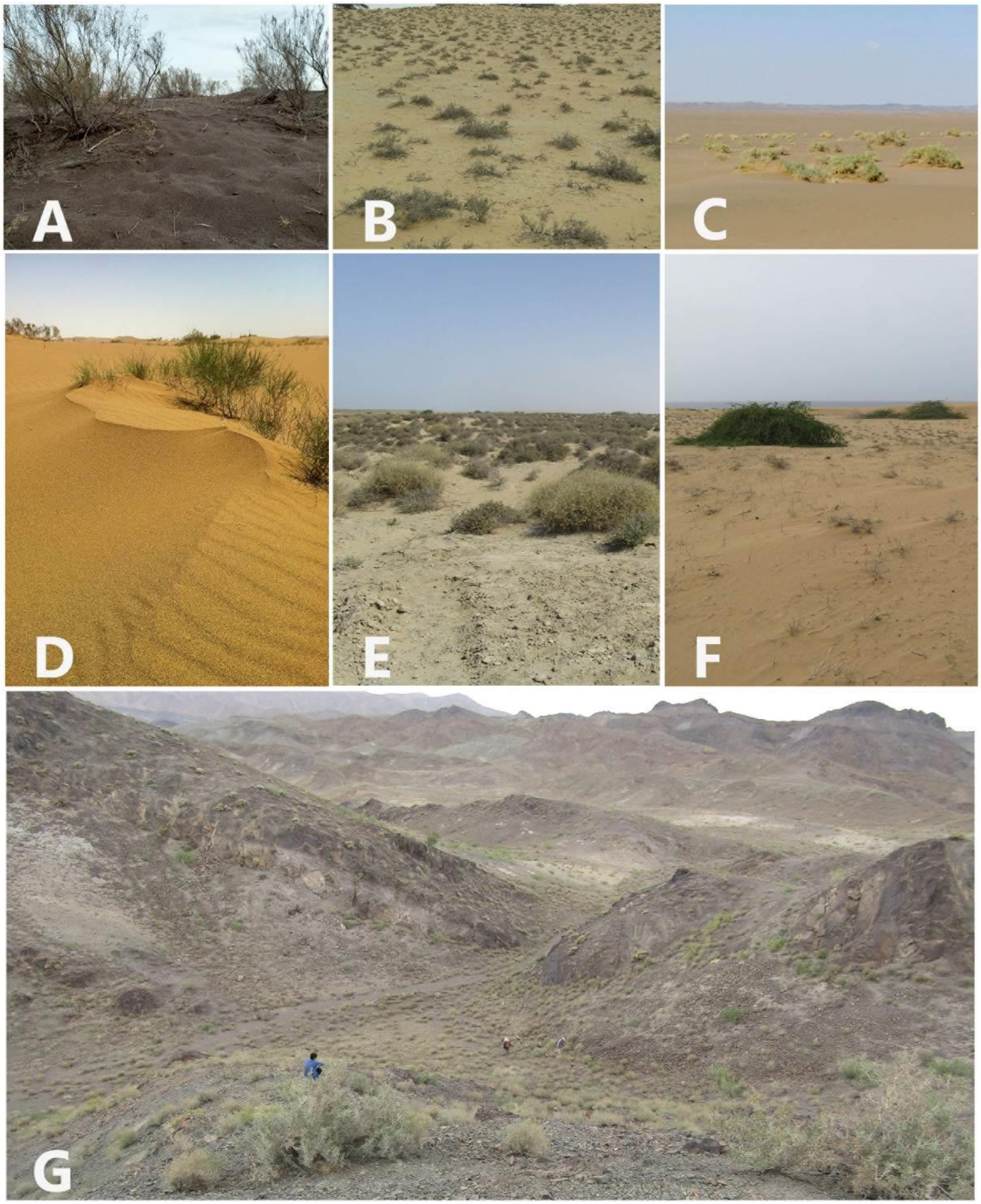

FIGURE 3. (A) One of the habitats of *Ophiomorus nuchalis,* Hoseynabad-e Mish Mast village, Qom province, Iran; (B) Type locality of *Ophiomorus blanfordii* is restricted to Chah Bahar, Iran; (C) Type locality of *Ophiomorus streeti*, Baluchistan, 11 miles west of Iranshahr, Iran; (D) Type locality of *Ophiomorus maranjabensis,* Maranjab, south of salt Lake, Iran; (E) Type locality of *Ophiomorus brevipes*, Sáadatabád (Now: Hajiabad, Hormozgan Province, Iran), S.W. of Karman; (F) East Zabol, one of the habitats of *Ophiomorus tridactylus*; (G) Rabor area in Kerman, one of the habitats of *Ophiomorus persicus*.

TABLE 1. Distribution records of the *Ophiomorus* used in this study.

Species	Latitude	Longitude	Locality
Ophiomorus blandfordii	25.121	61.228	Beris Village, Chabahar, Sistan and Baluchestan Province, Iran
Ophiomorus blandfordii	27.349	62.316	Saravan County, east of Sistan and Baluchestan Province, Iran
Ophiomorus brevipes	30.115	55.166	Shahrebabak city, Kerman Province, Iran
Ophiomorus brevipes	28.206	56.193	Vicinity of Hadjiabad (Sáadatabád) city, Kerman Province, Iran
Ophiomorus maranjabensis	34.311	51.863	Marnjab Desert, Aran o Bidgol, Isfahan Province, Iran
Ophiomorus nuchalis	35.097	51.855	Mobarakiyeh Village, Varamin, Tehran Province, Iran
Ophiomorus nuchalis	34.463	51.156	Hoseynabad-e Mish Mast Village, Qom Province, Iran
Ophiomorus cf. *nuchalis*	34.057	54.803	Mesr Desert,Khour va Biabanak County, Isfahan Province, Iran
Ophiomorus cf. *nuchalis*	33.519	53.855	Anarak-Khur road, Naein County, Isfahan Province, Iran
Ophiomorus cf. *nuchalis*	31.444	54.998	near Mehriz, 80 km SE form Yazd, Yazd Province, Iran
Ophiomorus persicus	29.262	56.979	Rābor, Baft, Kerman Province, Iran
Ophiomorus streeti	27.933	58.083	Roudbar Village, Kerman Province, Iran
Ophiomorus streeti	26.779	60.371	Espakeh-Chanf road, Sistan and Baluchestan Province, Iran
Ophiomorus streeti	27.172	60.735	Iranshahr, Sistan and Baluchestan Province, Iran
Ophiomorus tridactylus	25.796	57.815	Bandar-e-Jask, Hormozgan Province, Iran
Ophiomorus tridactylus	25.267	60.771	Chabahar, Sistan and Baluchestan Province, Iran
Ophiomorus tridactylus	26.128	60.109	Nikshahr, Sistan and Baluchestan Province, Iran
Ophiomorus tridactylus	27.628	62.779	Jālq, Sistan and Baluchestan Province, Iran
Ophiomorus tridactylus	27.112	63.222	Kuhak, Sistan and Baluchestan Province, Iran
Ophiomorus tridactylus	28.105	61.331	Khash, Sistan and Baluchestan Province, Iran
Ophiomorus tridactylus	29.068	61.385	Mirjaveh-Zahedan road, Sistan and Baluchestan Province, Iran
Ophiomorus tridactylus	31.066	61.652	Dust Mohammad, Zabol, Sistan and Baluchestan Province, Iran

TABLE 2. The main morphometric and meristic characters examined in the *Ophiomorus* specimens in this study.

	Character	Definition
Metric	SVL	Snout-Vent Length
	TL	Tail Length
	HL	Head Length (from end of snout to angle of jaw)
	HW	Head Width (at the widest point of head)
	HH	Head Height
	SL	Snout Length (from tip of snout to anterior corner of eye)
	LF	Length of eye (from anterior corner to posterior corner of eye)
	LA	Length of arm (Right)
	LFL	Length of forelimb (Right)
	LFH	Length of hindlimb (Right)
	LHF	Length between hindlimb and forelimb (Right)
Meristic	NSL	Number of supralabials (Right)
	NIL	Number of infralabials (Right)
	NDSB	Number of dorsal scales around body
	NMC	Number of scales from mental to anterior edge of cloaca

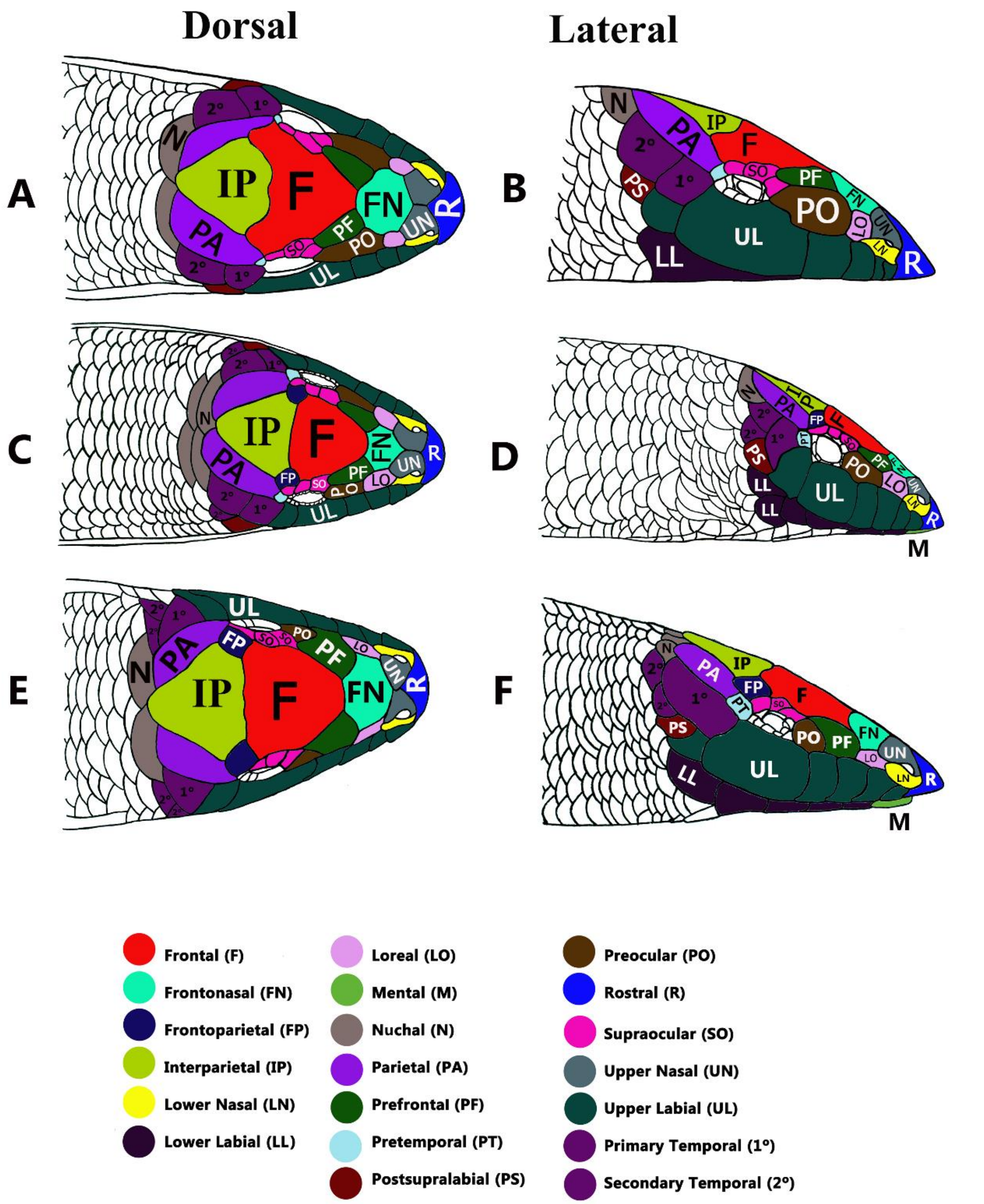

FIGURE 4. Head shape and types of head scales in members of the species group *tridactylus*. A-B: *Ophiomorus maranjabensis*; C-D: *Ophiomorus streeti*; E-F: *Ophiomorus tridactylus.*

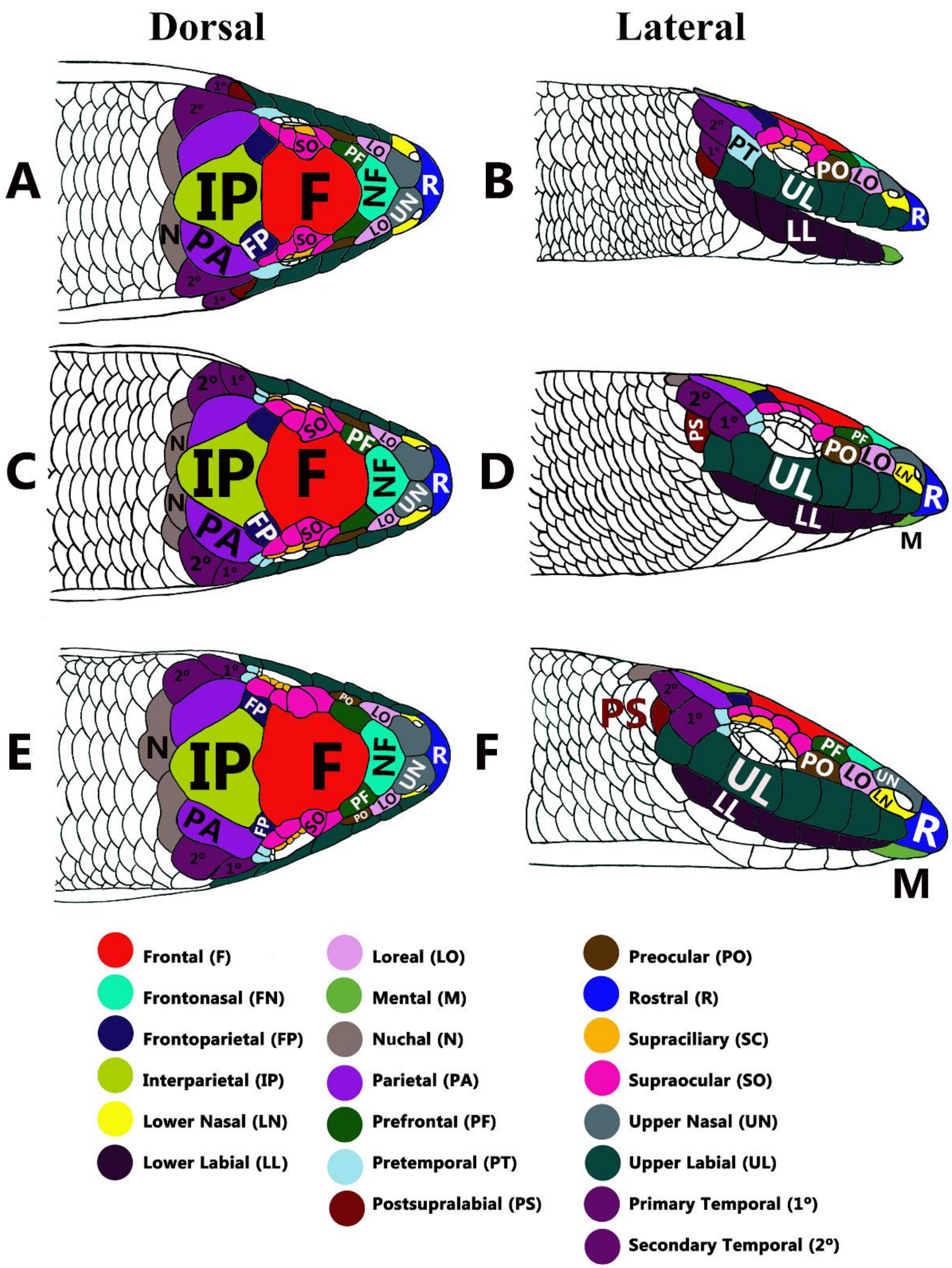

FIGURE 5. Head shape and types of head scales in members of the species group *brevipes*. A-B: *Ophiomorus blanfordii*; C-D: *Ophiomorus brevipes*; E-F: *Ophiomorus nuchalis.*

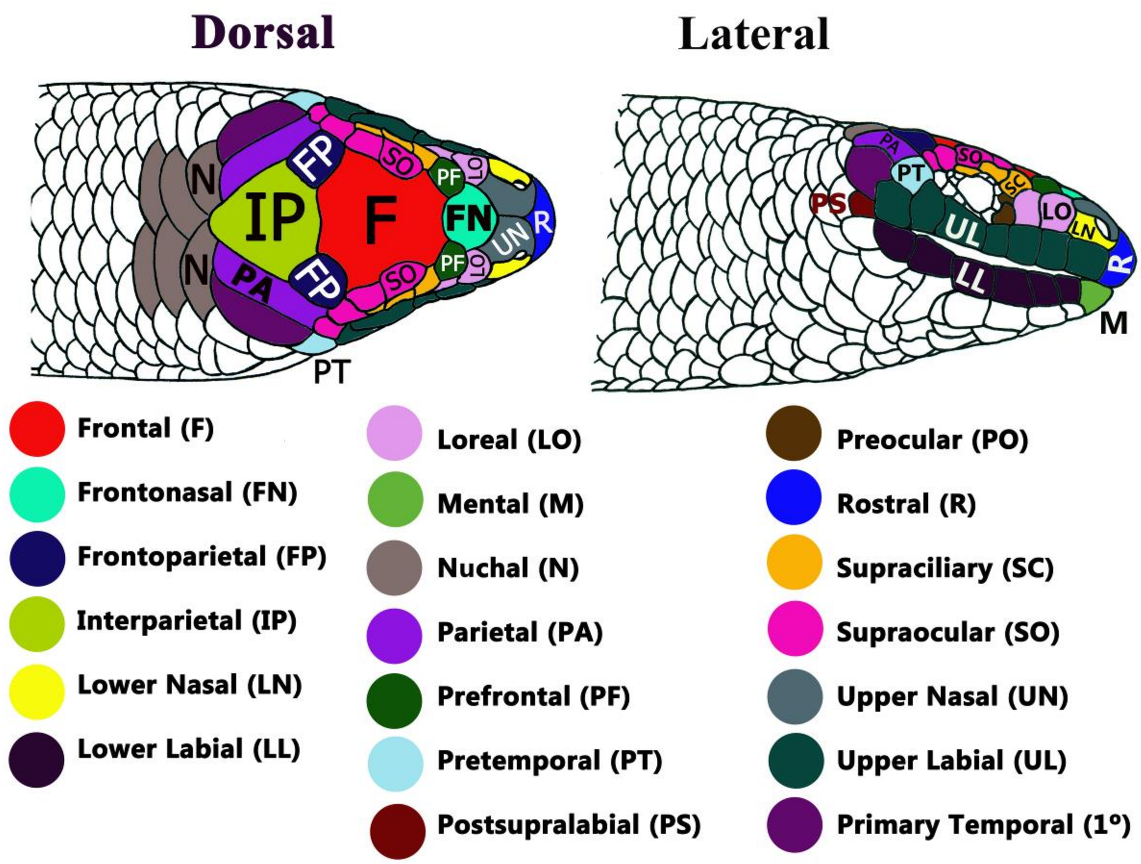

FIGURE 6. Head shape and types of head scales in *Ophiomorus persicus*.

SCALATION

The number of NSL and NIL scales is less in the *Ophiomorus* cf. *nuchalis* population than in the *Ophiomorus nuchalis*. There is an absent frontoparietal scale in the *Ophiomorus maramjabensis*, causing the frontal scale to be V-shaped (Fig. 4). In studies of the shape of the head scales, it was determined that the form of the parietals scale is differentiated between *Ophiomorus nuchalis* and *Ophiomorus brevipes* from species group's *Brevipes* and the population of *Ophiomorus brevipes* is semicircular, and all members of the *Ophiomorus nuchalis* population are rectangular (Fig. 5). Also, *Ophiomorus blanfordii* has a pretemporal scale compared to other members of the *brevipes* species group. The head shape of *Ophiomorus persicus* was smaller compared with the two other species groups (*tridactylus*: *O. maranjabensis*, *O. streeti*, and *O. tridactylus*; *brevipes*: *O. blanfordii*, *O. brevipes*, and *O. nuchalis*) (Fig. 6).

NORMALITY TEST

All characters have been examined for normality and distributed normally. Descriptive statistics of characters for each species and OTU are presented in Table 3. According to the descriptive statistics and ANOVA, the following characters were significantly differentiated between all species of the genus *Ophiomorus*: SVL, HL, HW, HH, SL, LF, LA, LFL, LFH, LHF, NSL, NIL, NDSB, and NMC (P <0.05) (Table 3). Based on the ANOVA, TL did not show a significant difference among species (Table 3). The meristic characters show zero variance at least between two OTU and then, we cannot use them in the PCA. In Principal Component Analysis (PCA) we used only the metric characters and the first three components explain 81.16% of the total variation.

TABLE 3. The mean, standard deviation, and range of 15 metric and meristic characters measured for *Ophiomorus* species on the entire distribution range in the Iranian Plateau.

	***O. tridactylus* (n = 12)**		***O. streeti* (n = 20)**		***O. persicus* (n = 4)**		***Ophiomoru* cf. *nuchalis* (n = 4)**		***O. nuchalis* (n = 7)**		***O. maranjabensis* (n = 10)**		***O. brevipes* (n = 11)**		***O. blanfordii* (n = 3)**		***P* value**
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
SVL	81.49 ± 10.57	64.53-95.77	67.66 ± 9.55	46.85-90.39	67.18 ± 8.59	55.34-75.83	86.70 ± 6.66	80-95.90	92.05± 6.43	86.12-102.74	83.98 ± 6.24	74.40-92.98	82.23 ± 6.44	72.61-90.32	77.47 ± 7.07	70.47-84.62	0.000
TL	47.93 ± 9.1	32.07-61.48	45.10 ± 5.52	35.07-53.65	64.62 ± 11.01	56.87-77.23	76.06 ± 17.96	55.34-87.15	67.90 ± 13.41	46.87-81.29	43.38 ± 10.43	27.07-55.25	68.60 ± 8.23	58.51-83.07	66.41 ± 17.34	54.15-78.68	0.362
HL	6.90 ± 0.79	4.77-7.64	6.57 ± 0.98	5.46-9.93	4.60 ± 0.37	4.09-4.95	7.56 ± 0.61	7.06-8.33	8.00± 0.49	7.33-8.72	7.41 ± 0.56	6.38-8.08	6.90 ± 0.66	5.99-7.84	7.47 ± 0.31	7.17-7.79	0.000
HW	5.15 ± 0.44	4.37-5.84	4.74 ± 0.41	3.70-5.37	3.89 ± 0.37	3.41-4.28	5.44 ± 0.25	5.23-5.81	6.06 ± 0.30	5.7-6.51	5.08± 0.34	4.64-5.71	5.75 ± 0.40	5.26-6.36	5.23 ± 0.64	4.57-5.86	0.000
HH	3.5 ± 0.49	2.81-4.63	3.37 ± 0.48	2.26-4.01	3.19 ± 0.46	2.52-3.60	3.8 ± 0.54	3.10-4.24	4.47 ± 0.30	3.90-4.86	3.20 ± 0.36	2.89-4.10	4.30 ± 0.49	3.46-4.98	3.73 ± 0.47	3.44-4.29	0.000
SL	4.20 ± 0.29	3.51-4.55	3.89 ± 0.34	3.27-4.45	2.44 ± 0.21	2.20-2.70	4.38 ± 0.27	4.02-4.62	4.60 ± 0.34	4.22-5.18	4.44 ± 0.24	4.09-4.79	4.31 ± 0.36	3.44-4.77	4.43± 0.44	3.92-4.71	0.000
LF	5.45 ± 0.70	4.12-6.61	4.87 ± 0.44	3.84-5.52	1.59 ± 0.22	1.27-1.81	5.73 ± 0.71	5.06-6.68	6.00 ± 0.23	5.57-6.52	5.30 ± 0.44	4.43-5.83	5.45 ± 0.47	4.70-6.00	4.77 ± 0.31	4.55-5.13	0.000
LA	2.80 ± 0.17	1.87-2.41	2.39 ± 0.23	1.97-2.82	1.36 ± 0.13	1.21-1.54	3.35 ± 0.14	3.15-3.47	3.29 ± 0.39	2.69-3.83	2.05 ± 0.14	1.8-2.23	3.2 ± 0.36	2.50-3.90	2.7 ± 0.49	2.16-3.14	0.000
LFL	5.25 ± 0.84	4.17-6.75	6.03 ± 0.56	5.02-6.98	4.38 ± 0.33	3.89-4.61	7.47 ± 1.21	6.27-9.04	8.59 ± 0.83	7.54-9.64	5.36± 0.40	4.63-5.94	7.94 ± 0.58	6.86-9.21	7.22 ± 0.94	6.21-7.92	0.000
LFH	13.21 ± 2.96	5.37-17.23	12.47 ± 1.41	10.20-15.29	4.25 ± 0.29	3.86-4.58	13.38 ± 1.71	11.43-15.20	16.13 ± 0.23	15.63-16.33	13.53 ± 0.98	11.74-15.05	13.78 ± 1.15	11.26-15.93	12.95 ± 0.5	12.49-13.49	0.000
LHF	62 ± 8.94	47.67-74.11	49.81 ± 8.35	32.29-70.64	52.05 ± 6.5	43.15-58.78	65.03 ± 5.18	60.32-72.43	69.9 ± 6.63	62.30-80.93	65.10 ± 5.6	55.58-72.85	61.44 ± 5.85	51.86-69.72	55.35 ± 9.92	45-64.78	0.000
NSL	6.33 ± 0.000	6-6	7 ± 0.41	5-6	5.9 ± 0.000	7-7	7 ± 0.57	6-7	6.50± 0.000	7-7	7 ± 0.031	5-6	5.8 ± 0.000	7-7	6 ± 0.57	6-7	0.000
NIL	5.25 ± 0.45	5-6	5.35 ± 0.48	5-6	6 ± 0.000	6-6	5.5 ± 0.57	5-6	6 ± 0.000	6-6	5.9± 0.31	5-6	6 ± 0.000	6-6	5.33 ± 0.57	5-6	0.000
NDS B	21.17 ± 0.57	21-23	19.65 ± 0.48	19-20	20± 0.000	20-20	22 ± 0.000	22-22	22 ± 0.000	22-22	22.2 ± 0.63	22-24	21.19± 0.3	21-22	21 ± 1.7	20-23	0.000
NMC	124.25 ± 6.15	116-131	110.6 ± 4.24	103-118	124.75 ± 6.39	118-132	117.5 ± 3.78	115-123	117.14 ± 4.67	112-123	124.4 ± 7.66	112-137	116.27 ± 3.66	111-124	109.67 ± 9.5	100-119	0.000

TABLE 4. Factor loading of the first three principal components (PCs) from a correlation matrix of ten characters for the *Ophiomorus* populations used in this study.

Character	PC1	PC2	PC3
SVL	.885	.294	-.210
HL	.734	.198	.590
HW	.866	-.140	-.184
HH	.745	.020	-.216
SL	.521	.095	.832
LF	.724	.002	.003
LA	-.029	.876	-.261
LFL	.642	-.524	-.261
LFH	-.332	.876	.020
LHF	.853	.355	-.231
Eigenvalue	4.673	2.089	1.354
Accumulated percent of trace	46.732	67.625	81.161

TABLE 5. Factor loadings of the first three canonical variates of metric characters in the studied species of the genus *Ophiomorus* in Iran.

Character	CVA		
	1	**2**	**3**
SVL	.586	1.452	.870
HL	-.118	-.211	-.211
HW	.221	.359	.272
HH	-.271	.266	-.172
SL	.259	-.024	.259
LF	.546	-.819	-.078
LA	.367	.716	.149
LFL	.453	.559	-.474
LFH	.643	-.024	-.315
LHF	-1.140	-1.627	.197
Eigenvalue	18.287	5.458	1.019
Cumulative percent	71.6	93.0	97.0

Of this value, 46.73% was explained by PC1, in which SVL, HW, and LHF have the most weight; 67.62% was explained by PC2, which is mainly attributed to LA and LFH; and 13.53% was explained by PC3, which is mainly attributed to HL and SL (Table 4 and Fig. 7). Discriminant Function Analyses (DFA) has been done to provide more accurate discrimination between all species**.** The CVA between all species is highly significant, and the first component explained 97% of all variance (Table 5). Based on the CVA chart, species having four fingers in their forelimbs are separated from species having three fingers in their fore and hindlimb and finally, these species groups get differentiated completely from *Ophiomorus persicus* (Fig. 8). Based on table 6 and Appendix 1, metric characters that have shown the most differences between species have been determined. The results of all parametric tests of OTUs based on all significant characters are presented in table 6 and Appendix 1. Furthermore, all morphological characters were measured on all specimens and are presented in Appendix 2. *Ophiomorus persicus* is the only extant representative of the *punctatissimus* group, which has shown the most morphological differences with the members of the *tridactylus* group**.** Therefore, *O. persicus* with 11 morphological characters has the most differences with *O. streeti*, nine morphological differences with *O. tridactylus*, and seven morphological differences with *O. maranjabensis*. These members of the *tridactylus* group have three fingers in both the forelimb and hindlimb (Table 6). *Ophiomorus persicus* has also shown a significant morphological difference with the members of the *brevipes* group, which have four fingers in the front limb, including the most differences with *O. bervipes*, *O. nuchalis* species in seven, and *O. blanfordii*, *O.* cf. *nuchalis* in six morphological characters (Appendix 1).

DISSCUSSION

Iran has a diversity of ecosystems from mountainous to plains, deserts, and forests, so the diversity of ecosystems in Iran has played a crucial role in the diversification of reptiles (Anderson, 1999). The Zagros Mountain in the west of Iran has caused changes in the shape of the center of the Iranian plateau. These changes have affected the isolation of the population and the process of speciation of reptiles in the plateau of Iran (Rajabizadeh, 2013). In the central plateau of Iran, lizards of the genus *Ophiomorus* have ecologically and morphologically diverse radiation that has successfully inhabited most of the terrestrial arid ecosystems. In the genus *Ophiomorus,* a line of specialization adapted to life in the wind-blown sand and consequently, the other one line of specialization resulted in the legless western species (*O. kardesi*, *O. latastii*, *O. persicus*, and *O. punctatissimus*) occupying an upland, under-rock habitat. Within living organisms, the relationship between morphological characters and functional capabilities has been studied

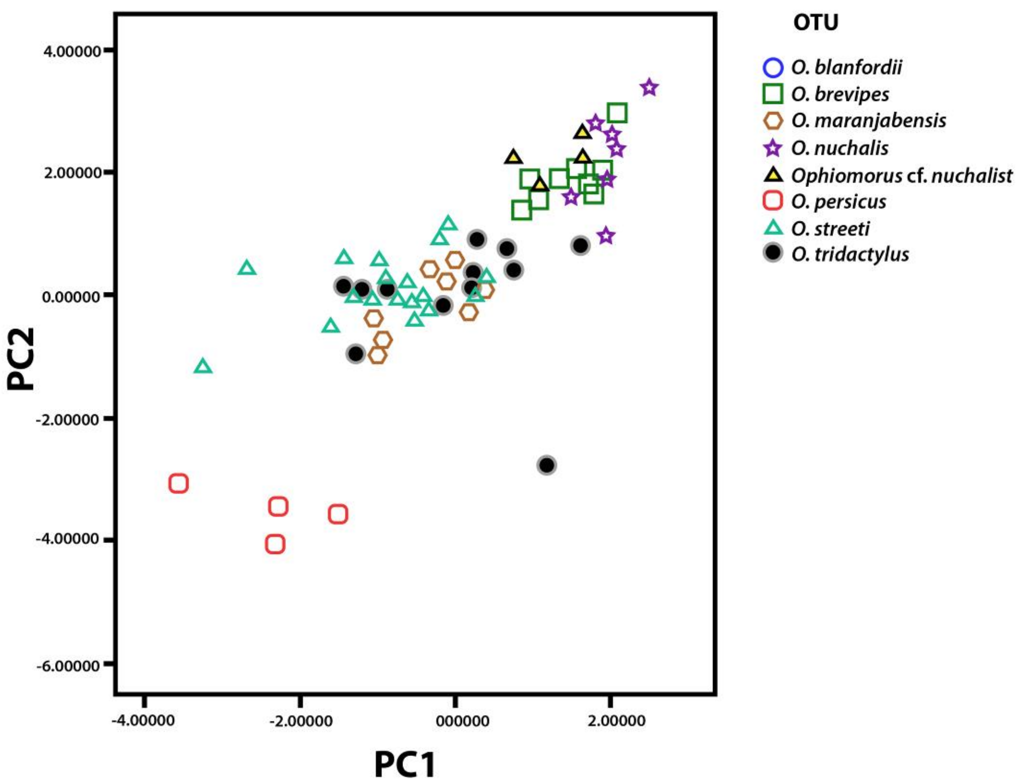

FIGURE 7. The PCA plot of inter-specific variation based on metric characters within the genus *Ophiomorus* in the Iranian Plateau.

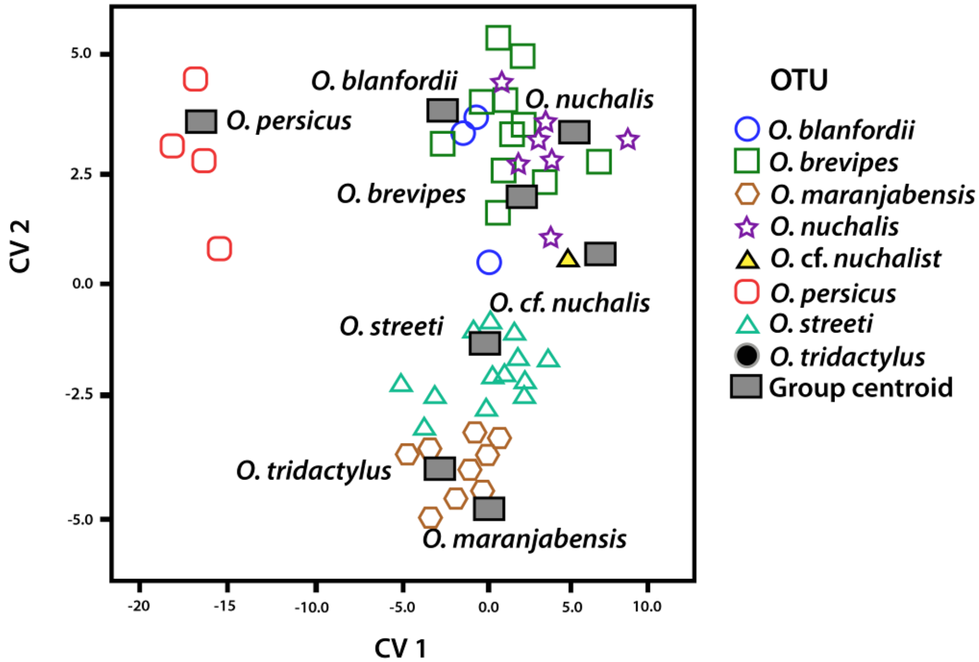

FIGURE 8. Ordination of the individuals of all species of the genus *Ophiomorus* in the Iranian Plateau on the first two canonical variates of metric characters.

by many researchers (Tulli et al., 2010). Accordingly, many studies on a range of animals have shown that morphology correlates to the type of habitat. (e.g. mammals: Norberg, 1994; birds: Collins & Paton, 1989; Miles & Ricklefs, 1987; fish: Douglas, 1987; McDowall, 1998; and reptiles: Moermond, 1979; Williams, 1983; Pounds, 1988; Losos & Sinervo, 1989; Losos, 1990). Scincid lizards probably constitute the most remarkable lizards to illustrate the high frequency of convergent limb loss (Miralles et al., 2012). Within this family, full limblessness as the complete absence of any external limbs is well observed in two genera, *Ophiomorus* and *Chalcides*. (Poulakakis et al. 2008; Brandley et al. 2008; Miralles et al., 2012). In *Ophiomorus* species, limbs can vary from slightly-developed to absent, trunks from short and stout to long and thin, and tails from long to short. The *Ophiomorus persicus*, have forelimbs that are much less reduced than the hindlimbs (Reduced in size or in number of fingers). In contrast, four other species of *Ophiomorus* (*O. maranjabensis*, *O. raithmai*, *O. streeti*, and *O. tridactylus*) have an equal number of fingers in the forelimbs and hindlimbs. Eventually, three species of *Ophiomorus* (*O. kardesi*, *O. latastii*, and *O. punctatissimus*) lack forelimbs and hindlimbs. Anderson and Leviton (1966) devided *Ophiomorus* in three groups include *brevipes*, *punctatissimus*, and *tridactylus* in terms of the tendency to degeneration of motor organs (especially fingers)**.** In another grouping, Anderson (1999) states that the members of the *Ophiomorus* are classified into western and eastern groups based on habitat selection and morphology, respectively. Recent studies on geometric morphometrics showed that changes in the shape of the head scales in Iran's *Ophiomorus* species emphasized the division based on habitat selection and morphology (Nabizadeh et al., 2022)**.** However, we have examined 71 specimens from throughout the range of distribution in the central plateau of Iran and have found that morphological differentiation among three groups' *brevipes*, *tridactylus*, and *punctatissimus* is distinctive**.** The results of our morphometric study showed that the Iranian *Ophiomorus* species emphasize division based on their tendency to limb reduction (especially fingers). Accordingly, ANOVA results showed that fourteen morphological characters (SVL, HL, HW, HH, SL, LF, LA, LFL, LFH, LHF, NSL, NDSB, NMC, and NIL; ten metric and four meristic) were significantly different between all *Ophiomorus* species.

TABLE 6. The results of all parametric tests of the OTUs based on all significant characters.

	O. tridactylus	***O. streeti***	***O. persicus***	***O.* cf. *nuchalis***	***O. nuchalis***	***O. maranjabensis***	***O. brevipes***
O. blanfordii	NSL- LFL/SVL	LF/SVL	HW/HL- HH/HL- LF/SVL- LA/SVL- LHF/SVL- LFL/SVL	***********	NSL- NIL	NIL- NMC- TL/SVL- LA/SVL- LFL/SVL- LHF/SVL	NSL- NIL- HH/HL
O. brevipes	NIL- NDSB- NMC- TL/SVL- HW/HL- HH/HL- LFL/SVL	NIL- NMC- TL/SVL- HW/HL- HH/HL- LA/SVL- LF/SVL	NDSB- NMC- SL/HL- LF/SVL- LA/SVL- LFL/SVL- LHF/SVL	NSL- NIL- HH/HL	HW/HL- SL/HL	NMC- TL/SVL- HW/HL- HH/HL- LA/SVL- LFL/SVL- LHF/SVL	
O. maranjabensis	NIL- NDSB- HH/HL- LA/SVL- LHF/SVL	NIL- NMC- TL/SVL- HH/HL- LF/SVL- LHF/SVL	NSL- NDSB- TL/SVL- HW/HL- HH/HL- SL/HL- LF/SVL	NIL- TL/SVL- LA/SVL- LFL/SVL- LHF/SVL	NIL- NMC- TL/SVL- HH/HL- LA/SVL- LFL/SVL		
O. nuchalis	NSL- NDSB- NMC- TL/SVL- LA/SVL- LFL/SVL	NIL- NMC- LF/SVL- LHF/SVL	NDSB- HW/HL- HH/HL- SL/HL- LF/SVL- LA/SVL- LFL/SVL	NSL- NIL			
O.* cf. *nuchalis	NSL-NDSB- NMC- TL/SVL- LA/SVL- LFL/SVL	NSL- NDSB- NMC- LA/SVL	NDSB- HW/HL- HH/HL- LF/SVL- LA/SVL- LHF/SVL				
O. persicus	NSL- NIL- TL/SVL- HW/HL- HH/HL-SL/HL- LF/SVL- LA/SVL- LHF/SVL	NSL- NIL- NMC- TL/SVL- HW/HL- HH/HL- SL/HL- LF/SVL- LA/SVL- LFL/SVL- LHF/SVL					
O. streeti	TL/SVL- LFL/SVL- LHF/SVL						

The results of PCA and CVA in this study approve this claim to a large extent. *Ophiomorus persicus* is the only extant representative of the *punctatissimus* group, which has shown the most morphological differences with the members of the *tridactylus* group**.** Also, we found that morphological differentiation between members of the two groups' *brevipes*, and *tridactylus* is distinctive**.** Based on Tables 4 and 5, the distribution of different species of *Ophiomorus* in Figs 7 and 8 shows that *O. persicus* from *punctatissimus* group is completely separated from the *brevipes* and *tridactylus* in the CV1 graph. This separation is based on the characters of the distance between LHF, LFH, and SVL. But, the members of the *brevipes* group in the CV2, in one complex, are separated from the members of the *tridactylus* group, and this separation, which is the most effective factor between these groups, is based on the SVL, LHF, LF, and LA (Table 4-5). In conclusion, it can be said that this separation is based on choosing different habitats, as the habitat of *O. presicus* is completely separated and differentiated from other two groups**.** According to our results, species including *O. streeti*, *O. maranjabensis*, and *O. tridactylus* observed in sand habitats in which there are sand dunes, furthermore, this sand habitat is adaptive for their distribution, feeding, and procreation, and also, they never leave sand habitat naturally. But species like *O. blanfordii*, *O. brevipes*, *O. nuchalis*, and also *Ophiomorus* cf. *nuchalis* observed in habitats with steppe soils along with sandy microhabitates where they look for food, procreate, and shuttle between sand microclimates. But being diggers and Cryptozoic, they do feed in this microclimate. It is worth mentioning that the habitat of *O. persicus* is completely different from the members of the two other groups. They have distribution in the stony and rocky lands and spend their daytime under stones and holes. Choosing these habitats also has changed the shape of the head scales. According to the results of the morphological geometric done on the heads of all species existing on the Central Plateau of Iran, it is shown that members of the *tridactylus* group prefer sandy habitat with sand dunes**.** They have a bigger and triangular head shape, and the rostral (snout acutely cuneiform, with a sharp angular labial edge) is sharper to be able to burrow the sand easier and quicker (Fig. 5). Supraoculars also level with the eyes, which makes the head more triangular. But, the members of the *brevipes* group prefer habitats with steppe soils along with sandy microclimates making supraoculars more popped out than eyes, making supraoculars and eyes non-level (The supraoculars resemble the brim of a hat for the eyes) (Fig. 6). Consequently, the head compared to the prior group is slightly triangular to conical and rostral is also slightly conical (Fig. 6). Since, *O. persicus* distributed on the foothills (the transition zone between plains and low-relief hills), alluvial fans, and under stones, it leads to a completely conical head (snout acutely rounded, the rostral scarcely projecting beyond the lip) and rostral round (Fig. 7). According to Greer and Wilson (2001) and our morphological study on the head scale of *Ophiomorus* species in the current study, it is determined that 12 species except the *O. maranjabensis* species have a frontoparietal scale (Fig 5-6-7)**.** It is worth mentioning that Kazemi et al (2011) have not mentioned this significant trait for this species in identification keys, but having frontoparietal, is a key trait to determine this species from other *Ophiomorus***.** Given the morphological differences between the three species groups of *Ophiomorus* and according to the history of their description, we assigned these three species groups for all species of *Ophiomorus* in Iran. Finally, we suggest three species groups based on the tendency to limb reduction (especially fingers) and habitat preferences, which are explained as follow:

brevipes*: *O. blanfordii, O. brevipes, O. chernovi,* O. *nuchalis

Based on morphological compatibility with the type of steppe soil habitat with sand microhabitat, they have strong bodies compared to the two other groups, and based on four fingers on the forelimb and three on the hindlimb, they are able to move on steppe soil and burrow in sand microclimate.

tridactylus*: *O. maranjabensis, O. raitmai, O. streeti, O. tridactylus

The members of this group have their special morphological compatibility based on burrowing life and are extremely dependent on their own habitat. So, head and body shape are changed according to the sand habitat. Their specifications include a complete triangular head, wedge-shaped snouts, extremely smooth imbricate scales, and overlap. The members of this group never leave sand dunes and they are adapted to living in loose windblown dune sand, moving through this medium with strong lateral undulations**.**

punctatissimus*: *O. kardesi, O. latastii, O. persicus, O. punctatissimus
The members of this group have an extreme tendency to the reduction of hindlimbs or have no limbs. They have elongated cylindrical bodies, the head completely conical, and the snout acutely rounded. They are adapted to inhabit under stones and steppe ground with loose soil.

Finally, we suggest the following updated identification key for *Ophiomorus* species present in Iran:

Key to the species of *Ophiomorus* in Iran

1A. Fingers 4, toes 3..2
1B. Fingers 3, toes 2 or 3...5
2A. Scale rows 20 at midbody, 1 pretemporral scales………………………*Ophiomorus blanfordii*
2B. Scale rows 22 or more at midbody, 2 pretemporral scales…………………….……….……3
3A. Scale rows 22……………………………………………………………………….……..4
3B. Scale rows 24……………………………………………………….… *Ophiomorus chernovi*
4A. Parietals semicircular shape ……………………………………...……*Ophiomorus brevipes*
4B. Parietals rectangular shape……………….……………………..……...…*Ophiomorus nuchalis*
5A. Fingers 3, toes 2……………………………………………..……….*Ophiomorus persicus*
5B. Fingers 3, toes 3……….……………………………….………………………………….6
6A. Frontoparietals absent ……………………………………..…….*Ophiomorus maranjabensis*
6B. Frontoparietals present …………………………………………………………………….7
7A. Prefrontals not in contact with upper labials……………….………………..*Ophiomorus streeti*
7B. Prefrontals in contact with upper labials……………………………..*Ophiomorus tridactylus*

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APPENDIX

Appendix 1: Results of all parametric tests in numerical form for all the OTUs.

	O. blanfordii	*O. brevipes*	*O. maranjabensis*	*O. nuchalis*	*O.* cf. *nuchalis*	*O. persicus*	*O. streeti*	*O. tridactylus*
O. blanfordii	*	3	6	2	0	6	1	2
O. brevipes	3	*	7	2	4	7	7	7
O. maranjabensis	6	7	*	6	5	7	6	5
O. nuchalis	2	2	6	*	2	7	4	6
O. cf. *nuchalis*	0	3	5	2	*	6	4	6
O. persicus	6	7	7	7	6	*	11	9
O. streeti	1	7	6	4	2	11	*	3
O. tridactylus	2	7	5	6	6	9	3	*

Appendix 2: All measurements of *Ophiomorus* specimens were collected from Iran (metric characters were measured in mm).

NO.	SVL	TL	HL	HW	HH	SL	LF	LA	LFL	LFH	LHF	NSL	NIL	NDSB	NMC
RAN-3437- *O. blanfordii*	77.33	78.68	7.17	5.28	3.44	4.66	4.64	2.16	7.75	12.88	56.29	6	5	20	110
RAN-3436- *O. blanfordii*	70.47	54.15	7.79	4.57	3.48	3.92	4.55	2.8	6.21	12.49	45	6	5	20	100
HNH-65- *O. blanfordii*	84.62	99999	7.46	5.86	4.29	4.71	5.13	3.14	7.92	13.49	64.78	7	6	23	119
RAN- 4082- *O. brevipes*	72.61	62.09	6.38	5.26	3.86	4.22	4.78	2.5	7.5	13.45	51.86	7	6	21	116
RAN-4081- *O. brevipes*	89.66	74.11	7.71	6.23	4.98	4.77	5.75	3.2	7.89	15.93	66.73	7	6	22	114
RAN-4660- *O. brevipes*	77.27	63.91	6.2	6.02	3.56	4.21	6	3.15	7.78	14.53	57.03	7	6	22	111
RAN-4661- *O. brevipes*	87.61	34.02	6.93	6.36	4.42	4.57	5.16	3.23	9.21	13.91	64.93	7	6	22	115
RAN-4662- *O. brevipes*	80.5	68.84	7.26	6.1	4.39	4.55	5.96	3.46	8.31	13.81	59.18	7	6	22	117
RAN-4663- *O. brevipes*	73.4	58.51	6.27	5.41	4.41	4.17	5.43	3.36	7.62	13.43	53.65	7	6	22	113
RAN-4664- *O. brevipes*	90.32	49.88	7.64	5.44	4.52	4.67	5.8	3.69	8.33	14.42	69.72	7	6	22	124
RAN-4665- *O. brevipes*	87.28	83.07	7.1	6.02	4.36	4.22	5.12	3.9	8.04	13.24	66.81	7	6	22	119
RAN-4666- *O. brevipes*	82.68	37.22	6.57	5.34	4.48	4.14	5.36	3.22	7.77	13.21	60.83	7	6	22	113
RAN-4667- *O. brevipes*	86.18	69.64	7.84	5.74	4.96	4.48	5.97	3.11	8.07	14.44	66.11	7	6	22	119
HNH-192- *O. brevipes*	77.08	99999	5.99	5.34	3.46	3.44	4.7	3.04	6.86	11.26	59.04	7	6	22	118
ERP-7280- *O. maranjabensis*	87.38	40.83	7.59	5.59	4.1	4.79	4.94	2.11	5.23	14.14	69.36	5	5	22	125
HNH-99- *O. maranjabensis*	74.4	45.25	6.38	5.07	3.31	4.09	4.43	1.86	4.63	12.75	55.58	6	6	24	122
HNH-171- *O. maranjabensis*	81.15	53.77	7.56	5.08	3.32	4.14	5.82	2.15	5.23	15.05	63.33	6	6	22	120
HNH-172- *O. maranjabensis*	81.11	33.57	6.91	4.92	3.32	4.65	5.83	2.28	5.17	14.14	61.6	6	6	22	129
HNH-173- *O. maranjabensis*	91.65	44.82	7.56	5.71	2.93	4.41	5.77	2.03	5.75	14.04	70.61	6	6	22	133

NMC	NO.	SVL	TL	HL	HW	HH	SL	LF	LA	LFL	LFH	LHF	NSL	NIL	NDSB	NMC
121	HNH-174- *O. maranjabensis*	89.62	55.25	8.03	5.18	2.9	4.5	5.23	2.1	5.79	14.07	70.27	6	6	22	137
118	HNH-175- *O. maranjabensis*	80.91	29.22	8.08	4.64	2.97	4.15	5.08	1.8	4.99	11.74	61.03	6	6	22	127
112	HNH-176- *O. maranjabensis*	83.71	27.07	7.49	5.03	3.12	4.55	5.43	2.02	5.94	13.75	66.08	6	6	22	115
107	HNH-177- *O. maranjabensis*	92.98	53.82	6.73	4.76	3.2	4.5	5.15	2.21	5.62	13.3	72.85	6	6	22	124
108	HNH-178- *O. maranjabensis*	76.89	50.27	7.84	4.82	2.89	4.67	5.29	2.01	5.31	12.41	60.33	6	6	22	112
115	ERP-6662- *O. nuchalis*	95.91	81.29	8.17	5.82	4.44	4.52	5.57	3.34	7.54	16.24	74.69	7	6	22	123
116	ERP-6656- *O. nuchalis*	89.31	51.37	8.34	5.86	3.9	4.5	6.07	2.93	8.77	16.09	69.25	7	6	22	116
106	ERP-6657- *O. nuchalis*	96.63	79.01	8.06	5.96	4.32	4.68	5.87	3.35	9.08	16.13	72.7	7	6	22	123
107	ERP-6660- *O. nuchalis*	102.74	46.87	8.27	6.19	4.62	5.18	6.05	3.38	8	16.3	80.93	7	6	22	119
105	ERP-6661- *O. nuchalis*	86.3	73.73	8	6.51	4.67	4.86	6.52	3.25	9.39	16.33	64.14	7	6	22	115
107	RAN-4318- *O. nuchalis*	86.12	72.22	7.33	5.7	4.52	4.23	5.91	3.65	7.77	15.63	62.3	7	6	22	112
108	RAN-4066- *O. nuchalis*	87.34	70.84	7.43	6.4	4.86	4.22	6.01	2.69	9.64	16.2	65.36	7	6	22	112
108	ERP-6659- *O.* cf. *nuchalis*	95.9	99999	8.33	5.4	3.68	4.58	5.88	3.35	9.04	12.54	72.43	7	6	22	123
116	ERP-6658- *O.* cf. *nuchalis*	85.04	87.15	7.06	5.35	3.1	4.33	5.06	3.44	6.27	11.43	64.04	7	6	22	117
115	RAN-3317- *O.* cf. *nuchalis*	85.83	55.34	7.79	5.81	4.23	4.02	5.33	3.47	6.82	15.2	63.34	6	5	22	115
112	RAN-3318- *O.* cf. *nuchalis*	80	85.7	7.08	5.23	4.24	4.62	6.68	3.15	7.75	14.38	60.32	6	5	22	115
114	RAN-3080- *O. persicus*	69.59	59.78	4.61	3.79	3.38	2.51	1.81	1.21	4.61	4.58	53.4	7	6	20	132
113	RAN-3090- *O. persicus*	55.34	9.27	4.09	3.41	2.52	2.2	1.27	1.54	4.55	4.23	43.15	7	6	20	128
111	RAN-3326- *O. persicus*	75.83	77.23	4.79	4.09	3.6	2.35	1.65	1.35	4.5	3.86	58.78	7	6	20	118

NMC	NO.	SVL	TL	HL	HW	HH	SL	LF	LA	LFL	LFH	LHF	NSL	NIL	NDSB
111	ERP-3957- *O. persicus*	67.97	56.87	4.95	4.28	3.27	2.7	1.6	1.37	3.89	4.34	52.87	7	6	20
103	ERP-5294- *O. streeti*	90.39	99999	7.01	4.95	3.91	4.19	4.43	2.05	6.45	13.55	70.64	6	5	20
131	RAN-3347- *O. streeti*	53.65	47.43	6.28	4.44	3.33	3.48	4.43	2.8	5.7	11	37.75	5	5	20
129	RAN-3349- *O. streeti*	46.85	35.07	5.73	3.7	2.92	3.58	4.58	2.78	5.41	10.84	32.29	5	5	20
117	RAN-3348- *O. streeti*	50.56	45.79	5.46	4	2.38	3.69	3.84	1.97	5.02	11.11	37.08	5	5	20
118	RAN-3343- *O. streeti*	67.4	53.65	6.55	4.67	3.27	4.37	4.3	2.06	5.18	12.17	48.05	5	5	20
128	RAN-3342- *O. streeti*	71.67	50.56	5.88	4.62	3.39	3.71	4.94	2.3	5.68	10.2	55.56	6	5	20
118	RAN-3340- *O. streeti*	66.9	37.45	6.66	4.54	2.74	3.48	5.29	2.26	5.43	11.8	48.23	6	5	20
128	RAN-3338- *O. streeti*	64.83	41.95	5.88	5.07	3.6	3.94	5.33	2.37	5.41	11.85	46.1	6	5	20
118	RAN-3341- *O. streeti*	68.56	19.41	6.72	5.25	3.4	3.74	4.44	2.3	5.73	11.73	50.02	6	5	20
128	RAN-3346- *O. streeti*	63.29	39.68	6.28	4.45	3.33	4.32	5.25	2.34	6.39	12.93	45.37	6	5	20
131	RAN-3339- *O. streeti*	70.44	52.11	6.01	5.03	3.66	4.45	5.52	2.65	6.71	12.15	52.87	6	5	20
116	RAN-3344- *O. streeti*	75.09	44.85	7.23	4.79	3.59	4.09	4.89	2.64	6.61	14.09	56.25	6	5	20
129	RAN-3134- *O. streeti*	70.59	41.46	6.52	4.89	3.29	3.64	5.45	2.61	6.44	11.96	50.45	6	6	19
	RAN-3133- *O. streeti*	74.25	44.1	6.57	5.19	3.62	4.12	5.25	2.27	6.03	15.29	57.1	6	6	19
	RAN-3136- *O. streeti*	69.47	27.96	5.9	4.47	3.29	3.75	4.56	2.3	6.11	14.02	50.11	6	6	19
	RAN-3135- *O. streeti*	71.5	32.56	9.93	5.19	4.01	4.26	5.01	2.65	6.02	14.16	52.15	6	6	19
	RAN-3138- *O. streeti*	73.96	32.84	6.48	5.37	3.84	3.68	5.29	2.35	6.78	14.6	56.19	6	6	19
	RAN-3137- *O. streeti*	65.14	33.39	6.6	4.87	3.83	3.27	4.82	2.24	6.27	12.48	47.91	6	6	19

NO.	SVL	TL	HL	HW	HH	SL	LF	LA	LFL	LFH	LHF	NSL	NIL	NDSB
ERP-3958- *O. streeti*	75.09	49.23	7.87	4.85	2.26	4.34	5.08	2.5	6.98	12.65	56.06	6	6	19
RAN-3345- *O. streeti*	63.59	48.19	5.84	4.63	3.8	3.73	4.78	2.54	6.44	10.88	46.18	6	5	20
ERP-5969- *O. tridactylus*	92.27	99999	7.64	5.06	3.65	4.55	6.61	2.41	5.8	13.06	70.17	6	6	21
ERP-5972- *O. tridactylus*	92.37	51.52	7.44	5.16	3.17	4.39	5.7	2.12	5.72	13.95	69.52	6	6	21
RAN-3156- *O. tridactylus*	78.74	54.06	6.7	5.45	3.94	4.27	6.02	2.25	4.17	13.34	60.52	6	5	21
RAN-3431- *O. tridactylus*	77.71	34.89	7.6	5.44	3.79	4.51	5.85	2.12	4.63	12.57	57.71	6	5	21
RAN-3189- *O. tridactylus*	91.08	39.14	6.81	5.37	3.72	4.08	5.05	2.22	5.75	14.54	72.48	6	5	21
RAN-3155- *O. tridactylus*	66.52	51.54	6.24	4.99	3.34	4.14	5.35	1.92	4.46	12.46	48.27	6	5	21
RAN-3187- *O. tridactylus*	72.77	28.11	7.02	4.81	3.51	4.54	4.12	2.08	4.67	15.63	55.32	6	5	21
RAN-3157- *O. tridactylus*	64.53	32.07	4.77	4.37	2.81	3.51	4.53	2.24	4.36	13.01	47.67	6	5	21
RAN-3186- *O. tridactylus*	88.85	47.34	7.18	5.84	4	4.24	6.14	1.87	4.84	5.37	66.74	6	5	21
ERP-5971- *O. tridactylus*	81.84	46.35	7.19	5.09	3.23	4.1	5.69	2.41	6.75	17.23	63.5	6	5	21
HNH-82- *O. tridactylus*	75.43	99999	7.46	4.52	3.01	4.22	4.93	2.25	5.56	11.57	58.05	6	5	23
RAN-3188- *O. tridactylus*	95.77	61.48	6.67	5.71	4.63	3.92	5.46	2.32	6.35	15.9	74.11	6	6	21