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Sexual size dimorphism of *Darevskia schaekeli* (Sauria: Lacertidae)

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Abstract: Sexual dimorphism stands out as a significant evolutionary outcome of sexual selection between males and females across various species. Reptiles also exhibit distinct morphological differences between males and females. For instance, the genus Darevskia, exemplified by Darevskia schaekeli in this study, displays sexual dimorphism. Examination of morphological traits in this species revealed that males possess greater head length, trunk length, forelimb and hindlimb length, as well as a higher number of femoral pores compared to females. All these morphological distinctions, favoring males, are pivotal in their mating and reproductive processes. In this species, the mating process commences with the male biting the female's head. Subsequently, he restrains her by gripping her hindlimbs and positions their cloacal edges to rotate his body in front of hers. Greater body length and hind limb size are crucial for this maneuver. During the mating season (spring), males exhibit a more diverse and prominent dorsal and lateral color pattern compared to females, suggesting a form of sexual selection within this species.

Key words: Sexual selection, courtship, rock lizard, breeding season, Elburz Mountains

Sexual size dimorphism (SSD) represents a significant morphological distinction between sexes that directly influences the mating process (Andersson, 1994). While metric morphological traits such as snout-vent length may have a lower impact mating, the length of forelimbs and hindlimbs largely influences the process (Stamps, 1993). In addition to the size dimorphism, shape dimorphism may also vary between sexes, indicating differences in the proportions of various traits relative to body size (Bookstein, 1989). Sexual selection and male-male competition are two evolutionary forces that may affect SSD, but the probable evolutionary scenario for SSD predominantly involves female selection of larger body size in males (Olsson et al., 2002).

Genus *Darevskia* Arribas, 1999, classified within the family Lacertidae, comprises 10 species found in the northern part of Iran (Šmíd et al., 2014). The genus was recently revised (Ahmadzadeh et al., 2013), leading to the description of new species within the two *D. chlorogaster* and *D. defilippii* species complexes. Hosseinian Yousefkhani et al. (2022) conducted a morphological examination of seven species of this genus along the Elburz Mountains range. Their results confirm a correlation between body shape and habitat type, indicating greater flexibility in rocky-dwelling lizards (Hosseinian Yousefkhani et al., 2022). *Darevskia schaekeli* Ahmadzadeh, Flecks, Carretero, Mozaffari, Böhme, Harris, Freitas and Rödder, 2013 is among these species found in the eastern Elburz region. Given the lack of detailed information regarding the sexual dimorphism of the species thus far, we decided to investigate this hypothesis. In the present study, sexual size dimorphism was examined in *Darevskia schaekeli* in the eastern Elburz Mountain.

In the present study, we collected 17 male and 16 female individuals of *Darevskia schaekeli* from the Siyah Khani waterfall region, located 70 km northwest of Damghan city in Mazandaran Province. This region experiences a mild summer and cold winter climate. This species starts its activity in early April and remains active until the end of September, during which individuals can be observed in their natural environment through direct observation. We measured 13 morphological characters (11 morphometric and 2 meristic) in the wild. After measurements were taken, all specimens were released back into the same location in the field. The morphological characters measured were as follows: snout-vent length (SVL; distance from the tip of the snout to the anterior edge of the cloaca), tail length (TL; distance from the posterior edge of the cloaca to the tip of the tail), trunk length (LHF; distance between the hindlimb and forelimb), head length (HL; distance from the tip of the snout to the posterior edge of the tympanum), head height (HH; maximum distance between the upper

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head and lower jaw), head width (HW; distance between the posterior eye corners), length of forelimb (LFL; distance from the top of the shoulder joint to the tip of the fourth toe), length of hind limb (LHL; from hip joint to tip of fourth toe), tympanum diameter (TD; largest size), length of widest part of tail base (LBT), and length of widest part of belly (LWB), number of femoral pores (NFP), and number of scales around the precloacal scale (APC). Morphometric measurements were conducted using a digital caliper with 0.01 accuracy, while meristic characters were observed under a Stereo Microscope Olympus.

The normality of the dataset was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests for both parametric and nonparametric characters. In the normality test, H_0 indicates a normal distribution of the dataset. If this hypothesis is confirmed, sexual dimorphism can be analyzed using independent-samples T-test and descriptive statistics between sexes. Descriptive statistics, including the mean, standard deviation, minimum, and maximum, were computed separately for each sex. Significance levels were set at $p \leq 0.05$ for all characters extracted by T-test analysis. The meaningful plot differentiation was illustrated and confirmed by the principal component analysis (PCA) and discriminant function analysis (DFA) between the two sexes. The analyses were conducted using SPSS 20.

Thirteen morphometric characters were examined on 33 specimens (17 males and 16 females), revealing that 8 characters were significant (Table 1). The PCA was performed using these significant characters, and the first three principal components (PCs), evaluated with the varimax method, accounted for 74.67% of the variation between males and females. Specifically, PC1 explained 35.62% of this variation (Table 2; Figure). In PC1, head width and length of forelimb are the most effective characters in sex-based variation. Discriminant function analysis revealed that CV1 explained 100% of the total variance, with Wilks' Lambda indicating a significant value ($p = 0.000$). In addition to the morphometric characters, males exhibit more pronounced color patterns during the breeding season compared to females. Males display a dorsal coloration featuring dark creamy tones with scattered lateral black stripes, while their ventral surfaces showcase hues ranging from orange to red with blue dots on the lateral scales. In contrast, females exhibit very light dorsal coloration and their ventral surfaces display a pale orange tone without blue scales.

Sexual dimorphism stands as a pivotal morphological characteristic distinguishing males from females within a species, a result of evolutionary pressures spanning many years (Shine, 1989; Cox et al., 2003; Berns, 2013; Katona et al., 2021). In animals that undergo sexual reproduction, the process of morphological differentiation between males and females is recognized as a positive evolutionary path. This is because the differences seen in the morphology between the sexes play a crucial role in attracting them to each other for reproduction (Van Damme et al., 2008). Color variation is one of the most basic changes typically observed between males and females, enhancing

Table 1. Descriptive table of 13 morphometric characters examined in *Darevskia schaekeli*. Significant values ($p < 0.05$) are shown in bold.

Characters	Males (N = 17)		Females (N = 16)		p-value
	Mean±STD	Range	Mean±STD	Range	
SVL	54.06±3.67	44.51–58.54	53.09±3.77	44.92–58.52	**0.45**
TL	91.03±10.39	80.20–101.40	87.19±15.45	63.30–110.10	0.60
LHF	28.17±2.30	24.62–33.36	29.88±2.25	25.16–32.72	**0.40**
HL	12.54±0.80	10.87–13.44	10.76±0.75	9.35–11.91	**0.00**
HH	6.10±1.99	4.50–13.60	5.08±0.72	4.20–7.20	0.06
HW	7.78±0.89	6.02–9.37	6.84±0.65	5.12–8.11	**0.00**
LFL	17.56±2.64	8.44–21.03	15.58±1.04	12.34–16.55	**0.01**
LHL	27.87±2.93	19.08–30.47	24.36±1.35	21.19–26.51	**0.00**
TD	2.23±0.16	1.97–2.67	1.99±0.19	1.63–2.29	**0.00**
LBT	10.16±1.92	6.22–12.92	9.70±2.54	4.90–13.56	0.55
LWB	5.61±2.50	3.37–12.28	5.59±2.98	2.36–11.92	0.98
NFP	17.41±1.50	14.00–19.00	16.31±1.25	13.00–18.00	**0.03**
APC	5.76±0.97	4.00–8.00	6.12±0.61	5.00–8.00	0.21

Table 2. Principal component analysis results and the values of the first three PCs. Additionally, cumulative values for all PCs presented.

Character	PC1	PC2	PC3
SVL	0.617	0.279	0.416
LHF	0.730	–0.317	0.263
HL	0.265	0.845	–0.335
HW	0.944	–0.058	0.190
LFL	0.854	–0.308	–0.232
LHL	–0.034	0.789	0.322
TD	–0.206	–0.478	–0.179
NFP	–0.450	–0.183	0.817
Eigen values	2.85	1.87	1.24
Cumulative	35.62	59.07	74.67

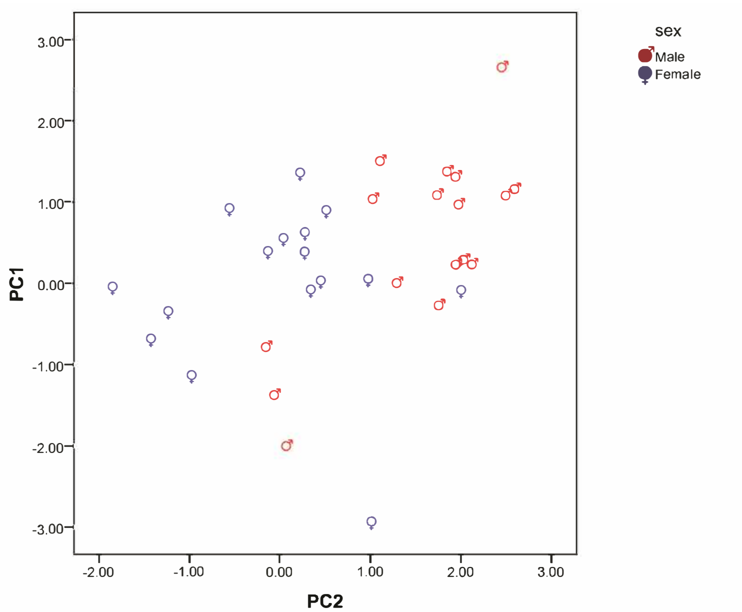

Figure. Sexual dimorphism pattern between *Darevskia schaekeli* males and females based on the first two PCs.

their attractiveness (Chen et al., 2012). This pattern of distinction is particularly evident between the sexes of *D. schaekeli*. In the realm of reptiles, during the breeding season, males display attractive and alluring colors to attract more females. This strategy is considered one of the crucial stages in the evolution of sexual dimorphism in reptiles (Pinto et al., 2005). Attractive coloration during the breeding season demonstrates the superior quality of the genome and characteristics to females, allowing them to select the most suitable male for mating. Other morphological differences, which include body structures, such as body structures, have subsequently emerged to adapt to the habitat and mating behaviors among individuals.

The members of the family Lacertidae in Iran exhibit significant diversity, comprising various species. Among these, the genus *Darevskia* boasts 10 representatives in Iran, distributed across the Alborz mountains and the northwest region of the country (Šmíd et al., 2014). *Darevskia schaekeli* is recognized as one of these endemic species of Iran, reported and described for the first time in 2013 from the eastern regions of South Alborz (Ahmadzadeh et al., 2013). This species exhibits localized and restricted populations, typically observed in small areas characterized by unique habitat features.

Sexual dimorphism observed in this species includes various traits in the forelimb and hindlimb organs, the number of femoral pores, and the length of the head and trunk (Table 1). Consistent with findings from morphological studies on the genus *Darevskia* in Caucasian species, males typically exhibit larger head sizes than females. This disparity offers two main advantages: 1) it aids in sexual selection and enhances bite force during the mating process; 2) it helps reduce food competition between the sexes (Bülbül et al., 2016; Gabelaia et al., 2017; Çavaş et al., 2018; Javanbakht and Noghanchi, 2019; Şahin et al., 2020). Age determination of *Darevskia valentine* revealed that sexual dimorphism in morphological features is evident among populations inhabiting regions characterized by harsh condition and low food availability (Caynak et al., 2021). In another study, researchers found that the longer hind and forelimbs in males compared to females are considered an evolutionary advantage. This anatomical difference allows males to exert greater strength and power when grasping the female during mating (Dehghani et al., 2014). Additionally, the longer head size in males significantly helps in biting the female, which is a fundamental part of the mating behavior in lizards (Olsson et al., 2002; Lappin and Husak, 2005; Herrel et al., 2010). Femoral pores, an integral aspect of the body's signaling for the reproductive season, are more numerous in males than in females. The larger size and greater quantity of these pores in males indicate their reproductive advantage (Oraie et al., 2013; Dehghani et al., 2014; Baeckens et al., 2015).

As a result, the observed differences between male and female *Darevskia schaekeli* individuals exhibit traits indicative of a reproductive advantage. These distinct morphological features between genders have become established through sexual selection, with females utilizing them as crucial criteria for selecting males with greater reproductive ability.

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