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Insights into teratology, melanization, and mechanical wear in some scorpions (Scorpiones: Buthidae, Scorpionidae) from central Morocco

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Abstract

Morphological inspection of 534 scorpions collected across central Morocco revealed eight cases of morphological alterations, including developmental anomalies, ecdysial complications, and natural injuries. Within the family Buthidae C. L. Koch, 1837, pectinal malformations were identified in *Buthus atlantis* Pocock, 1889 and *B. elmoutaouakili* Lourenço & Qi, 2006; *Buthus mardochei* Simon, 1878 exhibited an instance of ocular agenesis (absence of the median eye) alongside a significantly reduced movable finger on the right pedipalp; a specimen of *Androctonus bourdoni* Vachon, 1948 presented a malformed ambulatory leg; localized cuticular melanization was observed in *Androctonus argoubi* Kovařík, Lowe & Šťáhlavský, 2025, reflecting a physiological response to previous cuticular damage; finally, deformities of the walking legs associated with a fatal moulting failure were observed in a juvenile *Buthus lienhardi* Lourenço, 2003. Regarding the Scorpionidae Latreille, 1802, we recorded a bilateral truncation of the cheliceral fingers in *Scorpio mogadorensis* Birula, 1910; this manifestation of mechanical attrition is consistent with the characteristic burrowing lifestyle of the species. Collectively, these anomalies, especially those affecting critical sensory and trophic structures, illustrate the variability of developmental phenomena in scorpions. Such findings highlight how environmental stressors and life cycle-related factors shape the morphological integrity and physical condition of these arachnids. These findings expand the range of abnormalities observed in scorpions and provide essential reference data for the literature on morphological plasticity and changes in the life cycle of Morocco's scorpion fauna.

Keywords: *Androctonus* • *Buthus* • Magreb • natural history • *Scorpio*

Introduction

Morphological anomalies may be defined as any divergence or deviation from the normal and usual form of a species (Lincoln, Boxshall & Clark 1982). Anomalies may be either teratological disorders during development or regeneration that occurs during growth period. In arthropods, deformities have been reported from a wide range of animals collected in natural environments, including myriapods, arachnids and insects (Mitić *et al*. 2011; Noordijk, Heijerman & Morssinkhof 2016; Kizub & Leshchenko 2019; Izquierdo 2021; Mariano, Araújo & Delabie 2022). Scorpions have been characterized over time as a taxon particularly prone to teratological abnormalities (Polis 1990). The most spectacular teratological forms may be those involving metasoma duplication, a phenomenon reported in the literature on at least 16 previous occasions (Sherwood & de Armas 2023), with at least one case of a scorpion with three metasomas (de Armas, López & Hernández 1995).

According to Sherwood & de Armas's (2023) comprehensive checklist of scorpion literature dedicated to morphological abnormalities, anomalies affecting the pedipalps, pectines, walking legs, and metasoma are the most frequently reported (de Armas 1977; Santiago-Blay 1986; Teruel 2003; Gonzalez-Sponga 2004; De Sousa *et al*. 2009; Seiter & Teruel 2014), followed by malformations of the mesosoma, aculeus, and lateral eyes (Lourenço 1984; Mattoni 2005; Salabi, Jafari & Forouzan 2021). Less common are malformations affecting the telson, chelicerae, and genital operculum (Jahanifard, Navidpour & Masihipour 2008; Tate *et al*. 2013; Afifeh & Al-Saraireh 2023). The least frequently observed malformations are those impacting the sternum, prosoma, spermatophore, ovariuterus, and book lungs (Pavlovsky 1917; Matthiesen 1970; Dupré & LeGangneux 1997; David 2012; Di, Edgecombe & Sharma 2018). So far, anomalies have been documented in 14 families of scorpions, and among the 272 cases of malformations reported, 162 were observed in members of the family Buthidae (Sherwood & de Armas 2023). This apparent overrepresentation of anomalies among the Buthidae can potentially be attributed to two main factors. First, Buthidae is the largest family of scorpions, comprising 1291 of the 2898 species currently described worldwide (Rein 2025). Second, most of the species considered medically significant belong to this family, either due to the high toxicity of their venom (Aboumaâd, Iba & Dersi 2014; Santos *et al*. 2016; Lira *et al*. 2017; Darkaoui *et al*. 2022) or because their venoms contain bioactive compounds with therapeutic potential, such as anticancer and antimicrobial agents (Estrada-Gómez *et al*. 2017; Rincón-Cortés *et al*. 2022; Mabunda *et al*. 2025). As a result, members of the Buthidae may be more likely to be encountered, studied, and documented than members of other scorpion families.

Materials and methods

A total of 534 scorpions were collected from four regions of central Morocco (Souss-Massa, Guelmim-Oued Noun, Marrakech-Safi and Beni Mellal-Khenifra) between June 2020 and June 2023. Specimens belonged to 14 species distributed across five genera and two families (Buthidae and Scorpionidae), including four species of *Androctonus* (*A. bourdoni* (n = 43), *A. mauritanicus* (n = 48), *A. sergenti* (n = 10), and *A. argoubi* (n = 17)), eight species of *Buthus* (*B.*

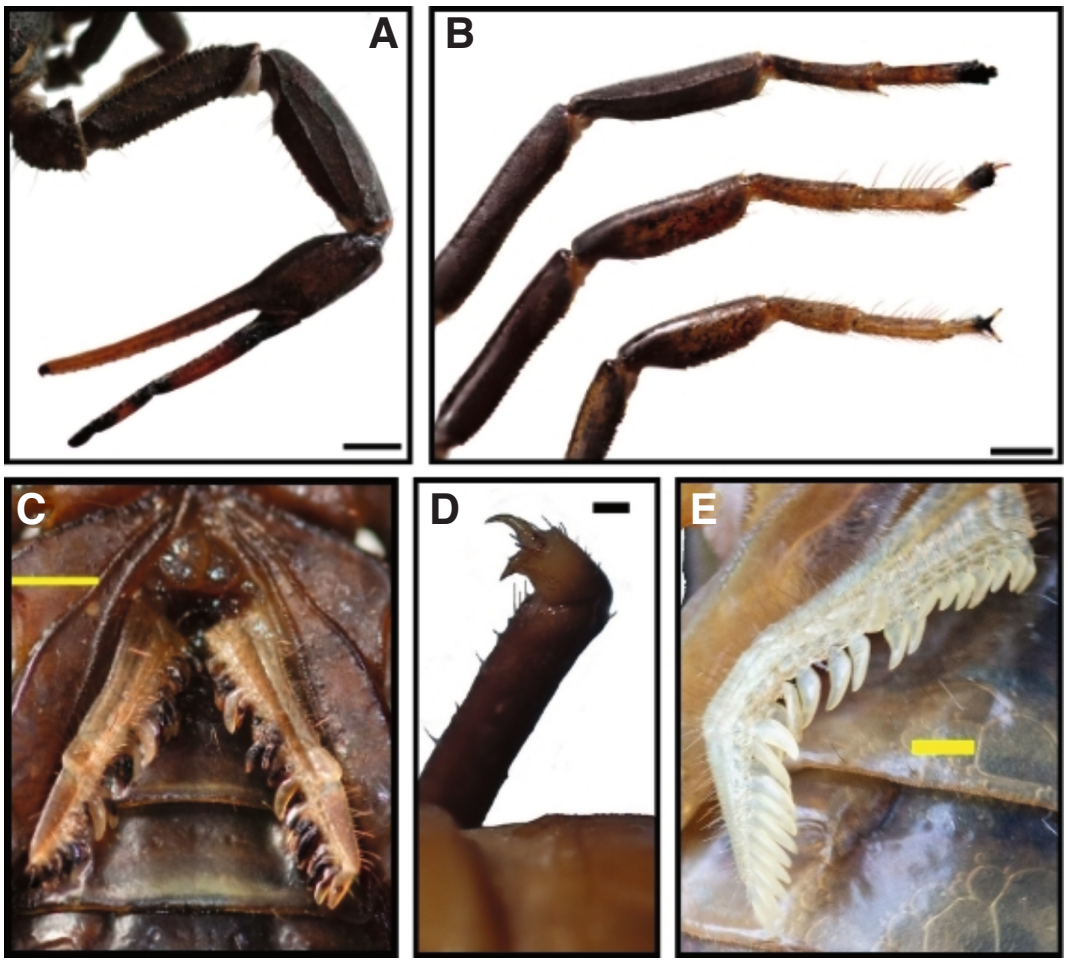


Fig. 1: Morphological alterations in central Moroccan scorpions. **A** *A. argoubi*, localized cuticular melanization observed on mobile finger of left pedipalp; **B** same, distal segments of walking legs; **C** same, pectines; **D** *A. bourdoni*, with fourth left walking leg lacking tarsus, with reduced tibia and single claw; **E** *B. atlantis*, anomalous pectine with structural bend. Scale bars = 2 mm. Photographs by F. Salhi.

atlantis (n = 58), *B. draa* (n = 30), *B. elmoutaouakili* (n = 46), *B lienhardi* (n = 36), *B. malhommei* (n = 15), *B. mardochei* (n = 39), *B. paris* (n = 18), and *B. parroti* (n = 50)), a single species of *Orthochirus* (*O. innesi* (n = 16)), and two species of *Scorpio* (*S. mogadorensis* (n = 75) and *S. weidholzi* (n = 33)).

Scorpions were captured using 16 cm stainless steel forceps when searching potential shelters such as under rocks and logs, in burrows, or within the leaf litter. Searches were performed both during daylight hours and at night using an ultraviolet light. All scorpions were identified using a stereomicroscope and identification keys (Vachon 1952; Lourenço 2003, 2005; Lourenço & Qi 2006; Kovařík, Lowe & Šťáhlavský 2025). Specimens presenting morphological abnormalities were documented, photographed, preserved in 95% ethanol and stored at the Laboratory of Aquatic Systems: Marine and Continental Environments (AQUAMAR) at the Faculty of Sciences, Ibnou Zohr University, Agadir, Morocco. A summary of specimens and localities is provided in Table 1.

Buthidae C. L. Koch, 1837

***Androctonus* Ehrenberg, 1828**

***Androctonus argoubi* Kovařík, Lowe & Šťáhlavský, 2025**

Material examined: Sidi Ifni Province, vicinity of Lakhssas (south of Agadir), 29.391950°N 9.701185°W, 1 adult ♂, 15 July 2022, collected by F. Salhi.

Taxon	Habitat	Life stage and gender	Malformations
Androctonus argoubi (Vachon, 1948)	Argan grove	Adult male	localized cuticular melanization
Androctonus bourdoni Vachon, 1948	Palm trees	Subadult male	leg malformation
Buthus atlantis Pocock, 1889	Argan grove	Adult female	a left twisted comb
Buthus elmoutaouakili Lourenço & Qi, 2006	Argan grove	Adult male	short comb length
Buthus lienhardi Lourenço, 2003	Lack of vegetation	A juvenile	fatal failure of moulting
Buthus mardochei Simon, 1878	Cultivated barley field	Adult male	ocular anomaly
Buthus mardochei Simon, 1878	Argan grove	Adult female	deformed pedipalp
Scorpio mogadorensis Birula, 1910	*Euphorbia* steppe	Adult female	transversely truncated chelae fingers

Table 1: Summary of information on specimens with malformations.

Description: Morphological examination revealed various cuticular alterations of traumatic origin. We focused particularly on the melanized areas, as these could potentially represent an immune and scarring response triggered by external injuries. These post-traumatic melanization phenomena primarily affected the distal segments of the left pedipalp, several ambulatory legs, specifically the fourth left leg and the second and fourth right legs, as well as the combs (Fig. 1A–C). The movable finger of the left pedipalp exhibits two distinct scar deformities, indicative of physical trauma that has undergone complete cuticular repair. Regarding the walking legs, the trauma resulted in varying degrees of claw loss: the absence of a single claw on RII, two on RIII, and all claws on LIV. A visible difference was observed in the healing process: while the pedipalps and walking legs underwent effective healing through sclerotization, the pectines exhibit persistent lesions. These lesions, characterised by a dark pigmentation—which may result from either partial melanization or the sclerotization of the cuticle by dried haemolymph—show signs of active infection and haemolymphatic suppuration, preventing the restoration of the structural integrity of the combs. Careful examination of the affected areas reveals several crucial diagnostic indicators that guide our interpretation. On the one hand, the chromatic demarcation is particularly distinct: this abrupt transition between the healthy integument and the hyperpigmented areas indicates a localized immune reaction, rather than a degenerative process. On the other hand, the strict preservation of the segmental architecture and structural integrity of the cuticle confirms that the underlying tissue remains viable and that the original shape of the appendage has not been altered by tissue lysis. Finally, the complete absence of melanin diffusion or peripheral discoloration—characteristic signs of invasive infections—allows us to rule out the hypothesis of systemic necrosis. Together, these observations suggest post-traumatic melanization, a manifestation of an active physiological response aimed at sealing the cuticular barriers.

Androctonus bourdoni Vachon, 1948

Material examined: Agadir prefecture, vicinity of Amskroud (north-east of Agadir), 30.531511°N 9.323874°W, 1 subadult ♂, 21 September 2022, collected by F. Salhi.

Description: The fourth ambulatory leg on the left side had a noticeable anomaly characterised by the total absence of the tarsus and a substantial reduction of the tibia, which ended in a single claw (Fig. 1D). This abnormality is characteristic of aberrant regeneration following an injury rather than a congenital defect. In such cases, the organism attempts to repair or regrow a damaged structure, but the process is incomplete or incorrect, leading to a functional but morphologically abnormal structure. The initial trauma could have resulted from an accident during ecdysis (moulting), a failed predation attempt, or other adverse environmental encounters.

Buthus Leach, 1815

Buthus atlantis Pocock, 1889

Material examined: Essaouira province, rural outskirts of Essaouira city (west of Marrakesh), 31.504039°N 9.686445°W, 1 adult ♀, 27 May 2023, collected by F. Salhi.

Description: This individual exhibited pectinal deformations, consisting of a twisted right comb (Fig. 1E) and a left comb with two fused teeth (Fig. 2A). The deformation observed on the left comb is likely the result of a developmental anomaly, whereas the irregularity on the right comb appears to be an old injury.

Buthus elmoutaouakili Lourenço & Qi, 2006

Material examined: Ait Baha province, vicinity of Tanalt (South-east of Agadir), 29.795617°N 9.178583°W, 1 adult ♂, 19 April 2022, collected by Dr J. P. Dunbar.

Description: This particular individual presented a significantly shorter right pecten, displaying a single marginal lamella, a reduced number of teeth (n = 14), and median lamellae diminished in both number (n = 5) and size, deviating from the typical characteristics of the species (Fig. 2B). The presence of fundamental structural alterations, such as the absence of marginal lamellae and the substantial reduction in the number of teeth and median lamellae, suggests a disruption during development rather than imperfect regrowth after trauma.

Buthus lienhardi Lourenço, 2003

Material examined: Taroudant province, vicinity of Tislit (South-west of Ouarzazate), 30.572981°N 7.604017°W, 1 juvenile, 15 May 2023, collected by Dr C. J. Coates.

Description: this specimen was recovered, having succumbed during the critical process of ecdysis. Measuring 26 mm and exhibiting visible tegumentary granulation, the individual was identified as being in its fourth instar, a developmental stage typically reached between six and nine months of age. The ecdysial failure was manifest, with the exuviae remaining persistently attached to the posterior third of the metasoma, while the nascent cuticle was insufficiently sclerotized and malleable. A morphological examination revealed a suite of remarkable developmental anomalies affecting multiple body regions: the pedipalps exhibited a profound attenuation and significant axial distortion of both the fixed and movable fingers of the chelae. This generalized dysmorphia extended to the ambulatory legs, which displayed an irregular and asymmetric angularity across various podomeres, specifically within the tarsal and basitarsal segments. Most notably, the fifth metasomal segment appeared developmentally stunted; it was disproportionately reduced and lacked the structural maturation and cylindrical contour characteristic of this stage. Furthermore, the telson was equally affected, with the aculeus displaying a pale, non- sclerotised base, indicative of a failure

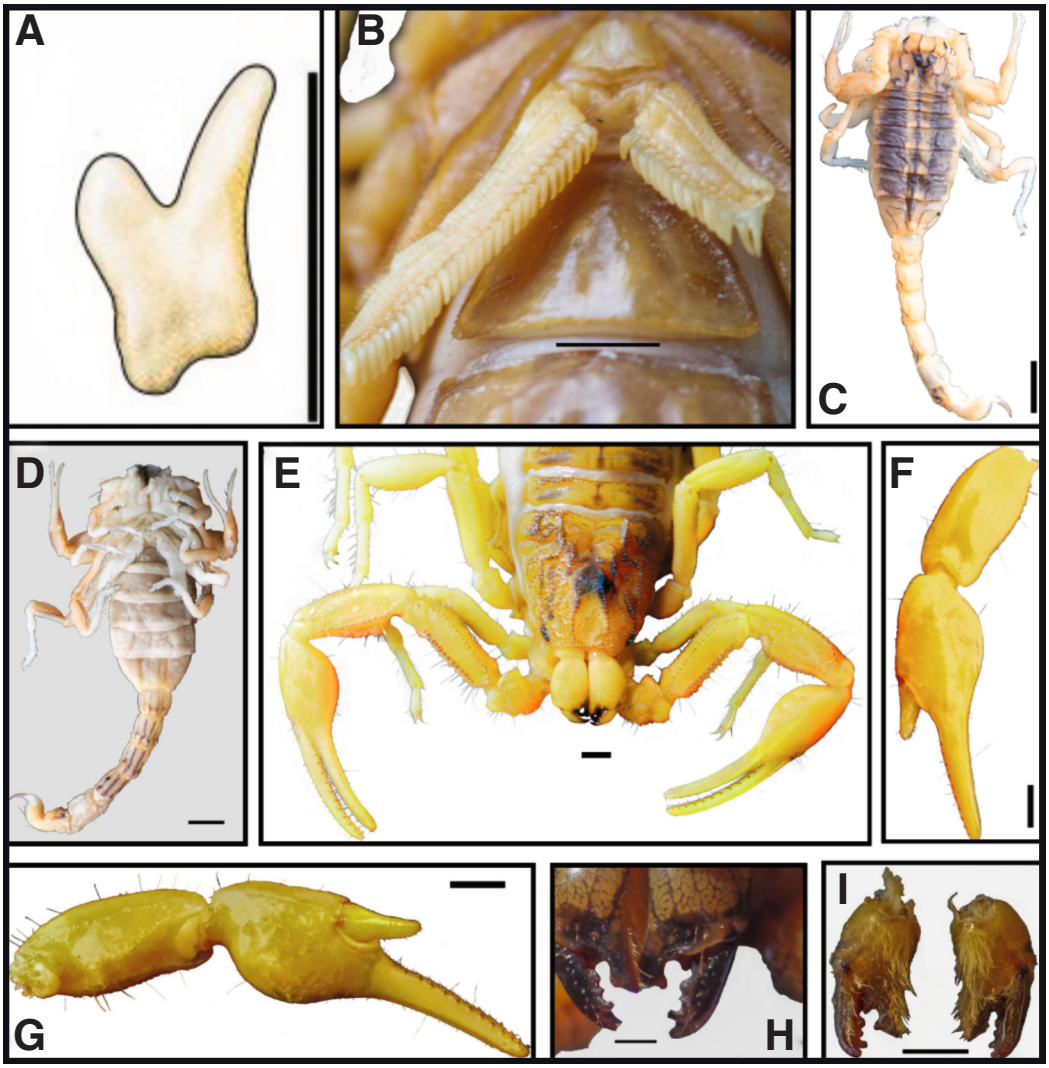


Fig. 2: Morphological alterations and mechanical wear in central Moroccan scorpions. **A** *B. atlantis*, bifid pectinal tooth; **B** *B. elmoutaouakili*, severe pectinal reduction. **C** *B. lienhardi*, fatal ecdysial failure showing ambulatory legs distortions dorsal view; **D** same, ventral view; **E** *B. mardochei*, ocular agenesis (absence of right median eye); **F** *B. mardochei*, reduced movable finger on right pedipalp, external lateral view; **G** same, internal lateral view; **H** *S. mogadorensis*, bilateral mechanical attrition of the chelicerae; **I** same, separated chelicerae. Scale bars = 2 mm. Photographs by F. Salhi.

in the chemical hardening of the cuticle (Fig. 2C–D). The synchronicity of these multi-regional aberrations suggests a systemic developmental perturbation. It is likely that complications during the delicate ecdysis process inhibited the successful formation and sclerotization of the new exoskeleton, thereby increasing the specimen's physiological vulnerability and ultimately leading to its death.

Buthus mardochei Simon, 1878

Material examined: Essaouira province, vicinity of Idaougard (W of Marrakesh), 31.426533°N 9.637591°W, 1 adult ♂, 27 June 2022, collected by Dr J. P. Dunbar; Agadir prefecture, rural outskirts of Aourir (NW of Agadir), 30.479333°N 9.663500°W, 1 adult ♀, 26 August 2021, collected by F. Salhi.

Description: A male specimen of *B. mardochei* lacked its right median eye (Fig. 2E). This specific malformation is likely the result of a teratological event that interfered with the normal embryonic development of the scorpion's ocular structure. In the female, the right movable finger was significantly reduced, measuring approximately one-third the length of its normal counterpart on the left pedipalp (Table 2). In addition, this abnormal finger did not have the semi-oblique series of granules that are normally present on both the movable and fixed fingers of each pedipalp (Fig. 2F–G). This abnormal finger is covered with setae, suggesting that the deformity could be a developmental defect or the result

Pedipalp measurements	Left pedipalp	Right pedipalp
Femur length	5	5
Femur width	1.8	1.8
Patella length	4.1	4.1
Patella width	2.9	2.9
Chela	11.7	11.6
Fixed finger	6.3	6.3
Movable finger	7.6	**2.9**

Table 2: Measurement values (in mm) of different pedipalps of the studied female *B. mardochei*.

of a partial regeneration process following the loss of the mobile finger.

Scorpionidae Latreille, 1802

***Scorpio mogadorensis* Birula, 1910**

Material examined: Essaouira province, Borj Enadour in Safi city (W of Marrakesh), 32.325583°N 9.269978°W, 1 adult ♂, 26 June 2022, collected by F. Salhi.

Description: This individual exhibited truncated fixed fingers in both chelicerae. A detailed morphological examination revealed an abrupt break at the level of the first tooth, with the complete absence of the distal tooth on both fixed fingers of the chelicerae. Furthermore, the three teeth of the mobile fingers appeared distinctively rounder than the typical configuration for this species (Fig. 2H–I). This bilateral truncation observed in the cheliceral fixed fingers of this mature *S. mogadorensis* is interpreted here as an instance of mechanical attrition rather than an ontogenetic malformation. Such wear is a frequent consequence of the fossorial life history characteristic of the Scorpionidae, whose chelicerae are subject to sustained abrasion against hard or gritty substrates during years of burrow excavation. The wear of these chelicerae in an aging, final-instar adult illustrates the cumulative impact of environmental interaction on the feeding apparatus, reflecting a life-history trade-off between behavioural demands and morphological integrity.

Discussion

The morphological integrity of scorpions results from a delicate balance between genetic programming, the proper progression of their developmental stages, and continuous interaction with their environment. Following a detailed morphological study of 534 specimens collected from various habitats in central Morocco, we documented eight distinct cases of morphological deviations. These findings are distributed across seven species and two families, involving seven representatives of the Buthidae—belonging to the genera *Buthus* (n = 5) and *Androctonus* (n = 2)—and one member of the Scorpionidae. Many of the observed anomalies, including malformations of the pedipalps, tergites, ambulatory legs, and median eyes, as well as pigmentation aberrations, align with established teratological categories frequently reported in the literature (González-Sponga 2004; David 2012; Watz & Dunlop 2022; Sherwood, Jessnitz & Tang 2025). In addition to these teratological patterns, the abnormalities identified also include cases of fatal abnormal moulting and cuticular wear. It should be noted that the shortening of the chelicerae in *S. mogadorensis* results from functional wear rather than developmental anomalies similar to those described by Teruel (2003). Analysis of these eight morphological aberrations provides a better understanding of how environmental stressors and specific lifestyles influence the morphological integrity and architecture of the scorpion exoskeleton.

Within the order Scorpiones, colour variations constitute a distinct category of non-lethal anomalies, encompassing phenotypes ranging from albinism (near-total loss of melanin pigmentation) to partial leucism, as well as chimeric patterns in which distinct colored morphs coexist within a single individual (Locket 1986; Lira, Pordeus & Albuquerque 2016; De Armas & Cubas-Rodriguez 2023; Sherwood *et al*. 2024; Tang & Liu 2024; Lakušić *et al*. 2026). Although increasingly documented through observations in the wild and in captivity, these phenotypic expressions remain generally rare at the population level (Sherwood *et al*. 2024). However, it is important to distinguish these global pigmentary deviations from localized color changes resulting from adaptive physiological processes The *A. argoubi* specimen studied here belongs to a species recently described by Kovařík, Lowe & Šťáhlavský (2025), which was previously classified within the complex *Androctonus sergenti* Vachon, 1948, but differs from it in the more pronounced granulation of the metasoma and distinct genetic characteristics. This specimen exhibits localized darkening that is not the result of an innate phenotypic variation, but rather a trauma-induced melanization response (Fig. 1A–C). This process is mediated by the phenol oxidase cascade, in which hemocyanin is converted into an active enzyme to initiate melanin synthesis. This defense mechanism, highly conserved among arthropods, serves a dual function: rigorous antimicrobial protection and mechanical stabilization of the damaged integument (Burmester 2002; Cerenius & Söderhäll 2004; Bilandžija *et al*. 2017). Our study highlighted the differential physiological response observed among the appendages. While melanization fulfilled its role as a protective barrier on the pedipalps and walking legs—sealing the lesions and stabilizing the cuticle—it proved ineffective on the pectines (combs). On these sensory organs, the melanic reaction was only superficial and incomplete, leaving active infection foci and an unrepaired integument. This disparity suggests that, in *A. argoubi*, the efficacy of the phenoloxidase cascade may be determined by the structural nature of the affected appendage, favoring robust segments at the expense of finer sensory structures.

Alongside the observations made on *A. argoubi*, we documented a further case affecting the left ambulatory leg IV of an adult male *A. bourdoni*. This case is similar to the anomaly described by Sherwood & de Armas (2023) in *Tityus insignis*, with a single claw at the end of the patella, accompanied by a complete absence of the tibia and tarsi. However, our specimen had a tibia reduced in length by about two-thirds (Fig. 1D). The literature comprises reports on a range of anomalies affecting the walking legs of scorpions, including damaged legs in nymphs, malformations affecting the patella, femur, tibia, or trochanter, cases of fusion, deformation, or absence of the tibia and tarsi as well as abnormally elongated, bifurcated, or even supernumerary terminal claws (Vachon 1954; de Armas 1977; Santiago-Blay 1986; González-Sponga 2004; Sherwood & de Armas 2023). This diversity of morphological alteration reflects the variability of abnormal phenotypes, and our finding fits

within this framework, adding a new case of aberrant developmental phenomena in scorpions.

The study revealed a pectinal anomaly in an adult male specimen of *B. elmoutaouakili*, in which only the left structure was affected, while its right homologue remained perfectly normal. Pectines are complex structures composed of three marginal lamellae and a variable number of fulcra and teeth depending on sex and species. Each tooth is equipped with vital sensory receptors, the peg sensillae (Hjelle 1990). Vachon (1952) reported that female *B. elmoutaouakili* bear either 23 and 24 teeth, while males have between 27 and 29 teeth. On our male specimen, the intact pecten consisted of three marginal lamellae, 29 teeth, and six median lamellae. However, the deformed comb showed striking differences: it had only one marginal lamella, a drastically reduced number of teeth (14), and only five median lamellae, the latter being significantly smaller in size (Fig. 2B). While scorpions have regenerative abilities for certain appendages—legs and pedipalps—which generally results in reduced structures, the regeneration of pectines has never been reported (Sherwood & de Armas 2023; Sherwood *et al*. 2024). In addition, Stemme (2024) demonstrated that pectines are unable to be regenerated. Another pecten anomaly was observed in a specimen of *B. atlantis*, a species known to prefers sandy substrates with stones and rocks. The two combs of this individual had 28 fulcra and 28 teeth, but the right comb was twisted (Fig. 1E) and the left comb had a bifid tooth (Fig. 2A).

Ecdysis represents one of the most critical and perilous biological processes in the evolutionary history of scorpions, a stage already documented in their extinct sister group, the eurypterids (Tetlie, Brandt & Briggs 2008). In extant Buthidae, such as *Buthus occitanus*, this transition phase is preceded by a prolonged fast (Le Berre 1979) and a marked reduction in metabolic and behavioural activity (Schultze 1927; Rosin & Shulov 1963). The success of this moult depends on strict environmental and ethological determinism: the specimen must select a humid microhabitat (Schultze 1927) and a substrate that provides adequate anchorage for its legs. As De Armas (1986) pointed out, a failure in initial positioning can irrevocably interrupt the process, leading to a lethal outcome. The complexity of this sequence is particularly illustrated by the postural sequence described by Auber (1963) in the genus *Buthus*: the animal begins the extraction in a ventral position before turning onto its back to free the abdomen. This delicate phase of moulting exposes the scorpion to mechanical stresses where sclerotization abnormalities may occur, placing it in a state of morphological vulnerability, such as that observed in the juvenile *B. lienhardi* described here. The simultaneous presence of multiple malformations in this same specimen—deformation and torsion of the pedipalps, distortion of the walking legs, and malformation of the fifth metasomal segment—which led to a lethal outcome (Fig. 2C–D), suggests an etiology linked to a critical accident occurring during ecdysis, at a precise moment when the new cuticle, still malleable, had not yet acquired its final rigidity. During this period of vulnerability, the normal development of the appendages may be impeded or subjected to abnormal mechanical forces before sclerotization is complete, thus leading to morphological malformations. These manifestations fall squarely within the scope of scorpion teratology, where difficulties in shedding the old exuvia as well as environmental stresses are among the most frequently cited causes. Teruel (2003) recorded this pedipalp chelae anomaly for 29 species belonging to 9 families. He was the first to attribute this anomaly to mating immediately after the last ecdysis, while the integument was not yet fully sclerotized. Similarly, Watz & Dunlop (2022) reported the case of an *Olivierus caucasicus* individual whose tips of two legs had been accidentally amputated during a moult and had regrown with morphological abnormalities, thereby demonstrating that disturbances occurring at the time of ecdysis can result in permanent anatomical abnormalities.

Several cases of malformations affecting the pedipalps have been reported in the literature, including asymmetries in finger length, abnormalities in the number or shape of denticles, and even fusions between the patella and chela (Lourenço 1984; Santiago-Blay 1986; Cao López & Solórzano 1991; González-Sponga 2004). We describe an anomaly observed in *B. mardochei*, a species with a preference for rocky environments, where it finds refuge under stones, sometimes digging small burrows (Salhi *et al*. 2024). According to Lourenço (2003), the cutting edges of *B. mardochei* pedipalpal fixed and mobile fingers contain 10 to 11 semi-oblique series of granules that are darker in colour than the fingers. This individual is characterized by a greatly reduced mobile finger (Fig. 2F–G). This case is similar to the one reported by Jahanifard, Navidpour & Masihipour (2008), which involved the fixed finger of the pedipalp in a member of the genus *Orthochirus*, as well as to the observation by Sherwood & de Armas (2023) concerning the mobile finger in a member of the genus *Hadruroides*. In our case, it is also the mobile finger that is affected. Our measurements show that all the structures of the abnormal pedipalp are comparable to those of a normal pedipalp, with the exception of the mobile finger, whose size and volume are considerably reduced—about one-third of those of a normal finger (Table 2).

Another significant anomaly was the total absence of the right median eye in a *B. mardochei* (Fig. 2E). A range of ocular malformations has been described previously, including the absence of one or more eyes, whether median or lateral, the fusion of two eyes into a single, aberrant structure, notable asymmetries of the median eyes, or the presence of an extra eye (Lourenço 1984; Santiago-Blay 1986; Neo, Ting & Lee 2004). Our finding echoes two similar cases reported by González-Sponga (2004), both involving adult males *Tityus carabobensis* and *Tityus clathratus* respectively, thus highlighting a form of recurrence of this type of ocular anomalies across different species.

Scorpio mogadorensis, a taxon formerly regarded as a subspecies of *Scorpio maurus* (*S. maurus mogadorensis*), possesses a cheliceral architecture as distinctive as its ecology. Under normative conditions, its chelicerae are distinguished by a fixed finger bearing three teeth—with the two

basal-most typically fused—and a movable finger likewise equipped with three teeth, the second of which is markedly prominent (Vachon 1952, 1963). While the literature reports numerous actual teratological anomalies affecting these structures, ranging from bifid dentition and supernumerary teeth to severe hypertrophy or complete unilateral reduction (Santiago-Blay 1986; de Armas & Marcanos 1992; Tate *et al*. 2013; Zouatine, Bissati & Sadine 2024), the bilateral truncation observed in our mature specimen of *S. mogadorensis* diverges fundamentally from these teratological anomalies. Rather than a stochastic developmental error, this condition likely reflects the mechanical toll of a long-lived, fossorial existence (Fig. 2H–I). As terraphilous specialists, these scorpionids spend an overwhelming 90–95% of their lives within self-built underground retreats (Hadley & Williams 1968; Tourtlotte 1974; Bradley 1982; Polis 1990). The construction and maintenance of these galleries represent a rigorous mechanical and energetic challenge of physical endurance, as some scorpions may excavate 200–400 times their body weight in sediment during burrow construction (Shorthouse & Marples 1980). In this context, the chelicerae function as cuticular tools, adapted to the hardness of the substrate; they are used to initially loosen and fracture compacted or gritty materials before the walking legs rake and scrape the resulting debris (Harington 1977; Eastwood 1978; Polis 1990; Rutin 1996; White 2001). Although these appendages are exceptionally well protected through the incorporation of zinc in the cuticle, which triples the hardness of the cuticle via a complex network of nanopores (Schofield *et al*. 2003), these structures are not indestructible. These scorpions have a lifespan of 25–30 years (Polis & Sissom, 1990), and repeated grinding against abrasive ground inevitably wears down the dentition of the chelicerae. The bilateral symmetry of the eroded chelicerae strongly suggests that it is a mechanical wear-and-tear anomaly resulting from years of activity, rather than a developmental malformation.

The etiology of morphological abnormalities remains a subject of debate, as the precise causes of malformations in scorpions are often unknown (Mattoni 2005; Salabi, Jafari & Forouzan 2021). Based on studies conducted on other arthropods, various factors may contribute to these abnormalities. These include genetic factors such as chromosomal abnormalities, genetic defects, and mutations (Poswillo 1976; Napiórkowska *et al*. 2023), as well as environmental factors such as humidity, temperature, and various teratogenic substances that may influence embryonic development (Li 1995; Li & Jackson 1996; Napiórkowska & Templin 2013). In the cases we report, malformations involving the pectines and median eyes suggest a developmental origin, possibly related to genetic or environmental factors. Other abnormalities, such as certain malformations of the legs and pedipalps, could result from similar developmental disorders, severe trauma, or partial regeneration following injury while the abrupt truncation of chelicera may be the result of an early developmental disorder.

The implications of these anomalies for the survivorship and reproduction of scorpions are not clear. Deformities affecting essential sensory organs such as pectines can impair chemoreception and substrate perception, which are essential for foraging, locating mates, and avoiding predators. Similarly, malformations of the pedipalps and chelicerae, which are essential for prey capture, defence, and feeding, can significantly compromise an individual's ability to thrive. Eye abnormalities could affect visual navigation or motion detection, although scorpions rely heavily on other senses. Leg malformations may impact mobility, escape responses, and ability to dig burrows. These deficiencies could collectively reduce an individual's fitness. Although our study describes a very limited number of anomalies representing just over 1% of our total sample, the potential role of environmental factors deserves further investigation. Scorpions were collected from various habitats, including argan groves, cultivated fields, and rocky terrain. Anthropogenic pressures, such as pesticide use in agricultural areas, habitat degradation, or pollution, could potentially contribute to developmental disorders, although this requires specific ecotoxicological research.

Future research could benefit from larger-scale surveys, potentially incorporating controlled experimental studies to investigate the impact of environmental stressors on scorpion development. Long-term observations of anomalous individuals, if feasible, could also provide critical insights into the consequences of these malformations on survival and reproduction.

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