ORIGINAL ARTICLE

Ecological distribution patterns of *Eremina desertorum* in relation to *Zygophyllum album*, *Thymelaea hirsuta*, and climatic factors in its habitat in Egypt

Amr E. Keshta[1], Hesham A.M. Ibrahim[2], Heba Bedair[1], Mohammed E. Gad[3], Soumya Ghosh[4], Ammar AL-Farga[5], Esraa El Saaed Ibrahim Ammar[1]*

[1] Botany and Microbiology Department, Faculty of Science, Tanta University, Tanta, Egypt
[2] Department of Agricultural Zoology and Nematology, Faculty of Agriculture, Al Azhar University, Assiut Branch, Assiut, Egypt
[3] Department of Zoology and Entomology, Faculty of Science, Al-Azhar University, Cairo, Egypt
[4] Natural and Medical Sciences Research Center, University of Nizwa, Nizwa, Oman
[5] Department of Biochemistry, Faculty of Science, University of Jeddah, Saudi Arabia, Jeddah, Saudi Arabia

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*Corresponding address:
esraa_ammar@science.tanta.edu.eg

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Abstract

This study examined the distribution of the desert snail *Eremina desertorum* (Forskål, 1775), a mollusk of economic importance, in arid desert environments. By exploring its ecological relationship with the plant species *Thymelaea hirsuta* (L.) Endl. and *Zygophyllum album* L.f. in Egypt, the research highlighted the correlation between these plants and the snail's habitat preferences. Over the course of a year (from March 2021 to March 2022), 40 field visits were conducted across various locations along Egypt's Mediterranean coast, encompassing all seasons. It was observed that *E. desertorum* tended to aggregate on *T. hirsuta* and *Z. album*, rather than on other wild plant species. Thus, the study aimed to predict the spatial distribution of *E. desertorum* by analyzing its relationship with these associated plants in Egypt, and the effect of prevailing climatic factors on its distribution, particularly seasonal precipitation and relative temperature. Spatial analyses over a decade (2012–2021) indicated that most *E. desertorum* populations were concentrated around the Nile and Upper Nile Deltaic regions, where *Z. album* was more prevalent than *T. hirsuta*. In contrast, *T. hirsuta* was predominantly recorded in the upper parts of Egypt, near the Mediterranean coast. Findings demonstrated a strong link between regions with higher precipitation and the presence of *E. desertorum* and its associated plants from the Zygophyllaceae (*Z. album*) and Thymelaeaceae (*T. hirsuta*) families. Furthermore, the snail showed a preference for plants known for higher water retention, which likely aids its survival in arid, water-scarce environments. These findings offer a useful framework for predicting the distribution of *E. desertorum* in relation to key plant associations and climatic conditions in arid environments. While the spatial data were based on previously recorded location coordinates, further studies focusing on population dynamics and broader plant comparisons could enrich the understanding of habitat preferences under shifting climate patterns.

Keywords: Egyptian flora, *Eremina desertorum,* precipitation. spatial analyses, temperature

Introduction

The phylum Mollusca is the second largest invertebrate phylum that has a global distribution (Atta *et al.* 2021). Terrestrial gastropods are the only mollusca class that has successfully invaded land which are widely dispersed by human activities, particularly by transporting soil and plant materials (Speiser and Kistler

2002). Terrestrial mollusks, including snails and slugs, belonging to the class Gastropoda, have significantly increased in their economic importance. Some species have become agricultural pests in the Nile Delta and occur in high numbers in the North Coast belt of the Mediterranean Sea (Mahmoud and Awad 2008; Mohammed 2015; Abdel kader *et al.* 2016). Additionally, Gastropoda represents a significant group of economic pests, exemplified by snails that pose a substantial threat to various agricultural and horticultural crops in temperate and humid environments across the globe. Variations in dispersal, movement, and daily activity patterns among land snail species are influenced by climatic conditions. Land snails feed on leaves, roots, tubers, and ornamental plants. Furthermore, they produce a mucus with an odor, which serves as a deterrent to humans and deters herbivory consumption of these contaminated plants (Khidr *et al.* 2020). The odor also impacts the population density and activity of land snails (Khidr *et al.* 2020). Land snails have been reported to damage tender plant tissues such as wheat blossoms, Egyptian clover, various vegetable crops, and fruits (Desoky 2018). They attack field crops, orchard trees, as well as ornamental and medical plants (El-Wakil *et al.* 2000; Abo-Elwfa *et al.* 2024). Snail slime contamination has led to animals avoiding feeding on contaminated plants. Consequently, the consumption value of these plants has diminished, resulting in a decline in crop marketability and export potential (Ali and Robinson 2020). In the geographical distribution correlation of snails with their plant habitats, the abundance density of snails decreased by increasing distances between orange trees (Khidr *et al.* 2020).

The bodies of many species of snails and slugs that belong to this phylum, such as *Eremina desertorum* (Forskål, 1775), secrete rich mucus which helps reduce desiccation under arid conditions (Gabriel *et al.* 2011; Nantarat *et al.* 2019; Ibrahim *et al.* 2022). This mucus and its derivatives, like mucin, may contribute to its beneficial pharmacological activities (Gabriel *et al.* 2011; Trapella *et al.* 2018; Abd El Azeem *et al.* 2020). For instance, it has been suggested that *E. desertorum* mucin holds potential as an antioxidant, hepatoprotective, and anti-inflammatory agent for the treatment of hepatic disorders as well as colon and liver cancers (Atta *et al.* 2021; El-Zawawy and Mona 2021; Ibrahim *et al.* 2022).

Eremina desertorum snails live in sandy deserts and feed on shrubs (Ali *et al.* 2016; Holyoak *et al.* 2018). Throughout the year desert snails occur on wild plants in a natural, arid ecosystem with low precipitation. (Ali 2017a, b). This desert species is commonly found across various locations along the Mediterranean region, from Alexandria to Egypt's border with Libya (Kaltenbach *et al.* 1934; Ali 2017a). Arad reported that *E. desertorum* has a high degree of resistance to water loss in standardized laboratory studies (Kaltenbach *et al.* 1942). Therefore, it can live in an arid desert environment, which feeds and finds shade under many wild plants (Holyoak *et al.* 2018). *Eremina* L. Pfeiffer, 1855 is a geographically restricted genus to many countries of the North Africa region (Schileyko 2000) such as Egypt, Libya and Tunis (Ali 2017b). Its distribution encompasses the entirety of the northern desert region of Egypt and the desert of northern Sinai, and southern Tunisia. Additionally, it can be found along the shores of the Red Sea and the Atlantic Ocean up to Rio of Oro, a southern geographic region located in northwestern Africa (Pallary 1909; Pallary 1924). The genus is also present in the southwestern regions of Morocco and Mauritania and apparently in the Cape Verde Islands (Groh and Rolán 2005; Groh 2012). The genus is unknown in E. Morocco and Algeria, extending southwards through Arabia to Somalia (Neubert 1998). *Eremina* samples were collected from many regions along Egypt's northern coast from Alexandria to El Sallum village (Ali *et al.* 2016). According to previous studies, the presence of these mollusk species in arid desert regions can be attributed to favorable and suitable environments that support their growth and reproduction. This is facilitated by the existence of certain wild desert plants.

Thymelaea hirsuta (L.) Endl. is the sole taxon within the Egyptian flora, classified as *Thymelaea*. The native range of this species encompasses the Mediterranean region. The plant in question is classified as a subshrub or shrub, and its primary habitat is the subtropical biome. Furthermore, it inhabits dunes, sand flats, rocky ground, banks of water bodies, plains, depressions, wadis, roadsides, and cultivated lands of oases, North Sinai, and the Mediterranean western desert of Egypt (Boulos 2000; Bedair *et al.* 2020). It is a prevalent species found in Egypt, serving as a habitat for a wide range of fauna throughout the year (Hegazy *et al.* 2022). The population of *T. hirsuta* in Egypt is experiencing a decline, resulting in habitat reduction potentially leading to species extinction in the future (Bedair *et al.* 2020). An almost continuous row of tourist facilities occupies the coastline along the northern coast. This has not only led to the complete destruction of the habitats, but also degradation of vast areas of habitats surrounding them. Consequently, this threatens plants in these habitats such as *T. hirsuta* (Książkiewicz-Parulska and Ablett 2016; Hegazy *et al.* 2022). *Zygophyllum album* L.f. is a prevalent subshrub characterized by its typical woody stem that supports slender branches adorned with succulent leaves. It thrives in the saline sandy soils of coastal and inland regions of the Mediterranean, Oases, Sinai, the Red Sea, and Egyptian deserts (Boulos 2000). The native range of this species globally is near-endemic (NE) Spain, S. & E. Mediterranean, the Arabian Peninsula, and Somalia. It grows primarily in a subtropical biome (POWO 2021). Interestingly, this species serves as a microhabitat for several snail species during the summer (Aubry and Magnin 2005).

Accordingly, climate changes over the years may alter the chemical composition of certain weeds, which in turn can affect the organisms that feed on them. Temperature fluctuations have influenced the life traits of organisms, which eventually have dictated population growth rates (Nikolova 2025). Indeed, predicting how different species will respond to environmental changes is challenging due to the diversity of natural ecosystems (Balakrishnan and Yapp 2004). Understanding the distribution patterns of species within their habitats is crucial for ecological research and conservation efforts (Balakrishnan and Yapp 2004). In arid environments like Egypt, where desert ecosystems prevail, investigating how organisms adapt to their surroundings becomes particularly relevant. In this study, the distribution patterns of the desert snail *E. desertorum* in its natural habitat were focused on. Specifically, its interactions with two common plant species, *Z. album* and *T. hirsuta,* were explored. By modeling these distribution patterns, the aim of this study was to better understand the ecological dynamics and adaptations of this snail species under the challenging desert conditions of Egypt. The study aimed to investigate the predictive occurrence of the geographic range of the interaction between *E. desertorum* and two plant species, *Z. album* and *T. hirsuta.* Using field observations of this snail on the plants under study in its habitat in Egypt the study sought to explore the influence of climatic changes on the distribution of the desert snail in conjunction with the two desert plants through spatial analyses.

Materials and Methods

Study Area

Egypt is situated in the northeastern part of Africa and includes the Nile region, which encompasses temperate grassland, desert, and semi-desert biomes. The Nile region in Egypt spans around 1,520 kilometers, which accounts for 23% of the entire length of the river and sustains a population of approximately 80 million individuals. The composition of the region includes three primary elements: the Nile Delta, Nile Fayium, and Nile Valley. The Nile Delta, along the Mediterranean coast, extends 240 km from Alexandria to Port Said. The Nile Fayium, a wind-eroded depression formed about 1.8 million years ago, covers approximately 12,000 square kilometers and lies below sea level (Ammar 2022) (Fig. 1). The Nile Valley and the southern part of the Nile Delta are hyper-arid, while the northern section is arid, reflecting Egypt's overall arid to hyper-arid climate. From 2012 to 2018, annual rainfall varied between 80 and 200 mm, with the Mediterranean coast near Alexandria receiving the most precipitation. The hot and arid summer season lasts from May to October (https://weather-and-climate.com). This study relied on the fact that the desert snail *Eremina desertorum* was observed in abundance on certain desert plants, *Thymelaea hirsuta* and *Zygophyllum album*, in its habitat in Egypt, where it was observed over the course of a year (from March 2021 to March 2022), during 40 field visits. Observations along the Mediterranean coast, were conducted over all seasons. It was seen that *E. desertorum* tended to congregate on these

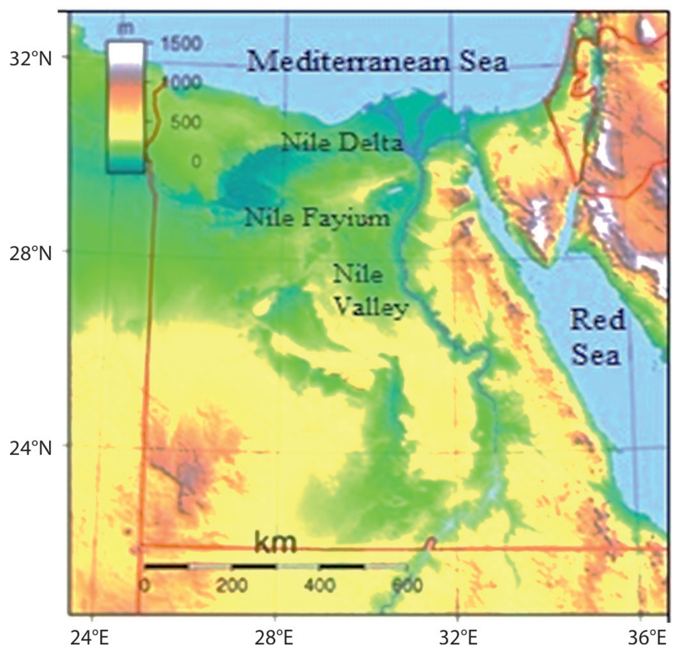

Fig. 1. Topographical map of the Nile region in Egypt, illustrating the varying landscapes and geographical features within the area

plants more than on others. Therefore, it was necessary to elucidate the geographical distribution of the desert snail on some associated desert plants in Egypt, and the effect of prevailing climatic factors on its distribution over a decade-long period spanning from 2012 to 2021.

Eremina desertorum occurrence datasets

The recorded locations of *E. desertorum* (from the year 2000 until now) were compiled through access to available online databases and literature searches. Databases were used to search for any literature related to the occurrence and distribution of the land snail *E. desertorum* and its above-mentioned sub-species. The obtained search results were examined to extract literature that recorded this snail in Egypt during the study period. Accordingly, a distributional data set was created that included geographical coordinates. If the geographical coordinates were not available for a region, we assigned them through geographical maps. The recorded locations and geographic coordinates of *E. desertorum* in Egypt (El-Wakil *et al.* 2000; Hassan 2015; Ali 2017a; Ali *et al.* 2016; El-Zawawy and Mona 2021) are shown in Table S1. This species was formerly known as *Helix desertorum* Forskål, 1775.

Plants occurrence datasets

Regarding *T. hirsuta* and *Z. album*, the available data on locations and distributions of the studied plant species were recorded, from March 2021 to March 2022, including all the seasons. Different locations were visited which covered the phytogeographical regions of the Oases, the Mediterranean, the Nile region, the Red Sea, the Eastern desert and Sinai and from the herbaria of Tanta University (TANE), Cairo University (CAI), Assiut University (ASTU), Agricultural Research Center (CAIM), Desert Research Center (CAIH), National Research Centre (CAIRC), and National Registry for Egyptian Herbaria (2023). These recorded locations are shown in Table S2.

Geospatial and statistical data analyses

A geospatial distribution map was created to demonstrate the relationship between localities of *E. desertorum* (both empty shells and living samples) and the geographical distribution of both *Z. album* and *T. hirsuta*. Point feature classes (for both plant and animal localities) were created in ArcMap 10.9 (Law and Collins 2015). Additionally, all vector shapefiles were spatially projected and geo-referenced to the World Geodetic System (WGS) 1984 datum. For plant and animal localities, annual averages for both precipitation ($mm \cdot day^{-1}$) and temperature (°C) were presented during the years 2013, 2017, and 2021 as graduated color classes overlaid on top of the point feature classes for both animal and plant locations. To test the significance ($p < 0.05$) of the relationship between precipitation ($mm \cdot day^{-1}$) and temperature (°C), Pearson correlation coefficients (r) were calculated. All statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, U.S.A.).

This study investigated the influence of temperature and precipitation on the occurrence of *E. desertorum*. Data on temperature and precipitation were collected for 10 years, from 2012 to 2021, utilizing the Power NASA website (https://power.larc.nasa.gov/). Subsequently, the relationship between them was tested (Tables S1 and S2). Occurrence records from different periods were combined for spatial distribution analyses.

Results

The occurrence and distribution of terrestrial gastropods vary significantly depending on habitats, vegetation cover and climatic conditions. This variation is evident because many of these environmental variables provide favorable habitats for these animals. Regarding the taxonomic and descriptive background of the desert snail, the desert snails *E. desertorum* (Forskål, 1775) from the Helicidae family (Gastropoda: Pulmonata) are terrestrial snails in the genus *Eremina*. The shell of this genus ranges from 14 to 26 mm in height, with 22–35 mm in diameter (Blume 1952). It has a semi-spherical shell which is quite solid, opaque with shouldered whorls, and white to yellowish-corneous. There are reddish bands or yellowish streaks with irregular radial striation. The aperture is round, sometimes slightly angulated, straight or with a little reflexed margin. The umbilicus is very small or absent (Ali 2017b).

The size of the shells of this genus ranges from medium to large, depressed with thick walls (Neubert 1998). Shell size and shape are related to climate change from cooler and more humid conditions along the Mediterranean coast to arid and hot conditions inland (Ali *et al.* 2016). This genus is represented by a number of species, including sub-species *E. desertorum desertorum* (Forskål), *E. d. irregularis* (Férussac) and *E. d. zitteli* Boettger, which are reported in northern Egypt (Ali 2017a).

Eremina desertorum and its habitat plants' geographical distribution

The desert snails were observed to congregate more frequently on the wild plants *Zygophyllum album* L.f. and *Thymelaea hirsuta* (L.) Endl. during field trips conducted from March 2021 to March 2022, across the study area. These trips covered all four seasons, including dry, wet, hot, and cold conditions (Fig. 2). Therefore, the relationship between the geographical distribution of both snails and plants was studied to understand the extent of the correlation between their distribution. After analyzing the plants' geographical distribution at the recorded sites (Fig. 3), it was observed that the predominant occurrence of *Z. album* was concentrated along the Mediterranean Sea coastline, except for three specific locations situated on the southern region of the Red Sea coast (Wadi Gimal, 50 km south Marsa Alam, and 12 km north Marsa Alam, see Table S1 for exact site location). In the Nile Delta (Fig. 4A), *Z. album* was recorded at two sites. In contrast, *T. hirsuta* was exclusively recorded in the northern region of Egypt, predominantly in close proximity to the Mediterranean Sea coastline.

The analysis conducted on the geographical distribution of *E. desertorum* revealed that a significant majority, more than 90% of the observed localities, were found close to the Nile River watershed areas and in the upper regions of the Nile Delta (Fig. 4C). Both empty shells and living samples of *E. desertorum* were recorded near the locations of both *Z. album* and *T. hirsuta* (see field images presented in Fig. 2 for more details). It was noted that the distribution of

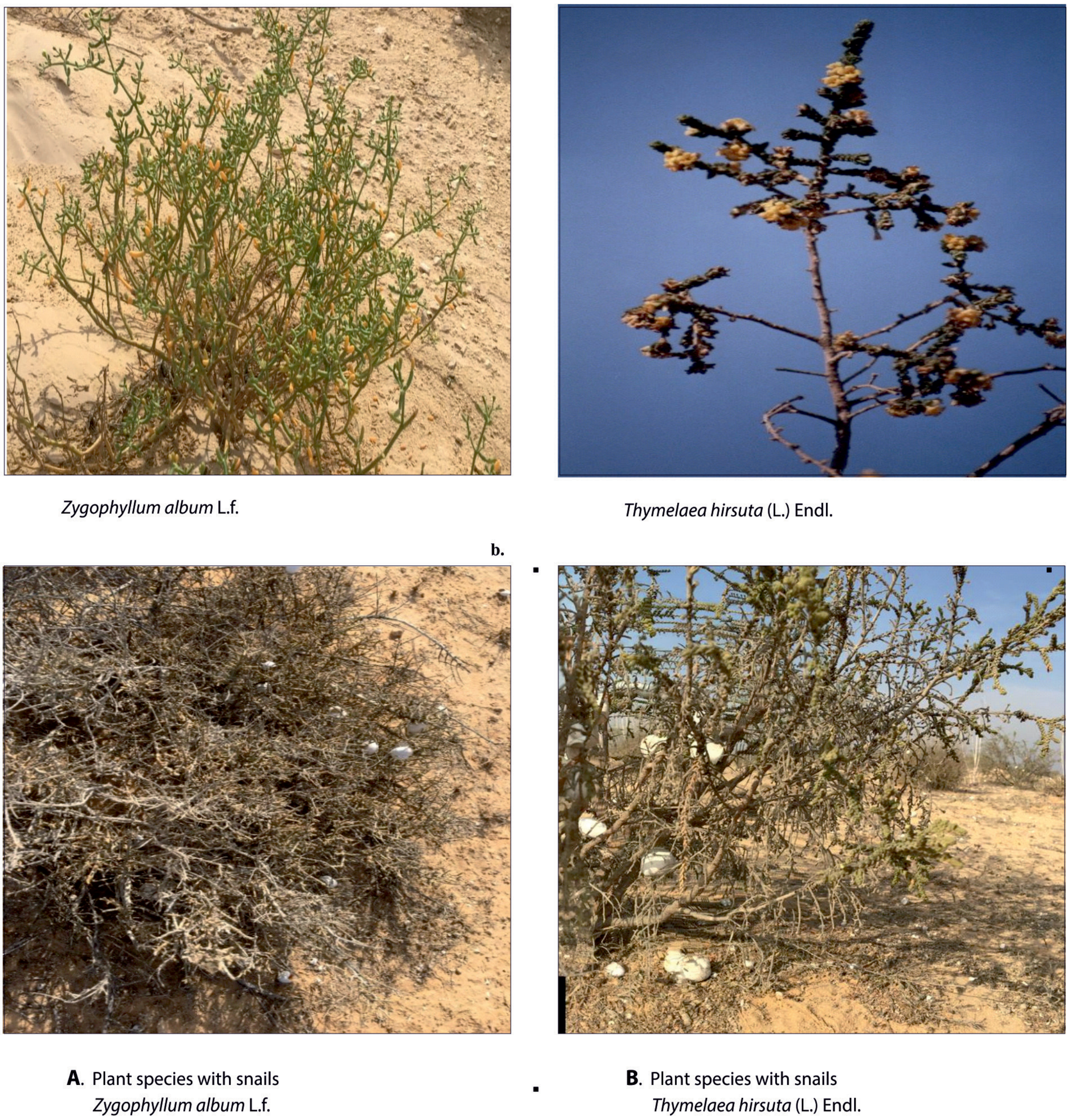

Fig. 2. *Eremina desertorum* snails found on *Zygophyllum album* L.f. – A and *Thymelaea hirsuta* (L.) Endl.– B along the Mediterranean Sea coast of Egypt (photo courtesy of the authors)

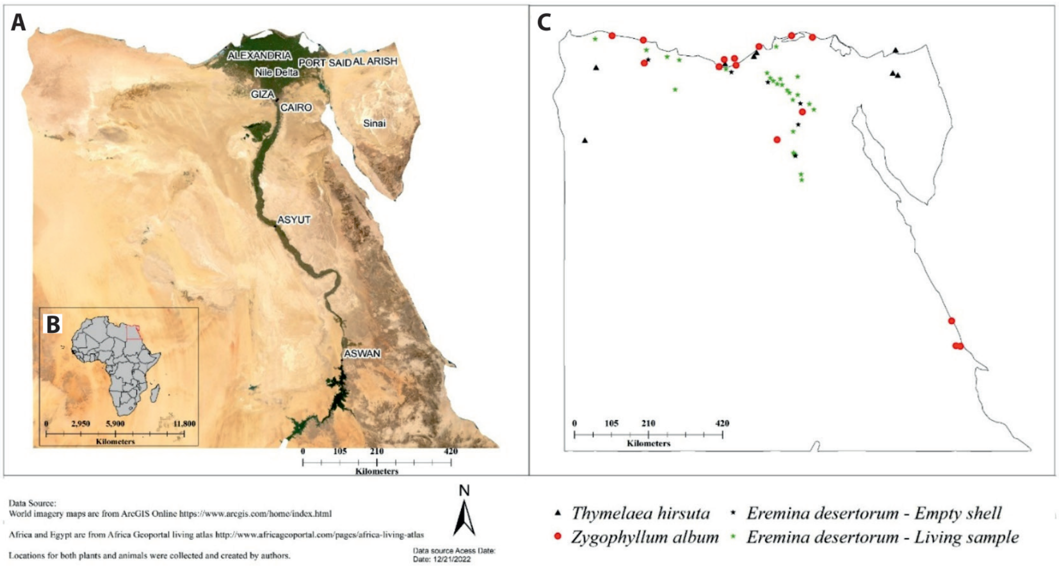

Fig. 3. A – Geographical distribution map of study sites in Egypt, displaying the locations of plant species (*Zygophyllum album* and *Thymelaea hirsuta*) in relation to *Eremina desertorum*. B – The inset map highlights the boundaries of Egypt within Africa. C – map generated using ArcMap 10.9.

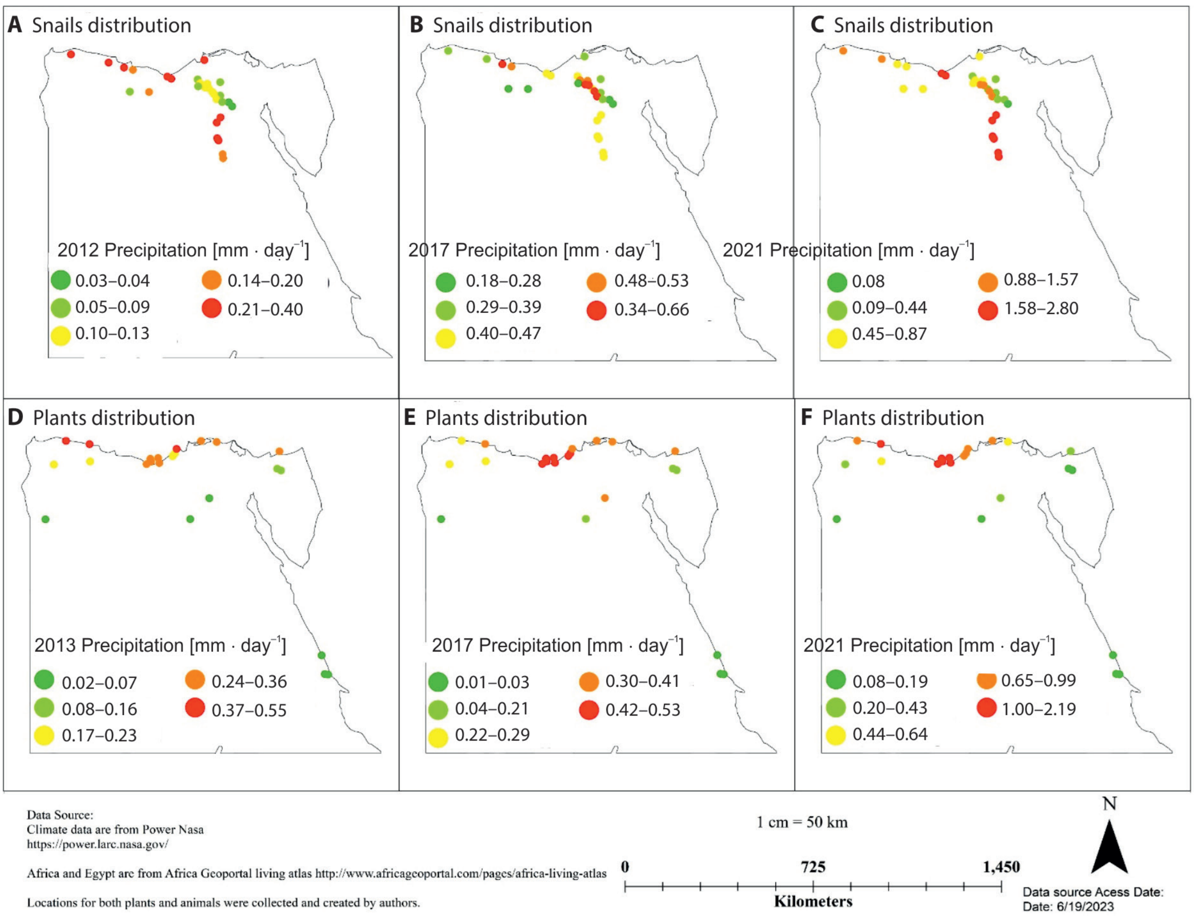

Fig. 4. Geographical map illustrating variations in precipitation (mm · day⁻¹) from 2012 to 2021, in relation to the distribution of *Eremina desertorum* snails and the plants *Zygophyllum album* and *Thymelaea hirsuta*. Map created using ArcMap 10.9

E. desertorum was more associated with *Z. album* than *T. hirsuta*, as indicated in the geographical distribution map (Fig. 4). For *E. desertorum* distribution, only six locations (out of 33) were noted as empty shells (Fig. 4C).

Climatic factors impacting plant and snail geographical distribution

The results of this research revealed that the potential distribution of snails associated with *T. hirsuta* was concentrated in the Mediterranean region in Omayed, Al-Alamein, Sallum and Lake Mariut, and the northern Sinai mountains of Halal and Maghara. *Z. album* was distributed on the Mediterranean in Burrulus, Al-Alamein, Burg El-Arab and Maqtala, the Red Sea in Wadi Gimal and Mersa Alam, the Eastern Desert in Wadi Degla and the Cairo-Suez Road, and the Nile Fayium. Annual averages for both precipitation (mm day-1) and temperature (°C) were presented along with the geographical distribution of snail and plant localities (Fig. 4 and 5, respectively) during 2013, 2017, and 2021 using the Power Nasa website (https://power.larc.nasa.gov/). Overall, for both snail and plant localities, higher precipitation was noted near the Mediterranean coast and the Nile Delta from 2012 to 2021 (Fig. 5). When the exact locations were compared, it was noted that there was higher precipitation (mm day^{-1}) during 2021 than in 2012 or 2013 (Fig. 5). For example, the highest precipitation (mm day^{-1}) was recorded during 2021 and ranged from 1.58 to 2.80 mm day-1 for snails' localities (Fig. 4 C) and 1.0–2.19 mm · day^{-1} for plant localities (Fig. 5 F) near the Mediterranean coast. Conversely, for the same snail and plant localities, 2012 had the lowest precipitation (mm · day^{-1}).

In 2017, the precipitation in the snail localities located south of the Deltaic region (Fig. 4B) was observed to be significantly lower than the precipitation levels recorded in 2012 (Fig. 4A) or 2021 (Fig. 4C). For temperature (°C) changes in terms of snail and plant geographical distribution, analyses of the

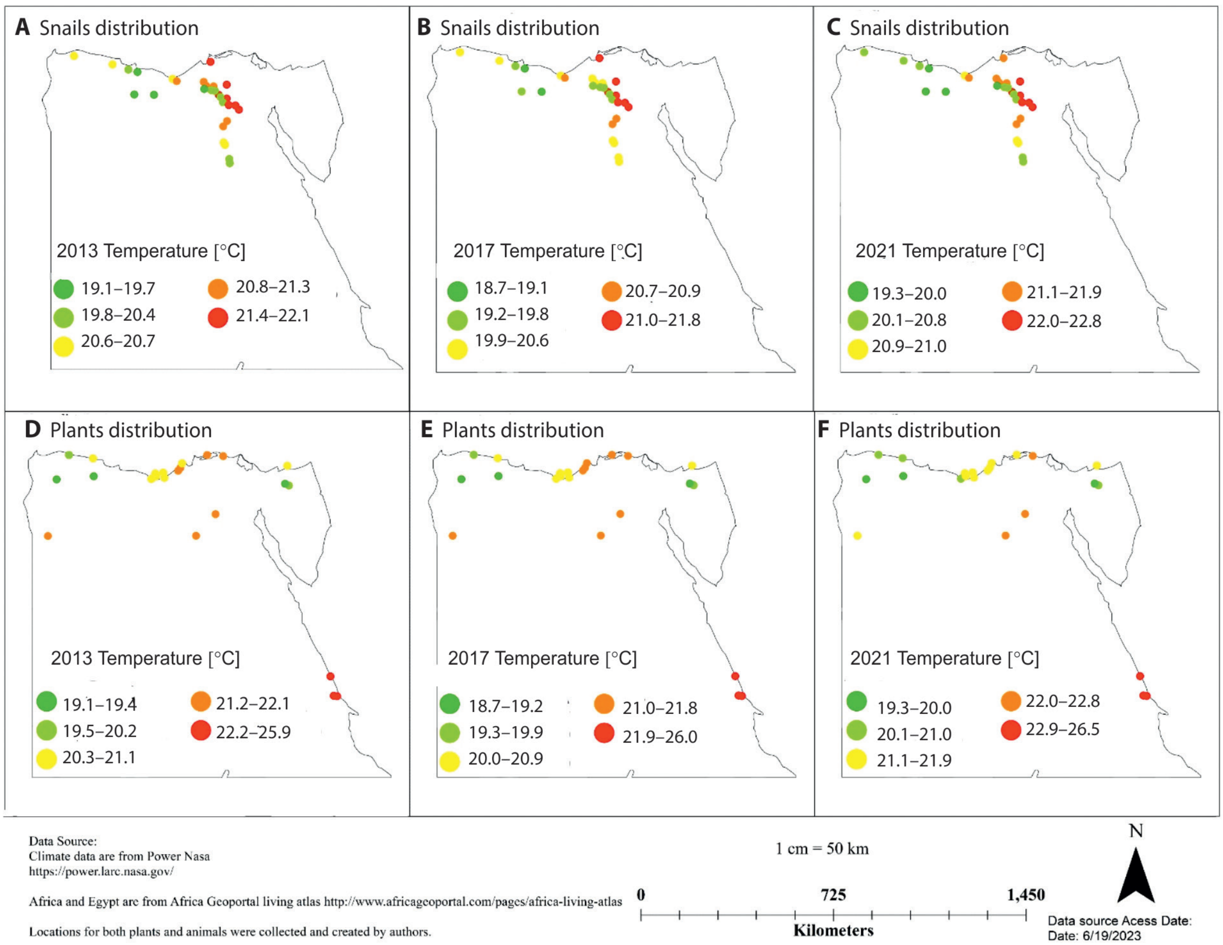

Fig. 5. Geographical map displaying the variations in air temperature (°C) from 2012 to 2021, in relation to the distribution of *Eremina desertorum* snails and the plants *Zygophyllum album* and *Thymelaea hirsuta*. Map generated using ArcMap 10.9

presented results indicated that coastal areas noted higher changes in temperature (°C) than inland areas (Deltaic and deserts areas, Fig. 5). In the context of snail geographical distribution and its correlation with temperature records spanning from 2012 to 2021, it was observed that there was a general increase in air temperature. Specifically, the lowest recorded temperature in 2012 was 21.0°C (Fig. 5A and Fig. 5B), while the highest temperature was recorded in 2021 at 22.8°C, (Fig. 5C) when comparing precise locations within Deltaic regions. The temperature ranges observed in plant locations, particularly in the southern region of the Red Sea (as depicted in Fig. 5D, 5E, and 5F), were notably higher. These locations include Wadi Gimal, located 50 km south of Marsa Alam, and two locations near Marsa Alam, one located 12 km to the north. It is worth noting that Z. album was documented in these specific areas. Statistical analyses revealed a significant negative correlation (r = –0.4, $p < 0.05$) between precipitation ($mm \cdot day^{-1}$) and air temperature (°C). The above finding was additionally validated through a comparative analysis of precipitation (Fig. 4) and temperature (Fig. 5) within the same geographical locations. For example, the three locations of Wadi Gimal, 50 km south of Marsa Alam and 12 km north of Marsa Alam, where *Z. album* was recorded, exhibited the lowest precipitation during 2013 (Fig. 5D), 2017 (Fig. 5E), and 2021, (Fig. 5F) (0.02–0.07, 0.01–0.03, and 0.08–0.19 $mm \cdot day^{-1}$, respectively). In contrast, the same locations exhibited the highest temperature in 2013 (Fig. 5D), 2017 (Fig. 5E), and 2021 (Fig. 5F) (22.2–25.9, 21.9–26, and 22.9–26.5, respectively).

Discussion

GIS monitoring joining plants and *Eremina desertorum* occurrences

The presented findings showed that the predominant occurrences of *Eremina desertorum* were primarily observed in the vicinity of the Nile and Upper Nile Deltaic areas. Furthermore, a notable association was observed between the geographic distribution of *E. desertorum* and the presence of *Z. album* and *T. hirsuta*. This finding confirmed the influential role of these plant species in influencing the distribution patterns of *E. desertorum*, as illustrated in the geographical distribution map (Fig. 3). A significant number of land-dwelling gastropods have been observed in high quantities on various host plants, particularly in the northern region of the Delta governorates (Mahrous *et al.* 2002; EI-Deeb *et al.* 2004; Heikal 2015; Mohammed 2015; Awad and Abd El-Galil 2020) and along the North Coast belt of the Mediterranean Sea (Abdel kader et al. 2016; Ali and Ramdane 2020). Succineidae gastropods prefer wet and humid environments such as margins of lakes and rivers, and are usually found on muddy surfaces (Kerney *et al.* 1983). These gastropods are frequently observed on plants close to the banks of small rivers, as well as in the shaded areas of plant pots in nurseries and gardens, where humidity levels are higher (Ali and Ramdane 2020; Hussein *et al.* 2011).

The composition of vegetation cover plays a significant role in shaping habitat characteristics, thereby influencing population density and species abundance. It is common for live snails to inhabit various habitats such as soil surfaces, open areas, loose rocks, or vegetation. These snails often exhibit a strong attachment to these surfaces, which may be facilitated by their wide peristome (Holyoak *et al.* 2018). Ali (2017a) mentioned that the snail *E. d. desertorum* was most frequently found on certain wild desert plants: *Haloxylon salicornicum* (Amaranthaceae), *Astragalus spinosus* (Fabaceae), *T. hirsuta* (Thymelaeaceae), *Artemisia monosperma*, and *Faunaea* sp. (Asteraceae).

The findings of this study indicated that *E. desertorum* exhibited a diverse diet, encompassing multiple plant species. However, it demonstrated a notable inclination towards the consumption of the plant *Z. album,* specifically within the geographical region of Egypt. Indeed, *E. desertorum* may prefer *Z. album* over other plant species for many reasons. First, *Z. album* is a prevalent frutescent plant found in arid regions of North Africa, coinciding with the distribution of *E. desertorum* (Shaltout and Bedair 2022). Moreover, *Z. album* exhibits a wide distribution in the Northern Deltaic Mediterranean region, including locations such as Burullus Lake, National Road at Baltim, Rashid-Burullus Road, and Qalabshu in the Dakahlia governorate. Notably, approximately 90% of the localities of *E. desertorum* were found in these specific areas (Bedair *et al.* 2020). Compared to other parts of Egypt, these regions are characterized by increasing precipitation and decreasing temperature, where *E. desertorum* is preferred the most (Ali *et al.* 2016). Second, *Z. album* possesses a variety of modifications that allow it to survive in arid conditions. For instance, it has small, succulent leaves that enable it to preserve water and a deep root structure that enables it to obtain water from a significantly deep subsurface (Shaltout and Bedair 2023). These physiological features may make *Z. album* a particularly rich source of nutrients and water, which could explain the snail's preference for this plant species over others.

Furthermore, a recent study by El-Amier and Abdullah (2015) found that *Z. album* has high potential as a fodder plant for snails due to its rich nutritive value, especially its fiber, protein, and fat content, reducing sugars, carbohydrates, and energy. Similarly, lipids are an essential component of cellular membranes and are necessary for several bodily functions (Norton 1994). It has a protein content of 19.63% and a fat content of 1.93%. In addition, it contains high amounts of nitrogen and phosphorus, followed by potassium, calcium, magnesium, and sodium. Furthermore, the examined plant microelement levels are iron (Fe) > manganese (Mn) > Zinc (Zn) > copper (Cu) > nickel (Ni) > lead (Pb) > cobalt (Co) > cadmium (Cd). Total digestible nutrition (TDN) is an estimated assessment of the food energy available to snails after digestion losses have been deduced. Weiss and Tebbe (2019) reported that the annual average TDN value was 75% DM. Indeed, the annual average TDN of *Z. album* is about 52.45% (El-Amier and Abdullah 2015).

Although there is limited research suggesting that *E. desertorum* prefers *T. hirsuta* as a food source, it is a significant shrub in the natural ecosystems of the Western Desert of Egypt, which supports a diverse arthropod fauna, including some species of snails year-round (Hegazy *et al.* 2022). A study by Shaltout (1992) indicated that *T. hirsuta* had relatively low nutrient contents of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), Fe, Mn, Cu, and Zn compared to many of the Egyptian desert plants. However, its low-growing habit may make it more accessible to ground-dwelling insects. Overall, both *Z. album* and *T. hirsuta* are desert shrubs. Their small leaves and succulent nature may provide the moist environment and water content required for *E. desertorum* growth and reproduction. In addition, their halophytic nature may possess a potential role in the diet of *E. desertorum*. Although most snails do not commonly feed on halophytes (Hasnain *et al*. 2023), *E. desertorum* may have evolved specific adaptations to cope with the high salt concentrations of these plants.

Monitoring of climate features affecting *Eremina desertorum* occurrences:

This study revealed distinct patterns of temperature changes in relation to the geographical distribution of snails and plants. This finding was confirmed by the increase in precipitation along the Mediterranean coast and Nile Delta from 2012 to 2021. Coastal areas experienced more significant temperature fluctuations than inland areas, with a noticeable negative correlation between precipitation and air temperature. The variability of gastropods can be explained by abiotic factors such as rainfall, relative humidity, and temperature (Vincent *et al.* 1982; Naggs and Raheem 2005). The presented findings were consistent with those of Kayeye *et al.* (2015), who illustrated that the densities of the recorded land snails varied seasonally. They found that the highest density occurred during the rainy season, while the lowest density was observed during the dry season. Ecological factors that may influence the distribution or variation of the recorded land snails were also determined, such as temperature, relative humidity, and rainfall. Consistent with the presented findings, Książkiewicz-Parulska and Ablett (2016) found that the interaction between habitat characteristics and weather significantly impacts snail populations and that both of these factors should be considered when interpreting monitoring results.

Several researchers have provided explanations regarding the impact of rainfall on the quality of habitats, making it suitable or unsuitable for the molluscan population and abundance (Okafor 1990; Omudu and Iyough 2005). Moreover, Myzyk (2011) reported that higher precipitation levels increased the litter moisture, resulting in a probable increase in the number of eggs laid by Vertigo angustior. According to the findings of Idowu *et al*. (2007), the fluctuations in seasonal patterns can be explained by the cyclical variations in the availability and abundance of food sources, competition among organisms, and the resumption of regular metabolic processes in individuals who have previously encountered adverse conditions. Interactions and climatic shifts within the natural environment also influence these dynamics. Ali *et al*. (2016) demonstrated that the average shell diameter of *E. desertorum* tends to increase with increasing precipitation and decreasing temperature toward the coast. Land snails are widely believed to engage in activity primarily during nocturnal hours and following rainfall events. These activities are typically observed within a temperature range of 10 to 27°C, accompanied by a relative humidity level exceeding 70%. It is further hypothesized that the growth of snails, particularly the secretion of their shells, occurs during periods with relatively moist conditions, which coincide with the snails' increased activity (Balakrishnan and Yapp 2004). The decrease in body size with decreasing precipitation and increasing temperature can be attributed to the limited feeding time in more arid regions. In contrast, snails may grow more prominent in regions where sufficient humidity allows for a more extended period of ingestion (Goodfriend 1986). During the rainy season, an increase in shell size (height) and sexual activity was observed, although snails were found in total sexual activity throughout the entire study period (Silva and Omena 2014). Precipitation controls the beginning and end of dormancy in *Helix aspersa* Muller, 1774, where periods of rainless days induce dormancy, and the return of rain indicates the end of dormancy (Iglesias *et al.* 1996).

According to Mashaly (2002), there are four primary factors: soil texture (fine fractions), moisture availability (moisture content), calcareous sedimentation (calcium carbonate), and soil fertility (organic carbon), that control how *Zygophyllum* species spread over Egypt's Deltaic Mediterranean coastal area. Indeed, *Z. album* and *T. hirsuta* exhibit optimal growth in regions characterized by moderate temperatures and relatively high precipitation levels. Nevertheless, it has been observed that these organisms exhibit a certain degree of tolerance towards arid conditions prevalent in the desert regions of Egypt (Shaltout and Bedair 2023).

Conclusions

The results of this study revealed that the distribution of *Eremina desertorum* was primarily concentrated in the Nile and Upper Nile Deltaic regions, areas that are closely associated with the distribution of *Thymelaea hirsuta* and *Zygophyllum album*. Additionally, *Z. album* was found in three specific locations along the southern Red Sea coastline and near the Mediterranean Sea shoreline, while *T. hirsuta* was identified predominantly in northern Egypt, near the Mediterranean coast. The study further established a positive correlation between increased precipitation and the prevalence of both plant species and desert snails in these regions. This supports prior research suggesting that *E. desertorum* is associated with plant species that have a high-water content. The findings also indicated that the desert snail thrives on such plants, which may help it survive in arid environments. Therefore, when the right environmental conditions, including favorable climate and plant species, are present, the growth and reproduction of *E. desertorum* are likely to occur.

Future perspective

While spatial patterns were interpreted using previously recorded coordinates, future studies focusing on population dynamics and broader plant associations could further enhance the understanding of its habitat preferences under changing climate conditions. Moreover, future research should focus on conducting physiological and biochemical analyses of *Thymelaea hirsuta* and *Zygophyllum album* to better understand the factors that attract *Eremina desertorum* to these plants over others. Given that these plants are known to have high water content, and *E. desertorum* tends to thrive in moist environments, it is likely that this factor plays a significant role in the snail's behavior. However, it is essential to explore further the specific substances released by these plants that may influence snail habitat preference. Additionally, the impact of climate change on the physiological characteristics and adaptive responses of *E. desertorum* should be examined, as these factors could potentially alter the snail's distribution patterns. Further investigation is also necessary to provide a more detailed explanation of the association between the desert snail and these particular plant species.

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