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Maternal habitat affects germination requirements of *Anabasis setifera*, a succulent shrub of the Arabian deserts

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ABSTRACT

The effects of maternal habitat on light and temperature requirements during germination were assessed for the succulent desert shrub *Anabasis setifera*. Seeds were collected from the Mediterranean habitats of Egypt and the hyper-arid subtropical habitats of the United Arab Emirates (UAE). Seeds from the two populations were germinated in three temperature treatments in both a light/dark regime and continuous darkness. Seeds from the Egyptian population germinated significantly greater and faster than those of UAE. Seeds stored for four months at room temperatures have little dormancy and germinate at wide range of temperatures and light conditions, but seeds stored four months in the natural habitat lost their ability to germinate and rotted 10 days after incubation. The germination response to temperature depended on the habitat type. Seeds of the Egyptian population attained a significantly greater germination at lower temperatures, compared with seeds from the UAE population, but there was no difference in germination between the two populations at higher temperatures. Germination of *A. setifera* was very fast; most seeds germinated within four days. These results reflect the adaptive strategy of germination in both populations, and may help explain the wide distribution of this species in different climatic regions.

Keywords: *Anabasis setifera*, desert, halophyte, maternal habitat, seed germination

Introduction

Desert plants face severe environmental stresses, such as extremely high temperatures, very low erratic rainfall and high salinity (Kigel 1995). In order to enhance survival and fitness in such stressful environments, desert plants developed complementary sets of adaptation and survival strategies during different stages of their life cycles (Gutterman 2002; El-Keblawy 2004). For example, factors such as seed morphology, mass, wing size and persistence can all greatly affect the seed dispersal, dormancy and germination behavior of many desert plants (Xing *et al.* 2013; El-Keblawy *et al.* 2013; El-Keblawy & Bhatt 2015). The perianth structures such as wings, in fruits of many species of Chenopodiaceae have been considered as an important trait that determine the proper place of seed storage and time of germination and thus affects soil seed bank dynamics (Wei *et al.* 2008; Xing *et al.* 2013). The persistence of perianth after dispersal has been described as a strategy used to regulate seed germination level and timing in several desert species (Takeno & Yamaguchi 1991; Wei *et al.* 2008; Xing *et al.* 2013).

The conditions under which seeds develop and mature on a maternal plant can determine the level and rate of seed germination and dormancy, which should affect time of germination and fate of next generation (Roach

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& Wulff 1987; Baskin & Baskin 1998; Meyer & Allen 1999; El-Keblawy & Al-Rawai 2006). Seed dormancy and germination requirements differ depending on maternal habitat, time of seed development and maturation on mother plants. For example, seed germination varies between populations of different species (El-Keblawy *et al.* 1996; Meyer & Allen 1999; Gutterman 2000; El-Keblawy & Al-Ansari 2000). In addition, environmental conditions experienced by maternal plants during the growing season have shown to play a significant role in determining subsequent germination responses in seeds of many species (Meyer & Monsen 1991; El-Keblawy & Al-Ansari 2000; Galloway 2002; Gutterman 2000). It is well established that temperature, rainfall, and day length are among the most important factors affecting maternal plants during the growing season (Roach & Wulff 1987; Baskin & Baskin 1998).

Fruits of some desert plants such as *Haloxylon salicornicum*, *H. ammodendron* and *Salsola imbricata* have persistent wings that help in seed dispersal and storage on soil surface (Huang *et al.* 2003; El-Keblawy 2013). Seeds of these plants germinate immediately after dispersal and consequently form a transient seed bank (Zaman & Khan 1992; El-Keblawy 2013). Conversely, other desert halophytes such as *Sporobolus ioclados, Diplachne fusca*, *Limonium axillare*, *Halocnemum strobilaceum* and *Halopeplis perfoliata* produce small un-winged, non-dispersed seeds that are usually buried in the soil (Morgan & Myers 1989; El-Keblawy 2013). Seeds of these species usually develop dormancy and form persistent seed bank (Morgan & Myers 1989; Gulzar & Khan 2002; Khan & Gul 2006; Zia & Khan 2008). *Anabasis setifera* Moq., another succulent desert facultative halophyte, however, produces fruits with wings that help them in dispersal but disintegrate shortly after landing on soil surface, leaving small rounded dark seeds. We noticed that seeds of *A. setifera* from a four-month soil bank were naked (i.e., perianths disintegrate) and stored in the top 10 cm of the soil (A El-Keblawy, unpubl. res.). It is not clear whether as a survival strategy *A. setifera* seeds would form a transient seed bank like halophytes with persistent wings or form a persistent seed bank like those that produce naked seeds.

Germination requirements are usually affected by environmental conditions that seeds face during development and storage (Roach & Wulff 1987; Ooi *et al.* 2009; Fan *et al.* 2012; El-Keblawy & Bhatt 2015). Seeds stored on soil surface face diurnal fluctuations in temperatures and are exposed to more light during storage, compared to small buried seeds that are stored at relatively more stable temperatures and in darkness (Moreno-Casasola *et al.* 1994; Nishimoto & McCarty 1997; Zalamea *et al.* 2015). Little difference was observed between light and dark germination in winged seeds of some halophytes, such as *Salsola imbricata* (El-Keblawy *et al.* 2007) and *Haloxylon salicornicum* (El-Keblawy & Al-Shamsi 2008). However, germination was very sensitive to light in species with small un-winged seeds of other halophytes, such as *Halocnemum strobilaceum* (Song *et al.* 2006; Qu *et al.* 2008), *Amaranthus palmeri* (Jha *et al.* 2010), *Halopeplis perfoliata* (El-Keblawy *et al.* 2015a). We hypothesized that seeds of *A. setifera* have high germination level like halophytes with winged fruits, but germination is sensitive to light, like halophytes with un-winged seeds, which bury in soil. The aim of the present study was to assess the light and temperature requirements for fresh and field-stored seeds of *A. setifera* from the Egyptian Mediterranean population and hyper-arid subtropical UAE populations. We expect different germination behavior for *A. setifera* seeds matured under different environmental conditions of the Mediterranean and hyper-arid conditions. Studying the germination requirements for seeds from populations that differ greatly in environmental conditions would help in understanding the adaptations of this species to survive under wide range of environmental conditions.

Materials and Methods

Anabasis setifera Moq. (Amaranthaceae) is a perennial dwarf succulent shrub, widely distributed in Egypt, Arabia, Iran, Afghanistan, Pakistan and India (Ali 1978). It produces winged fruits (hereafter referred as seeds) that are dispersed by wind (Lev-Yadun *et al.* 2009). The wings - about 3 - 4 mm in diameters-are not persistent and disintegrates shortly after dispersal. Every fruit carry a tiny seed; average mass of 1000 seeds is 0.43 and 0.28 g for the Egyptian and UAE populations, respectively (El-Keblawy *et al.* 2015b). Seeds of *A. setifera* usually mature in November and December and disperse predominantly between December and early January. The time of seed dispersal coincides with the time of onset of rainfall and consequently seeds germinate immediately after dispersal.

Seeds of *A. setifera* were collected from Seih Shuaib, Abu Dhabi, UAE (24°53’43.16”N, 54°55’49.45”E) and the eastern region of Cairo at Cairo - Suez road (30°6’20.45”N, 31°35’21.48”E), Egypt. The climate of the UAE is arid subtropical with high temperatures, but that of Egypt is semi-arid Mediterranean with moderate temperatures. The nearest meteorological station to the study Egyptian population (Cairo Airport) indicates that the average annual rainfall is around 100 mm. Most of rain falls during the period between November and April with December. The average low and high minimum temperature (8 and 19°C, respectively) is in January and the average low and high maximum temperature (23 and 36°C, respectively) is present in both July and August (www.worldweatheronline.com). In the UAE, the nearest station to the study population (Dubai Airport) indicates that the average total annual rainfall is 84.3 mm; 85% of it precipitated between December and March. Average minimum temperature is 14.3 °C in January and the average maximum temperature is 41.3 °C in August (https://services.dubaiairports.ae/dubaimet/MET/Climate.aspx). The average electrical conductivity of the Egyptian and UAE population was 0.52 and 17.5 ms/cm, respectively. In addition, the pH was 8.0 and 7.3 in the Egyptian and UAE populations, respectively (A El-Keblawy unpubl. res.).

Matured seeds on shrub canopies were collected during the last week of December 2013 from both populations and again from under the shrubs' canopy after four months following dispersal (April 2014). Immediately after collection, fresh seeds were stored in brown paper bags at room temperature (20 ± 2°C) until the experiment started in the third week of April 2014. Seeds were collected from 50-60 randomly chosen plants and mixed together in order to represent the genetic diversity of the populations.

Seeds of *A. setifera* collected from the two populations during both December 2013 and April 2014 were germinated at daily night/day temperature regimes of 15/25°C, 20/30°C and 25/35°C in both continuous darkness and alternating 12h light/12h darkness. The light period coincided with the higher temperature. In dark treatment, the petri-dishes were wrapped in aluminium foil to prevent any exposure to light. The germination was conducted in 9-cm tight-fitting petri-dishes containing one disk of Whatman No. 1 filter paper moistened with 10ml of distilled water. Three replicates, each with 35 seeds, were used for each treatment. Seeds were considered to be germinated with the emergence of the radicle. Germinated seeds were counted and removed every alternate day, for 14 days. However, seeds incubated in the dark were checked only after 14 days. Most of the germination occurred within 10 days following sowing and consequently we decided to stop seedlings counting after 14 days. All the un-germinated seeds were rotted after 10 days of incubation, indicating that they are not viable. A tetrazolium test had confirmed this.

Data analysis

Rate of germination was calculated with a modified Timson's germination velocity index: $\Sigma G/T$, where G is the percentage of seed germinated on every day, and T is the total germination period (Khan & Ungar 1998). The maximum possible value for our data using this germination rate index (GRI) was 50. The higher the value the more rapid the germination. The germination rate was only calculated for seeds incubated under light conditions.

As no germination occurred for seeds collected during April 2014 from the natural habitats of both the Egyptian and UAE populations, the results of these collections were excluded from data analysis. Three-way ANOVA was used to assess the significance of the main factors (maternal habitat, and temperature and light of incubation) and their interactions on final germination. Two-way ANOVA was used to assess the impact of maternal habitat and temperature of incubation and their interactions on the germination rate index (GRI). Tukey test (Honestly significant differences, HSD) was used to estimate least significant range between means. The germination rate was log-transformed and germination percentages were arcsine-transformed to meet the assumptions of ANOVA. This transformation improved normality of the distribution of the data. All statistical methods were performed using SYSTAT, version 13.0.

Results

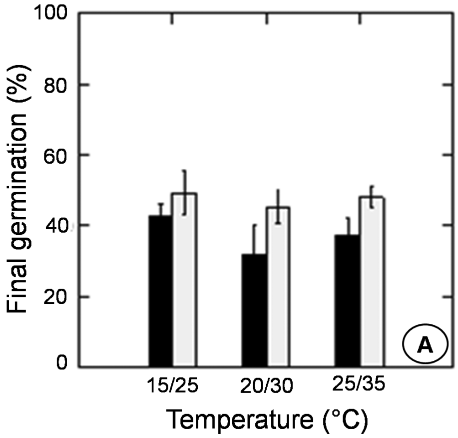
There was no germination for seeds collected after four months following dispersal (i.e., April 2014) from the natural habitats of both the Egyptian and UAE populations (data not shown). The effects of maternal habitat, temperature and light of incubation on final germination percentage of *A. setifera* were significant ($P<0.01$). However, there was no significant effects for the interactions between light and both maternal habitat and temperature and their interaction ($P>0.05$, Tab. 1). Generally, seeds from the Egyptian population attained significantly higher germination (66.4 ± 3.7%), compared to seeds from the UAE population (42.4 ± 2.0%). In addition, germination at lower temperatures (15/25 and 20/30 °C) was significantly greater than at higher temperature (25/35 °C). Furthermore, germination was significantly greater in light/dark regime (58.9 ± 3.9%) than in darkness (50.0 ± 4.2%).

Table 1. Three way ANOVA showing the effects of maternal habitat, and temperature and light of incubation on final germination percentage of *A. setifera* seeds.

Source of variation	df	Mean Squares	F-Ratio	p-Value
Habitat (H)	1	0.860	98.130	<0.001
Temperature (T)	2	0.140	15.973	<0.001
Light (L)	1	0.109	12.446	<0.01
H*T	2	0.203	23.138	<0.001
H*L	1	0.000	0.008	ns
T*L	2	0.001	0.110	ns
H*T*L	2	0.005	0.579	ns
Error	24	0.009		

The germination response to temperature of incubation depended on the habitat type; the interaction between maternal habitat and temperature was significant ($P<0.001$, Tab. 1). No significant difference was observed in germination between seeds of the UAE (42.7 ± 2.0%) and Egypt (49.3 ± 2.2%) at the higher temperatures (25/35 °C). However, germination at lower (15/25 °C) and moderate (20/30 °C) temperatures was significantly greater for seeds of the Egyptian population (67.3 ± 3.2% and 82.7 ± 3.7%), compared with seeds from UAE (46.0±2.9% and 38.7 ± 4.3%, respectively) (Fig. 1).

Germination of *A. setifera* was very fast; most seeds of the Egyptian and UAE populations were germinated within two and four days, respectively. There was a significant effect for the maternal habitat ($F_{1,12} = 11.35$, $P<0.001$), but not for temperature of incubation ($F_{2,12} = 1.20$, $P>0.05$) or the interaction between temperature and maternal habitat ($F_{2,12} = 0.18$, $P>0.05$) on the germination rate index. Germination was significantly faster for the Egyptian seeds (GRI = 48.6 ± 0.4), compared with that of UAE seeds (GRI = 43.3 ± 1.4) (Fig. 2).



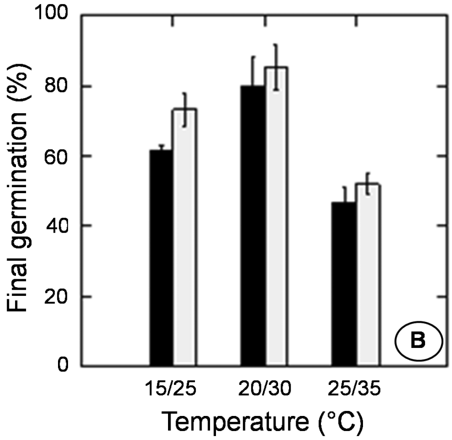


Figure 1. Effects of maternal habitat, and temperature and light of incubation on final germination percentage (mean ± SE) of *A. setifera* seeds from (A) United Arab Emirates and (B) Egyptian populations. Black bar = dark germination, light bars = light germination

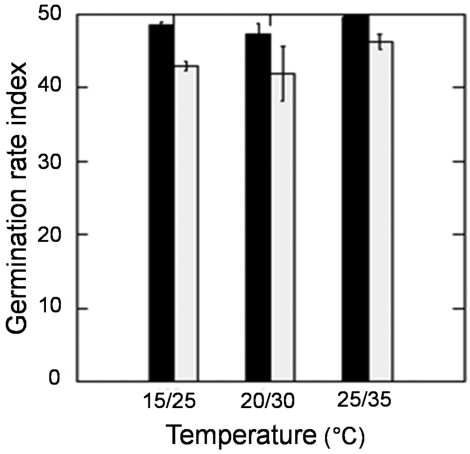


Figure 2. Effects of maternal habitat and temperature of incubation on germination rate (expressed as mean ± SE of germination rate index) of *A. setifera* seeds. Black bars = Egypt seeds, and light bars = United Arab Emirates seeds

Discussion

Plant species that grow in different geographical regions might experience different local environmental conditions due to climatic, soil and other habitat differences (Tieu *et al.* 2001). The studied species *A. setifera* experiences different environmental conditions in the habitats of Egypt and UAE. The climate is mild Mediterranean in Egypt, but dry hyper-arid in the UAE. Such a large difference in maternal habitats has affected germination level and speed. However, there were no significant effects for the interaction between maternal habitat and light and the interaction between maternal habitat, light and temperature of incubation. The lack of significant interactions indicates the ability of the seeds of *A. setifera* to germinate in wide range of environmental conditions. This would explain the wide range of distribution of this species in different climatic regions.

Seeds of the Egyptian population germinated significantly greater at lower temperatures compared with seeds from the UAE population. Such results could be an ecological adaption for the survival of *A. setifera* in the habitats of the two populations. Egyptian site has much lower temperatures during the time of seedling emergence, compared with that of the UAE. Seeds of both populations mature and germinate immediately after dispersal in December and January. In the Egyptian site, the minimum and maximum temperatures are 11 and 21°C during December and 8 and 19 °C during January. However, the minimum and maximum temperatures in the UAE site are 16 and 24.1 °C in December and 14.2 and 22 °C during January (Feulner 2006). This suggests that the requirement for lower temperatures in the Egyptian seeds would enhance their ability to germinate during December and January. However, there was no significant difference in the germination between the two populations at higher temperatures (25/35 °C). Such higher temperatures usually prevail during March and April in the UAE and during April and May in Egypt. During these months, no germination will take place in both populations, if rainfall happens. As evident from our results, seeds collected from the field at April did not germinate.

The present study indicated that seeds collected after four months of dispersal from natural habitats were not able to germinate and consequently did not form persistent seed bank. This phenomenon has been reported in many other succulent desert shrubs with seeds able to germinate immediately and disperse over long distances with the aid of winged perianths (e.g., *Salsola imbricata* and *Haloxylon salicornicum* - El-Keblawy 2013; *Haloxylon stocksii* - Gulzar & Khan 2001; *Haloxylon ammodendron* - Huang *et al.* 2003). El-Keblawy (2013) reported three reasons that would explain the transient nature of seed bank of above-mentioned desert shrubs. Firstly, maintenance of seed dormancy when conditions are optimal for germination can be a disadvantage in some species as seeds are exposed to lethal environmental factors such as granivory and extreme temperatures for longer periods. This is particularly true for seeds with winged perianth that keep them exposed to extreme diurnal temperatures and moisture fluctuations on soil surface. Secondly, species with non-dormant seeds might be expected to benefit from earlier germination more than those with dormant seeds. In general, Verdú & Traveset (2005) have also reported that the early emergence increase seedling survival, growth, and fecundity. Finally, seed storage might reduce germination speed, which usually reduce the competitive ability of the seedlings, as they emerge later in the season, compared to other species (Rees 1996; Zia & Khan 2004). The high annual fruit production in *A. setifera* should compensate the high seed mortality rate. This species produce enormous amount of highly dispersed fruits every year (roughly several hundreds of thousands), even in the dry seasons (El-Keblawy 2013). *A. setifera* plants rely mainly on atmospheric moisture and fog as main sources of water for their growth.

The results indicated that the germination of *A. setifera* was very fast; most seeds of the Egyptian and UAE populations were germinated within two and four days, respectively. Parsons (2012) reported 20 species of the family Amaranthaceae that have very fast germination rate. He indicated that the embryo cells of the seeds of these species elongate and the spiral embryo uncoils and ruptures within 10 minutes after imbibition. Fast germination has been considered as a strategy to utilize the brief period of water availability and ensure rapid seedling growth, early in the growing season, which can minimize competition (El-Keblawy & El-Shamsi 2008; El-Keblawy *et al.* 2007). Seedling coming earlier in the season can rapidly exploit temporarily favourable conditions for germination (Parsons 2012). Although rapid germination is an opportunistic strategy to cope with little precipitation and unpredictable rainfall of the deserts, it represents a high risk strategy as the established seedlings might die if no precipitation happen after seedling establishments (Gutterman 2012).

In conclusion, the study indicated that seeds of *A. setifera* can germinate in a wide range of environmental conditions that enable it to grow in different climatic conditions. Maternal habitats significantly affected temperature requirements during germination. Seeds collected from the natural habitats were not able to germinate after four months of their production. Therefore, further studies are needed to explain the transient nature of seed bank of this species.

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