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TESIS DOCTORAL

ESTRATEGIAS DE DISPERSIÓN DE PLANTAS EN DIFERENTES HÁBITATS ECOLÓGICOS DE LOS EMIRATOS ÁRABES UNIDOS

PLANT DISPERSAL STRATEGIES OF DIFFERENT ECOLOGICAL DESERT HABITATS OF UNITED ARAB EMIRATES

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Prefacio

Las investigaciones que han conducido a la redacción de la presente Tesis Doctoral se han de lasorealizado en el Departamento de Biología Vegetal de la Universidad de Málaga, en el ámbit actividades del Grupo de Investigación RNM115 “BIODIVERSIDAD, CONSERVACION Y tanRECURSOS VEGETALES” - del Plan Andaluz de Investigación, Desarrollo e Innovación de la Ju de Andalucía-, asi como en la Sharjah Research Academy (SRA) y el Sharjah Seed Bank and (Herbarium (SSBH) de Sharjah (Emiratos Arabes Unidos).

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Memoria presentada para optar
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ACREDITA

que D. Hatem Shabana, Licenciado en Biología, ha realizado, en el Departamento de Biología Vegetal de la Facultad de Ciencias de la Universidad de Málaga y en la Sharjah Research Academy (SRA) y Sharjah Seed Bank and Herbarium (SSBH), Sharjah (Emiratos Árabes Unidos), las investigaciones que le han conducido a la redacción de la presente Memoria de Tesis Doctoral, titulada **Plant Dispersal Strategies of Different Ecological Desert Habitats of UAE.**

La presente memoria, que recoge los resultados obtenidos, así como su interpretación, reúne los requisitos necesarios para ser sometida al juicio de la Comisión correspondiente. Por tanto, como directora de la tesis, autorizo su exposición y defensa para optar al Grado de Doctor en Biología.

Y para que conste en cumplimiento de las disposiciones vigentes, firmo la presente acreditación en

Málaga, a 10 de julio de 2017

Prof. Dra. Teresa Navarro
Directora de la Tesis

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I. ABSTRACT

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I. ABSTRACT

The Arabian Peninsula comprises the seven countries of the Arabian Gulf (Persian Gulf): Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates (UAE) and Yemen. The United Arab Emirates lies in the north-eastern part of the Arabian Peninsula between latitudes 22° 40' and 26° 00' north and longitudes 51° 00' and 56° 00' east. UAE is covering a total surface of 83.600 Km^2 and consists of seven Emirates: Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Fujairah, Ajman and Umm Al Quwain. Most of the UAE land is desert with predominance of Aeolian landform system. UAE geomorphologic features include mountains, gravel plains, sand sheets and saline flats. The sandy desert covers over 90.0% of the country's surface area. The major part of the sandy desert is characterized by the presence of sand dunes that rise gradually from the coastal plain reaching elevations up to 250 m above sea level (asl). The UAE mountainous regions of the UAE consist of north-south mountain ranges parallel to the east coast. The rainfall of Arabian Peninsula is erratic and unpredictable in time and quantity. In some years, certain areas may not receive rainfall. The UAE is a hyper-arid hot desert (subtropical hot desert) ecosystem which have two main seasons: a long hot summer (April to October) and a short mild winter (November to March). The rain falls mainly in winter season with maximum intensity during February and March. The mean annual rainfall is about 110 mm with extreme variability in space and time. Abu Dhabi (southern Emirates with sandy habitat) received the lowest annual precipitation (about 45 mm/year). The highest annual precipitation found in the north-east mountainous region of the country ranges between 125.6 and 172 mm/year. The annual average temperature is approximately 27 °C and humidity 45.0%. For the winter, the mean temperature is around 20 °C, while mean temperature of summer ranges between 35 - 40 °C. In addition, humidity could reach more than 90.0%.

The UAE flora comprises about 830 species which have specific physiological and morphological adaptations to survive in the harsh environmental conditions. Interestingly, the mountains area which occupies only 10.0% of UAE total area and receives the highest rainfall has more than 50.0% of the total identified plant species. The UAE have four vegetation ecosystems; costal lowlands region which is characterized by mangrove vegetation composed of *Avicennia marina* and halophytic plant communities. Desert regions occupy the most of the land surface of the country. These regions include two areas: a- western dunes which dominated by *Cyperus conglomeratus* and *Haloxylon salicornicum*, b- central desert which dominated by *Citrullus colocynthis* and *Stipagrostis plumosa*. Mountainous region corresponds to the Hajar Mountains series that extend from the UAE to the neighbouring Oman which dominated by *Euphorbia larica*, *Pulicaria glutinosa* and *Ochradenus aucheri*. Alluvial plains region which is dominated by some species such as *Aerva javanica*, *Asphodelus tenuifolius* and *Tephrosia apollinea*.

In extreme weather of arid and desert areas such as UAE, the plant communities usually do not have a closed canopy cover. Furthermore, the suitable conditions for growth are often restricted to small micro-habitats. Each desert plant species has its own complex of survival strategies that enable it to persist to appear in a certain desert habitat in which exhibit

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a complementary set of adaptations during the different stages of its life cycle. These adaptations enable the species to survive despite the presence of selective biotic factors (e.g., seed consumption) and abiotic factors (extreme, unpredictable amounts and distribution of rain).

Plant functional diversity could be defined as the type, level and relative abundance of the functional traits which are present in a community. Plant functional traits are the features such as morphological, physiological and phenological features that represent ecological strategies to determine how plant species adapt to environmental factors. Traits such as plant size (e.g., height) and seed size (e.g., seed length / mass) are key standardized functional traits used for all ecological studies.

The vegetative traits contain plant height, life cycles and growth forms. Plant height is associated with growth form and competitive vigor. The two main types of life cycles were recognized, the annual species (species dies within one growing season), and perennial (a species that grows for more than two season). In arid and desert ecosystems annual species are common. Growth forms are mainly determined by the canopy structure and canopy height. The growth forms could be recognized to herbaceous “short basal, semi-basal, erect leafy, tussocks”, dwarf shrubs, shrubs and trees.

The regenerative (reproductive) traits include seed size and seed dispersal. Dispersal is the departure of a diaspore unit (seed or fruits) from the mother plant. Dispersal is a crucial process for plants as it connects the end of the reproductive cycle of adult plants with the offspring establishment. Dispersal might enable plant to avoid competition with the mother plant and with other seedlings and predation by animals. There are different processes can move diaspores which correspond to dispersal modes. Spatial dispersal (dispersal in the space) present two main types: a) Species have diaspores equipped with structures that facilitate diaspore movement (developed spatial dispersal), which could be divided to developed dispersal by abiotic vectors “e.g., wind” and developed dispersal by biotic vectors “e.g., vertebrate”, and b) Species have diaspores lack such dispersal-enhancing structures (restricted spatial dispersal). Restricted spatial dispersal is prevailing in deserts as the suitable areas for growth “safe sites” are usually occupied with mother plants. Between dispersal modes we can distinguish; barochory (the plant use of gravity for dispersal), wind dispersal (anemo-meteochory) is one of the more primitive means of dispersal. Wind dispersal can take on one of two primary forms: seeds can float on the breeze or alternatively, they can flutter to the ground. The classic examples of these dispersal mechanisms, in the temperate northern hemisphere, include dandelions, which have a feathery pappus. Animals can disperse plant seeds in several ways, all named zoochory. Seeds can be transported on the outside of vertebrate animals (mostly mammals), a process known as epizoochory. Seed dispersal via ingestion by vertebrate animals (mostly birds and mammals), or endozoochory, is the dispersal mechanism for most tree and large shrubs species. Semachory, when plants disperse their seed without any help from an external vector, as a result this limits considerably the distance that plants can disperse their seeds. In the ombro-hydrochory dispersal mode, the plant disperses by the effect of rain and/or dew. Ballistic is a type of dispersal where the seed is forcefully ejected by explosive dehiscence of the fruit.

Seed mass “known as seed size” is one of the most important traits influencing the plant life cycle from seed dispersal, germination, emergence, survival and establishment of

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seedlings. In general, large seeds producing bigger and stronger seedling with better competitive ability with smaller seedlings, especially under resource-limited environment such as deserts. In arid deserts, some of annual species produce tiny dust-like seeds which are dispersed by wind after their maturation. These species adopt the escape strategy by falling into cracks below the soil surface and become a part of the long-lasting soil seed banks.

The mechanism in which the diaspore units are prevented from long-distance dispersal called “antitelechory” is considered a form of restricted spatial dispersal. Antitelechoric mechanisms are adaptive responses to high mortality of diaspore units in unpredictable deserts and help diaspore to inhabit the mother sites. The antitelechoric mechanisms include synaptospermy, myxospermy and trypanospermy. Synaptospermy, in which more than one seed is dispersed as one unit and always associated with arid environments. Myxospermic mechanism in which mucilage is produced by the diaspore when diaspore is exposed to moister which mainly associated with arid environments. Trypanospermy is an anchorage mechanism by the appendages of the diaspore, which support its burial in the soil at the point of initial contact.

Bradychory is adopted in some desert plants through which mature seeds are retained in plant canopy and delays seed dispersal for varying periods of time until the suitable condition of germination and seedling establishment.

In arid and deserts ecosystems plant species develop strategies through producing offspring that differ in time and place of germination, and tolerance to environmental stresses. Seed dormancy enhances seedling survival by preventing germination under unfavorable condition. The level and type of dormancy can be determined by environmental factors prevailing during seed maturation on mother plants. It was reported that mechanisms of releasing dormancy under harsh environmental conditions is influenced by several factors such as alternating temperatures and light.

Chapter 1: Dispersal traits in the hyper-arid hot desert of the United Arab Emirates (UAE)

Plant dispersal has an essential role in the colonization of new habitats, population dynamics as well as in species interactions and community structure and floral diversity. Seed size is an important ecological trait for seedling establishment, formation of a persistent seed bank, and dispersal. For instance, generally, large seeds increase the chance of seedling survival and establishment, while small seeds contribute more to forming seed bank. The large-seeded species are more likely to be animal dispersed, while small-seeded species are more likely to have unassisted seed dispersal. The dispersal spectrum is the frequency distribution of dispersal modes in a particular vegetation type. It is reported that the long-distance seed dispersal is less frequent in arid and semi-arid habitats than in mesic habitats and traits constraining seed dispersal are common in arid and semi-arid floras. This means that the restrictions to seed dispersal have been widely used to explain the origin and maintenance of patches in arid vegetation. Seed size is correlated with flowering time and dispersal phenology. In hyper-arid hot deserts, phenological events are mainly related to the amount and time of annual rainfall and soil moisture condition. In the Arabian desert, no studies exist that assess dispersal traits and dispersal phenology. The study included in this

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chapter described the dispersal traits of species in five Afro-Arabian habitats from the hyper-arid hot desert of UAE by determining the relation between diaspore size (seed and fruit length) and growth forms, spatial dispersal, dispersal modes, APG IV phylogenetic taxonomic groups, phytogeography and dispersal phenology.

Field sampling and phenological observations were carried out monthly between May 2014 and October 2016. Five different habitats were represented in this study “salt flats, gravel plains, sand sheets, mountains and high mountains”. Thirty quadrates were selected and sampled per habitat which represents a total of 150 quadrates. The quadrate size was 200 m^2, in each quadrate the species abundance has been estimated according to the ‘Braun-Blanquet’ scale. The studied species mostly common and some are rare species that characterize the vegetation of UAE. The voucher specimens of the most studied species were kept in the Sharjah Seed Bank and Herbarium, Sharjah Research Academy, Sharjah. Seven measured dispersal traits were analysed: (1) dispersal mode which include anemo-meteochory, ombro-hydrochory, semachory, ballistic and barochory, (2) diaspore size (diaspore length), (3) dispersal unit (fruit or seed), (4) presence of structures facilitating long distance dispersal (spatial dispersal), (5) diaspore appendages, (6) diaspore color and (7) dispersal phenology. One-way analysis of variance (ANOVA) and the Pearson χ^2 test-statistic were used to analyse the relation between the diaspore size and the other traits as well as association between nominal traits, by using SPSS 14 and SYSTAT 13.

A total of 302 species belonging to 51 families and 192 genera, were studied. Fabaceae, Asteraceae and Poaceae (12.6%, 9.9% and 9.6%, respectively) were the richest in species number. From the eight phylogenetic APG IV groups; Fabids and Basal Asterids were the predominant (22.2% and 20.5%, respectively). The dwarf shrubs species (41.1%) were dominant. Fruits (69.7%) were the dominant dispersal unit. Small diaspores were predominant (six orders of magnitude from 10^{-4} to 10^{2}) and ranged from 0.02 cm (*Sporobolus spicatus*) to 19.5 cm (*Prosopis juliflora*). Species lacking structures for long-distance dispersal (restricted spatial dispersal) were more represented (58.6%). The most dominant dispersal mode was semachory (43.7%) followed by anemo-meteochory (28.8%) and barochory (23.8%). Most of the species studied (64.2%) dispersed in the dry season (from April to October). The major diaspores were found in Fabids and Malvids phylogenetic APG IV group (mean size: 1.8 cm and 0.9 cm, respectively) and the minor in Commelinids (mean size: 0.30 cm). The trees had the largest diaspore (mean size: 3.9 cm) while tussocks had the smallest (mean size: 0.3 cm). Barochoric species (mean size: 1.8 cm) were the largest while semachoric (mean size: 0.4 cm) were the smallest. Species dispersed by biotic vectors (mean size: 2.9 cm) had the biggest diaspore. Barochory was predominant in trees (71.0%). Semachory was more represented in herbaceous species, such as tussock graminoids (82.4%). Anemo-meteochoric species with small diaspores were predominantly dwarf shrubs (39.7%) such as *Haloxylon* sp. Barochory mode was over-represented in Fabids (62.9%) and anemo-meteochory was predominant in Campanulids (76.5%). Semachory was predominant in Commelinids (82.4%). Restricted dispersal was the most common in all APG IV except for Campanulids. Restricted dispersal was over-represented in herbaceous species such as Tussocks (91.4%). Dispersal by biotic vectors was prevalent in trees (64.3%), while dispersal by abiotic vectors was over-represented in shrubs (47.3%). Dispersal by biotic vectors was

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mainly associated with Sudano-Decanian species (56.8%), which are species forming part of Saharan-African vegetation in the study area.

In the hyper-arid hot desert of UAE, the average of the diaspore size in the studied species and the dispersal spectra are coincided with those reported in other arid regions of the world but with particularities due to the presence of African floristic elements. In UAE, the small diaspores were common which have the ability to fall into soil cracks and avoid detection by predators and consequently help them to form a long-lived soil seed bank in the desert, which enable species survival under the heterogeneous and unpredictable desert conditions. The main dispersal mode is semachory which help the seeds to stay in the safe sites, near the mother plants which ensures seedling establishment. Most semachoric species were herbaceous plants, which is consistent with the results found in other desert ecosystem. Savanna trees such as *Acacia*, *Prosopis* and *Ziziphus* sp. are barochoric species that produce large diaspores secondarily dispersed by vertebrates. Graminoids such as *Stipa* sp. and *Stipagrostis* sp., without structures for long-distance dispersal had diaspore appendages acted as “active drills” in soil cracks. Most species dispersed in dry season which coincided with the other arid region from the world. Dry season favours the efficient dispersion by the wind for the small shrub species with haired capsule (e.g., *Aerva javanica*), winged calyx (e.g., *Astragalus squarrosus*) or wings (e.g., *Tribulus qatarensis*). Dispersal mechanisms can be associated with climatic factors (e.g., water availability) which could affect seedling establishment in hyper-arid hot deserts. About 25.0% of species disperse in the rainy season and they are mainly Sudano-Decanian barochoric species (Afro-Arabian species). Species dispersal throughout the year indicates an important seed resource e.g., barochoric species with fleshy fruits or pods with nutrient structures (e.g., *Senna italica* and *Indigofera* sp.). In general, species that disperse their diaspore throughout the year have lower dormancy and can germinate under restricted conditions. In general, diaspore characteristics were closely related to phylogeny, dispersal modes and growth forms and these characteristics allowed the plants to adapt to extreme hot desert environments.

Chapter 2: Seed mass and germination traits relationships among different plant growth forms with aerial seed bank in the hyper-arid hot desert of the United Arab Emirates (UAE)

Seed size (seed mass), growth forms, germination requirements and dispersal syndromes are among main plant life cycle traits that would affect community structure. Seed dormancy is an adaptation adopted by many plant species, especially in unpredictable heterogeneous environments, such as arid deserts. Dormancy delay seed germination until the arrival of favourable conditions that allow seedling establishment and minimize seedling mortality. Seed size might affect light requirements during germination where large seeds of many species germinate in both light and darkness, small seeds require light for germination. In deserts, germination of many plants occurs only when the particular combinations of light, temperature and soil moisture are optimal for plant growth. There are no clear relationships between seed size and dormancy which might be attributed to different environmental and developmental constraints that affect seed development in different growth forms and habitat types. Fewer studies assessed the relationship between seed size and germination level among different growth forms. In general, seed mass and growth forms can affect dispersal mode,

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seed storage place and consequently could determine site and fate of emerged seedling. we assessed the relationship between plant growth forms, place of seed storage (storage condition), and seed mass and light and temperature requirements during germination of 23 desert plants with an aerial seed bank in the hyper-arid hot desert (subtropical hot desert) from UAE.

Seeds of 23 species with aerial seed bank were used in this study. The 23 studied species had aerial seed bank with seeds stored after maturation either on mother plants (14 species) or on soil surface (9 species). The species represented three growth forms (six herbaceous, 11 small shrubs and six trees). For each species, the average seed mass (100 seeds, three replicates) and average seed size (length of 50 seeds). Mature seeds of the 23 species were collected during May - June 2015 from four habitats in the northern Emirates of UAE. In order to assess the effect of field storage, seeds of the same species were collected in February 2016 from either mother plants or soil surface. Seeds of May - June 2015 collection were divided into two parts; one part was germinated immediately after collection (fresh seeds) and the second part was stored in brown paper bags at room temperatures (20 ± 2 °C) until their germination in February 2016 (room temperature storage). Fresh and both field and room temperature-stored seeds were germinated in three growth chambers adjusted to three temperatures of 15/25 °C, 20/30 °C and 25/35 °C and two light regimes (12h light / 12h darkness). One-way analysis of variance (ANOVA) was used to assess the effects of different factors (e.g., growth form, seed storage, and light and temperature of incubation) of final germination, RLG (relative light germination) and GRI (germination rate index). Pearson correlation coefficients were used to assess the significance of the relationship between seed mass, and final germination, RLG and GRI. All statistical methods were performed using SYSTAT 13.

The species of trees growth form had significantly larger and heavier seeds (mean: 0.62 cm and 8.64 g). The overall germination of seeds of trees (46.0%), herbaceous seeds (42.6%) and shrubs (23.0%). Overall germination in light (40.3%) was greater than it in darkness (29.0%). The germination was greater at moderate temperatures (20/30 °C: 36.0%) than at higher temperatures (25/35 °C: 33.2%). Generally, in herbaceous plants, germination was significantly greater in light than in dark in seeds stored at different conditions. Room temperature storage improved final germination more than the other storage conditions (fresh and field). Germination of fresh and room temperature-stored seeds of herbaceous plants was significantly greater in light compared to that of the other two growth forms. Germination of field-stored seeds of trees was significantly greater in both light and dark than it in the other two growth forms. In trees, field-stored seeds germinated faster than both fresh and room temperature-stored seeds. In both herbaceous and shrubs species, room temperature seeds germinated faster than fresh and field-stored seeds. In general, the large-seeded species germinated better in dark and opposite condition with light. In herbaceous plants, however, large-seeded species germinated better in both light and darkness. In shrubs, small-seeded species had good germination in both light and darkness and large seeds germinate mainly in light. In trees, small-seeded species had higher dormancy in dark and lower dormancy in light. Germination rate index was greater for seeds of herbs and trees more than shrubs. The germination speed was faster for bigger seeds of herbs but the reverse was true for the seeds of trees.

It clears that in studied plant species, growth form, seed size and storage condition can affect light, but not temperature requirement. The large-seeded herbs germinated better than

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small-seeded ones. Therefore, smaller seeds of herbs contribute more to soil seed bank and consequently distribute the risk of germination along time. The result of the large seeds of shrubs germinated mainly in light is these seeds should be dispersed away from the canopies of the mother plants. The field storage improved germination of seeds of trees, the presence of large seeds of the trees on soil surface or on mother plant would help them in breaking down their physical dormancy by diurnal fluctuations in day and night moisture and temperatures in addition to sand drift scarification. Interestingly, room temperature storage improved germination of herbaceous seeds in light. Room temperatures could mimic the natural conditions under litters and dead plants.

Chapter 3: Delayed seed dispersal in the hyper-arid hot desert of the United Arab Emirates (UAE)

Bradychory (delayed seed dispersal) is adaption through which plants retain their mature seeds within the mother canopy and delay their dispersal for varying period of times. Therefore, bradychory is suggested to replace serotiny and bradyspory terms in the field of dispersal. Bradychory provides seeds with protection from predators (granivores) and/or abiotic stresses, such as heat, drought, fire, lack of nutrients. In addition, in several species, the bradychory delays seed release from the mother plants until arrival of favourable conditions for seed germination and seedling establishment. Around the 1200 bradychoric species (belong to 40 genera) have been identified in different regions across the world such as Mediterranean, south-western Australia, South Africa, North America regions and arid deserts. It has been documented that the bradychory is associated with specific plant traits, such as seed dispersal (e.g., spatial dispersal), antitelechoric mechanisms (e.g., myxospermy and synaptospermy) and plant life traits. In the desert of the Arabian Peninsula, there are no studies assessed the presence of the bradychory. The aims of this study are: (1) to identify the bradychoric species in the UAE Flora; (2) to assess the relationships among bradychory, growth forms, plant habits, spatial dispersal and antitelechoric mechanisms.

The incidence of bradychory was assessed in 307 species in several field trips covered growing seasons (May 2014 - October 2016) in four inland habitats (gravel plains, mountains, salt flats and sand sheets) in the hyper-arid hot desert of UAE. The selected species cover the most common and some rare perennial species that characterize the vegetation of the UAE. Voucher specimens of studied species were kept in the Sharjah Seed Bank and Herbarium (Sharjah Research Academy). The species was identified as bradychoric when the seeds are retained on mother plant for more than six months. Bradychoric species were classified into groups on the basis of the morphological structures that retain the diaspores (seeds or fruits) on the plants, dispersal characteristics, diaspore traits and growth season. The relationships between the bradychory and habitat types, growth forms, plant habits, spatial dispersal, time of seed release and antitelechoric mechanisms (myxospermy, synaptospermy and trypanocarpy) were assessed. Relationships between the traits were assessed with Pearson Chi-square tests and a nonlinear principal component analysis (NLPCA). All statistical analyses were performed by using SPSS 14 and SYSTAT 13. We classified bradychoric species into six groups: basicarpic species, species with persistent fruits, gradually open capsules species, species with schizocarpic fruits and species with persistent lignified fruits.

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A total of 46 species were recorded to adopt the bradychory (15.0% of 307 studied species). Fabaceae family had the highest number of bradychoric plants (17.4%). The dominant bradychoric group was species with persistent fruits (28.3%) and species with schizocarpic fruits was the least represented one (6.5%). Dwarf shrubs and herbs were the two growth forms with more bradychoric species (39.1% and 23.9%, respectively). Bradychory was associated with restricted dispersal (67.4%). Basicarpic species (8 species), gradually open capsules species and species with lignified persistent fruits (9 species each one) were restricted dispersal species, while as schizocarpic species were spatial dispersal by abiotic vectors. Bradychory was over represented in perennials species (60.9%). All graminoids species retain their seeds in persistent lignified fruits and 63.0% of the annual species were basicarpics and all basicarpic species were prostrates. Bradychory was strongly related with synaptospermy and all species with persistent fruits were synaptospermics. The main seed release time for bradychoric species was in the dry season, particularly for species with persistent and schizocarpic fruits. Sandy habitats had the highest number of bradychoric species (54.3%), whereas salt flats had the lowest (23.9%). All bradichoric types were represented in all habitats, except for species with persistent lignified fruits and schizocarpic fruits which were not present in salt flats.

In the hyper-arid hot desert of UAE, the presence of bradychory is lower than it in the arid Mediterranean vegetation (e.g., SE Spain semi-arid shrublands vegetation) but it coincided with the other arid region such as central Namib Desert. In the UAE, the rainfall is temporally unpredictable and usually restricted to short season. About 46.0% of bradychoric species dispersed their seeds in the dry season, which was explained in the light of the lower activity of granivores during that time of the year. In addition, the diurnal fluctuation in moisture and temperatures in the dry seasons would help in breaking seed dormancy. In UAE deserts, if seeds dispersed and germinated in response to ineffective rainfall they might die before reaching the next seasons. There was 54.3% of bradychoric species present in sandy sheets habitats, in which sand drifts by winds are a major problem that would bury seeds and seedling deep in the soil. Therefore, delaying seed dispersal would postpone seed germination till the end of windy seasons. Interestingly, many of the bradychoric species on sand dunes had erect habit that can adapt the sand burial on active sand dunes. All the recorded bradychoric species in salt flats habitats had restricted spatial dispersal which reflects the spatial adaptation of the halophytes to survive only in a very specific habitat type. The presence of different bradychoric species groups represents different types of survival adaptation in the arid deserts of the UAE. The bradychoric species group with persistent fruits were predominantly synaptospermics, which would improve seedling establishment and reduce diaspore losses through ant predation. Basicarpic species group was overspread in all studied habitats of the UAE. The basicarpy provide anchorage against surface run-off and protect diaspore from predators. In our results, basicarpic species group includes annual and prostrate species, which agree with the results of other studies, such as Negev Deserts and in Mojave and Sonoran deserts in California.

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Chapter 4: Effect of maturation time on dormancy and germination of *Citrullus colocynthis* (Cucurbitaceae) seeds from the hyper-arid hot desert of United Arab Emirates (UAE)

Environmental conditions prevailing at seed maturation time can affect dormancy and germination requirements. Many desert plants produce seeds with different types and levels of dormancy that could only be broken once they are exposed to proper environmental signals. It has been reported that environmentally induced parental effects can influence the phenotypic expression of morphological, physiological, and several life cycle traits in plants. For example, seeds matured at different seasons have different temperature and light requirements during germination. Several studies have reported that autumn or winter-matured seeds germinated significantly greater at higher temperatures and in continuous light, compared to spring- or summer-matured seeds. The seasonal timing of seed maturation and dispersal can in turn determine the season of seed germination and germination rate and consequently the overall life cycle. Photoperiod and light quality prevailing during seed maturation can affect seed dormancy and subsequent germination in several species. In general, germinability is promoted with short day regimes in several species. Temperature is another very important factor experienced during seed maturation that affects seed dormancy. In several species, seeds produced at higher temperatures have lower dormancy. Light and temperatures of germination greatly affect germination of several Cucurbitaceae species. *Citrullus colocynthis* (L.) Schrad., (Cucurbitaceae) is a perennial prostrate small shrub grows all over the year in the arid Arabian deserts. This species has many medicinal benefits including diabetes type I. In addition, *C. colocynthis* produces big amount of oily seeds that could be converted to low cost biodiesel. Many studies reported that, *C. colocynthis* seeds had a deep dormancy. In our study, we explored if seed dormancy and germination requirements of *C. colocynthis* depended on time of fruit collection and assessed the factors that might trigger germination, such as light and temperature, in hyper-arid hot deserts of United Arab Emirates (UAE). In addition, the impact of different treatments, such as dry storage, soaking in water and physical scarification on dormancy breakage and germination requirements of some seeds lot.

Matured seeds were collected at five different times during 2014 - 2015 (mid of October and December 2014, early March, and mid of April and June 2015) from a wild population of *C. colocynthis* growing around Dubai city, north of the UAE. For each collection, the average seed mass, average seed length, width and height, and seed coat thickness were determined. Seeds of March and December were stored in brown paper bags at room temperature for one year (room temperature storage). Fresh and room temperature-stored seeds were germinated at three temperature regimes (15/25 °C, 20/30 °C and 25/35 °C) in both continuous darkness and alternating 12h light / 12h darkness. Impacts of soaking in water and physical scarification on germination were applied on seeds collected in March which exhibited deep dormancy. The One-way analysis of variance (ANOVA) was used to assess the significance of the main factors (e.g., collection time, temperature and light of incubation and storage condition) on final germination and germination rate index (GRI). Pearson correlation coefficient (*r*) was used to assess the significance of the relationship between germination and different seed traits (e.g., seed length, mass and seed coat thickness). All statistical methods were performed using SYSTAT 13.

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March collected seeds did not germinate at all in both light and dark at the three temperatures. The overall seed germination of December collection (74.0%) was greater than seeds collected in April, June and October (52.0%, 27.8% and 36.7%, respectively). The germination increased with the increase in incubation temperature (15/25 °C: 13.6%, 20/30 °C: 38.4% and 25/35 °C: 44.0%) and was greater in dark (38.0%) than in light (26.0%). At the lowest temperatures (15/25 °C), seeds of all collections did not germinate in light and seeds of April collection didn't germinate in dark, but those of June, October and December collections germinated in dark. Interestingly, for December collection, germination reached almost 100.0% of total seeds at 25/35 °C in light but reached to the same level at 15/25 °C in dark. These results indicate that germination in light requires higher temperatures, but germination in darkness might be independent on temperature regime and depends more on the time of seed collection. Germination of all seed collections was significantly faster at 25/35 °C than at 20/30 °C. There were negative correlations between final germination and seed length, width, mass and coat thickness whereas seeds of March and June are bigger, heavier and with thicker seed coat but attained significantly lower germination. Physical scarification, water soaking and seed storage did not break dormancy of March collection. In general, storage resulted in the reduction of the germination (47.8% from 73.8%). In dark, germination of the stored seeds was reduced at 15/25 °C (39.0% from 100.0%) and 25/35 °C (28.0% from 82.0%), compared to that of fresh seeds. Also, in light, germination was significantly greater in fresh (70.0%), compared to stored seeds (31.0%), at 20/30 °C.

The germination behavior of seeds of *C. colocynthis* was very sensitive to light and temperature of incubation and time of seed maturation. These results are consistent with those reported in many species of Cucurbitaceae family, in which seeds germinated only at warm temperatures. In addition, many species of the Cucurbitaceae are negatively photoblastic; e.g., their germination is inhibited in light. The ability of seeds of the different collections, except March and April, to germinate in dark indicates that temperature requirement has a phylogenetic basis as well as motherly induced effect. Several studies have reported that longer day length during seed development produce thicker, harder seed coat structure that reduced seed germination of several species. In *C. colocynthis*, seed coat thickness could not explain the variation in germination; seeds matured during shortest days (December, thinner coat) as well as longest days (April, June and October) attained higher germination. in *C. colocynthis*, seeds collected in March didn't germinate at all which developed and matured at cooler temperatures. This indicates that lower temperature might be responsible for greater dormancy. Storage of December seeds resulted in a significant reduction in the dark germination at both low and high temperatures which indicates that storage didn't affect seed viability but might have changed phytochrome sensitivity in dark. Some studies attribute the total dormant seeds and not responded to any treatments of *C. colocynthis* to the presence of an inner seed membrane and these might be coincided with our study whereas neither physical scarification nor water soaking and their combination succeeded to stimulate the germination of dormant seeds of March collection.

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RESUMEN

La Península de Arabia comprende los siete países del Golfo de Arabia (Golfo Pérsico): Bahrein, Kuwait, Omán, Qatar, Arabia Saudita, Emiratos Árabes Unidos (EAU) y Yemen. Los EAU se sitúan en la parte noreste de la Península de Arabia, entre las latitudes 22° 40' y 26° 00' Norte y las longitudes 51° 00' y 56° 00' Este. Los Emiratos Árabes Unidos cubren una superficie total de 83.600 Km^2 y están compuestos por siete Emiratos: Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Fujairah, Ajman y Umm Al Quwain. La mayor parte de los Emiratos Árabes Unidos es un desierto con predominio del sistema de relieve terrestre eólico. Las características geomorfológicas de los EAU incluyen montañas, llanuras de grava, llanuras de arena fija y planicies salinas. El desierto arenoso cubre más del 90% de la superficie del país. La mayor parte del desierto arenoso se caracteriza por la presencia de dunas de arena que se elevan gradualmente desde la planicie costera alcanzando elevaciones de hasta 250 m sobre el nivel del mar (asl). Las regiones montañosas de los Emiratos Árabes Unidos consisten en cadenas montañosas norte-sur paralelas a la costa este. La lluvia en la Península de Arabia es errática e impredecible en tiempo y cantidad. En algunos años, ciertas áreas pueden no recibir lluvia. Los EAU son un ecosistema desértico cálido e híper árido (desierto cálido subtropical) que tiene dos estaciones principales: un verano caluroso (de abril a octubre) y un invierno templado (de noviembre a marzo). La lluvia cae principalmente en la temporada de invierno con la máxima intensidad durante febrero y marzo. La precipitación media anual es de aproximadamente 110 mm con una variabilidad extrema en el espacio y el tiempo. Abu Dhabi (emiratos del sur con hábitat arenoso) recibe la precipitación anual más baja (alrededor de 45 mm/año). La precipitación anual más alta encontrada en la región montañosa del noreste del país oscila entre 125.6 y 172 mm/año. La temperatura promedio anual es de aproximadamente 27 °C y la humedad del 45.0%. En el invierno, la temperatura media es de alrededor de 20 °C, mientras que la temperatura media del verano oscila entre 35 - 40 °C. Además, la humedad puede alcanzar más del 90.0%.

La flora de los EAU comprende c. 830 especies. Las especies de los EAU tienen adaptaciones fisiológicas y morfológicas específicas para sobrevivir en las duras condiciones ambientales. Curiosamente, el área de montañas que ocupa solo el 10.0% del área total de los EAU y recibe la mayor cantidad de lluvia tiene más del 50.0% del total de las especies de plantas identificadas. Los EAU tienen cuatro ecosistemas de vegetación; región costera que se caracteriza por la vegetación de manglares compuesta por *Avicennia marina* y las comunidades de plantas halófitas. Las regiones desérticas ocupan la mayor parte de la superficie terrestre del país. Estas regiones desérticas incluyen dos áreas: dunas occidentales dominadas por *Cyperus conglomeratus* y *Haloxylon salicornicum*, desierto central dominado por *Citrullus colocynthis* y *Stipagrostis plumosa*. La región montañosa corresponde a la serie de montañas Hajar que se extiende desde los EAU hasta Omán, dominado por *Euphorbia larica*, *Pulicaria glutinosa* y *Ochradenus aucheri*. La región llanuras aluviales dominadas por algunas especies como *Aerva javanica*, *Asphodelus tenuifolius* and *Tephrosia apollinea*.

En climas extremos de zonas áridas y desérticas, como los EAU, las comunidades de plantas no suelen tener una cubierta de dosel cerrada. Además, las condiciones adecuadas

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para el crecimiento a menudo se restringen a pequeños micro-hábitats. Cada especie de planta del desierto tiene su propia estrategia de supervivencia que le permite persistir en un determinado hábitat del desierto en el que exhibe un conjunto de adaptaciones durante las diferentes etapas de su ciclo de vida. Esto permite que la especie sobreviva a pesar de la presencia de factores bióticos selectivos (por ejemplo, consumo de semillas) y factores abióticos (lluvia impredecible en tiempo y cantidad).

La diversidad funcional de las plantas puede definirse como el tipo, nivel y abundancia relativa de los caracteres funcionales que están presentes en una comunidad. Los caracteres funcionales de las plantas son características morfológicas, fisiológicas y fenológicas que representan estrategias ecológicas para determinar cómo las especies de plantas se adaptan a los factores ambientales. Los caracteres como el tamaño de la planta (e.g., altura) y el tamaño de la semilla (e.g., longitud/masa de la semilla) son caracteres funcionales estandarizados clave utilizados para todos los estudios ecológicos.

Los caracteres vegetativos comprenden la altura de planta, ciclo de vida y forma de crecimiento. La altura de la planta está asociada con la forma de crecimiento y el vigor competitivo. Se reconocen dos tipos principales de ciclos de vida; la especie anual (la especie muere en una temporada de crecimiento) y la perenne (una especie que crece durante más de dos estaciones). En ecosistemas áridos y desérticos, las especies anuales son comunes. La forma de crecimiento está determinada principalmente por la estructura y la altura del dosel. La forma de crecimiento reconoce entre las plantas herbáceas; las de roseta basal, semi-basal, las carentes de roseta que presentan hojas a lo largo de un tallo erecto y las graminoides, entre las leñosas se distinguen; los arbustos pequeños, arbustos grandes y árboles.

Los caracteres regenerativos (reproductivos) incluyen el tamaño (peso) de la semilla y su dispersión. La dispersión es la salida de la diásporas (propágulos) (semillas o frutos) de la planta madre. La dispersión es un proceso crucial para las plantas ya que conecta el final del ciclo reproductivo de las plantas adultas con el establecimiento de las plántulas (descendencia). La dispersión permite a las plantas evitar la competencia con la planta madre y con otras plántulas y la depredación por parte de los animales. La dispersión espacial (dispersión en el espacio) se presenta en dos tipos principales: a) Las especies que tienen diásporas equipadas con estructuras que facilitan el movimiento de la diáspora (dispersión espacial desarrollada), que pueden dividirse en aquellas dispersadas por medio de vectores abióticos, como el viento y los vectores bióticos como por ejemplo los vertebrados y aves, y b) Las especies cuyas diásporas carecen de estructuras que facilitan la dispersión espacial (dispersión espacial restringida). La dispersión espacial restringida es la que predomina en los desiertos ya que las áreas adecuadas para el crecimiento (es decir, los sitios seguros generalmente están ya ocupados con las plantas madres). Entre los modos de dispersión podemos distinguir; barocoría (el uso de gravedad de la planta para la dispersión), la dispersión por medio del viento (anemo-meteocoría) es uno de los medios más primitivos de dispersión. La dispersión por medio del viento puede tomar una de las dos formas principales: las semillas pueden flotar o, alternativamente, pueden aletear hacia el suelo. Los ejemplos clásicos de estos mecanismos de dispersión, en el hemisferio norte templado, incluyen por ejemplo los “dientes de león”, que tienen una semilla plumosa (pappus). Los animales pueden dispersar las semillas de las plantas de varias maneras, todas llamadas zoocoría. Las semillas pueden ser transportadas en el exterior de animales vertebrados

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(principalmente mamíferos), un proceso conocido como epizoocoría. La dispersión de semillas a través de la ingestión de animales vertebrados (principalmente aves y mamíferos), o endozoocoría, es el mecanismo de dispersión para la mayoría de las especies de árboles y arbustos grandes. Semacoría cuando las plantas dispersan su semilla sin ayuda de un vector externo, como resultado esto limita considerablemente a las plantas en cuanto a la distancia que pueden dispersar su semilla. En el modo dispersión ombro-hidrocoro, la planta dispersa por el efecto de la lluvia y / o el rocío. Por último, la dispersión balística es un tipo de dispersión donde la semilla es expulsada con fuerza por la dehiscencia explosiva del fruto.

La masa de semillas "conocida como tamaño de la semilla" es uno de los caracteres más importantes que influyen en el ciclo de vida de la planta desde la dispersión de la semilla, germinación, emergencia, supervivencia y establecimiento de las plántulas. En general, las semillas grandes producen plántulas más grandes y más fuertes con una mejor capacidad competitiva con plántulas más pequeñas, especialmente en entornos con recursos limitados, como los desiertos. En los desiertos áridos, algunas especies anuales producen diminutas semillas similares al polvo que el viento dispersa después de su maduración. Estas especies adoptan la estrategia de escape cayendo en grietas debajo de la superficie del suelo y se convierten en parte de los bancos de semillas del suelo de larga duración.

El mecanismo que previene la dispersión a larga distancia llamado "antitelecoría" se considera una forma de dispersión espacial restringida. Los mecanismos antitelecóricos son respuestas adaptativas a la alta mortalidad de las diásporas en los desiertos ayudando a la diáspora a implantarse en los mismos sitios de la planta madre. Los mecanismos antitelecóricos tienen sinaptospermia, mixospermia y tripanospermia. La sinaptospermia en la que más de una semilla es dispersada en una sola unidad y siempre se asocia con ambientes áridos. Mixospermia, cuando la diáspora produce mucílago al ser expuesta a la humedad y que se asocia principalmente con ambientes áridos. La tripanospermia es un mecanismo de anclaje al suelo por los apéndices de la diáspora, que se entierra en el suelo en el punto de contacto inicial.

Bradicoria es una adaptación a través del cual las semillas maduras se retienen en el dosel de la planta y retrasa su dispersión por períodos de tiempo variables hasta que las condiciones son las adecuadas para la germinación y establecimiento de las plántulas.

En los ecosistemas áridos y desérticos, las plantas desarrollan estrategias a través de la producción de plántulas que difieren en tiempo y lugar de germinación así como a la tolerancia a las tensiones ambientales. La dormancia de las semillas mejora la supervivencia de las plántulas al evitar la germinación en condiciones desfavorables. El nivel y tipo de dormancia se puede determinar por los factores ambientales que prevalecen durante la maduración de la semilla en las plantas madres. Se sabe que los mecanismos para liberar la dormancia en condiciones ambientales adversas están influenciados por varios factores, como la temperatura y la luz alternas.

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Capítulo 1: Caracteres de dispersión en el desierto hiper-árido de los Emiratos Árabes Unidos (EAU)

La dispersión de las plantas tiene un papel esencial en la colonización de nuevos hábitats, en la dinámica de poblaciones, en las interacciones entre especies, en la estructura de las comunidades vegetales y en la diversidad floral. El tamaño de la semilla (diáspora; semilla o fruto, también llamado propágulo) es un carácter ecológico importante para el establecimiento de las plántulas, la formación de un banco de semillas persistente y la dispersión. Generalmente, las semillas grandes aumentan la posibilidad de supervivencia y establecimiento de las plántulas, mientras que las semillas pequeñas contribuyen más a formar un banco de semillas en el suelo bajo la planta madre. Las especies con semillas grandes son más propensas a ser dispersadas por los animales, mientras que las especies de semillas pequeñas son más propensas a tener dispersión de semillas no asistida. El espectro de dispersión es la distribución de frecuencia de los diferentes modos de dispersión en un determinado tipo de vegetación. Es sabido que la dispersión de semillas a larga distancia es menos frecuente en hábitats áridos y semiáridos que en hábitats templados, y que los caracteres que limitan la dispersión espacial de las semillas son más comunes en hábitats áridos y semiáridos. Esto significa que, la restricción de la dispersión espacial de las semillas, explica el origen y el mantenimiento de las manchas aisladas de vegetación en este tipo de hábitats. El tamaño de la semilla está correlacionado con el tiempo de floración y la fenología de dispersión. En los desiertos calientes hiper-áridos, los eventos fenológicos se relacionan principalmente con la cantidad y tiempo de la precipitación anual y la humedad del suelo. Actualmente, en el desierto de Arabia no existen estudios que evalúen los caracteres de dispersión ni la fenología de dispersión de especies vegetales. El estudio que se incluye en este capítulo describe los caracteres de dispersión de las especies más comunes en cinco hábitats de interior del desierto de los EAU, determinando la relación entre el tamaño de diásporas (longitud de semillas y frutos) y las formas de crecimiento de las especies, la dispersión espacial, los modos de dispersión, los grupos taxonómicos filogenéticos APG IV, la fitogeografía de las especies y la fenología de dispersión.

El muestreo de campo y las observaciones fenológicas se llevaron a cabo mensualmente entre mayo de 2014 y octubre de 2016. Cinco hábitats diferentes se representaron en este estudio; salinas, llanuras de grava, planicies de arena, montañas y altas montañas. Se tomaron muestras de treinta cuadrantes por hábitat que representan un total de 150 cuadrantes. El tamaño del cuadrante fue de 200 m^2, en cada cuadrante se estimó la abundancia de la especie de acuerdo con la escala 'Braun-Blanquet'. Las especies estudiadas son las especies más comunes y algunas especies raras que caracterizan la vegetación de los Emiratos Árabes Unidos. Los especímenes testimonios de las especies estudiadas se depositaron en el Sharjah Seed Bank and Herbarium (Sharjah Research Academy, Sharjah). Se estudiaron siete caracteres de dispersión: (1) modo de dispersión, que incluye anemo-meteocoría, ombro-hidrocoría, semacoría, dispersión balística y barocoría, (2) tamaño de diáspora (longitud de la diáspora), (3) unidad de dispersión (fruto o semilla), (4) presencia de estructuras que facilitan la dispersión a larga distancia (dispersión espacial), (5) apéndices de la diáspora, (6) color de diáspora y (7) fenología de dispersión. El análisis de varianza unidireccional (ANOVA) y el estadístico de prueba Pearson χ^2 se utilizaron para analizar la relación entre el tamaño de diáspora y los otros caracteres, así como la asociación entre caracteres nominales, se utilizó como programa de análisis estadístico SPSS 14 y SYSTAT 13.

Se estudiaron un total de 302 especies pertenecientes a 51 familias y 192 géneros. Fabaceae, Asteraceae y Poaceae (12.6%, 9.9% y 9.6%, respectivamente) fueron las familias

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más ricas en número de especies. De los ocho grupos filogenéticos APG IV; Fabidas y Asteridas Basales fueron los predominantes (22.2% y 20.5%, respectivamente). De entre las formas de crecimiento, los arbustos pequeños (41.1%) fueron dominantes. Los frutos (69.7%) fueron la unidad de dispersión dominante. Las diásporas pequeñas fueron predominantes reconociéndose seis órdenes de magnitud de 10^{-4} a 10^{2}, variando desde 0.02 cm (*Sporobolus spicatus*) hasta 19.5 cm (*Prosopis juliflora*). Las especies que carecen de estructuras para la dispersión a larga distancia (dispersión espacial restringida) fueron las más representadas (58.6%). El modo de dispersión dominante fue semacoría (43.7%) seguido por anemo-meteocoría (28.8%) y barocoría (23.8%). La mayoría de las especies estudiadas (64.2%) se dispersaron en la estación seca (esencialmente de abril a octubre). Las diásporas de mayor tamaño corresponden a las especies incluidas en el grupo filogenético APG IV de Fabidas y Malvidas (tamaño medio: 1.8 cm y 0.9 cm, respectivamente) y las menores en Commelinidas (tamaño medio: 0.30 cm). Los árboles presentan las diásporas más grandes (tamaño medio: 3.9 cm), mientras que las matas las más pequeñas (tamaño medio: 0.3 cm). Las especies barocóricas (tamaño medio: 1.8 cm) fueron las de diásporas más grandes, mientras que las semacóricas (tamaño medio: 0.4 cm) fueron las más pequeñas. Las especies dispersadas por vectores bióticos (tamaño medio: 2.9 cm) fueron las de diásporas más grandes. La barocória fue predominante en los árboles (71.0%), la semacórica en las especies herbáceas graminoides (82.4%) y las especies anemo-meteocóricas, con diásporas pequeñas, fueron predominantes en arbustos pequeños (39.7%) (e.g., *Haloxylon* sp). La dispersión barocórica fue predominante en Fabidas (62.9%), la anemo-meteocoría en Campanulidas (76.5%) y la semacoría en Commelinidas (82.4%). La dispersión espacial restringida fue la más común en todos los grupos taxonómico-filogenéticos de APG IV excepto para las Campanulidas. La dispersión restringida fue predominante en especies herbáceas graminoides (91.4%). La dispersión por vectores bióticos fue más frecuente en los árboles (64.3%), mientras que la dispersión por vectores abióticos lo fue en los arbustos (47.3%). La dispersión por vectores bióticos se asoció principalmente con las especies con distribución fitogeografía Sudano-decaniana (56.8%), que son especies que forman parte de la vegetación saharo-africana representadas en el área de estudio.

En el desierto hiper-árido de los EAU, el promedio del tamaño de las diásporas de las especies estudiadas y el espectro de dispersión coinciden con los descritos en otras regiones áridas del mundo pero con particularidades propias debidas a la presencia de elementos florísticos Sudano-decánicos (africanos). En los EAU, las diásporas pequeñas son comunes lo cual facilita su capacidad de caer en las grietas del suelo evitando ser detectadas por los depredadores y formando un banco de semillas en el suelo de larga duración, lo que permite la supervivencia de especies en las condiciones heterogéneas e impredecibles del desierto. El principal modo de dispersión es la semacoría, que ayuda a las semillas a permanecer en sitios seguros, cerca de las plantas madres, lo que garantiza el establecimiento de plántulas. La mayoría de las especies semacóricas son plantas herbáceas, lo cual es consistente con los resultados encontrados en otros ecosistemas áridos y desérticos. Los arboles de la sabana, como las especies de *Acacia*, *Prosopis* y *Ziziphus*, son especies barocóricas que producen diásporas grandes dispersadas secundariamente por vertebrados. Las diásporas de las especies graminoides de los géneros *Stipa* y *Stipagrostis* están provistas de mucrones y apéndices que facilitan su incrustación en las grietas del suelo cerca de la planta madre que las ha

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producido. La mayoría de las especies dispersan en la estación seca, como ocurre en otras regiones áridas del mundo. La estación seca favorece la dispersión eficiente por el viento para los arbustos pequeños que poseen frutos provistos de pelos u otras estructuras que facilitan su flotabilidad, por ejemplo la capsula algodonosa de *Aerva javanica*, el cáliz alado de *Astragalus squarrosus* o la capsula alada de *Tribulus qatarensis*. Los mecanismos de dispersión pueden asociarse con factores climáticos (por ejemplo, disponibilidad de agua) que pueden afectar el establecimiento de las plántulas en el desierto hiper-árido. Alrededor del 25.0% de las especies se dispersan en las estaciones lluviosas y son principalmente especies barocóricas sudano-decanianas. La dispersión de especies a lo largo del año indica un importante recurso de semillas, por ejemplo, las especies barocóricas con frutos carnosos o con vainas con estructuras nutritivas (e.g., *Senna italica* e *Indigofera* sp.). En general, las especies que dispersan su diáspora a lo largo del año tienen menor dormancia y pueden germinar en condiciones restringidas. En general, las características de las diásporas están estrechamente relacionadas con la filogenia, los modos de dispersión y las formas de crecimiento, y estas características permiten las plantas adaptarse a los ambientes extremadamente cálidos y áridos del desierto.

Capítulo 2: Masa de la semilla, requisitos de germinación y su relación con la forma de crecimiento de las plantas con banco de semillas aéreo en el desierto hiper-árido de los Emiratos Árabes Unidos (EAU)

El tamaño de la semilla (masa de la semilla), las formas de crecimiento, los requisitos de germinación y los síndromes de dispersión se encuentran entre los principales caracteres de las plantas que afectarían a la estructura de las comunidades vegetales. La dormancia de las semillas es una adaptación adoptada por muchas especies de plantas, especialmente en ambientes heterogéneos e impredecibles, como los desiertos áridos. La dormancia retrasa la germinación de la semilla hasta la llegada de condiciones favorables que permiten el establecimiento de las plántulas y minimizan su mortalidad. El tamaño de la semilla puede estar relacionado con el requerimiento de luz durante la germinación. Las semillas grandes de muchas especies germinan tanto en la luz como en la oscuridad, mientras que las semillas pequeñas requieren luz para la germinación. En los desiertos, la germinación de muchas plantas ocurre solo cuando las combinaciones particulares de luz, temperatura y humedad del suelo son óptimas para el crecimiento de la planta. No existen relaciones claras entre el tamaño de la semilla y la dormancia, lo que puede atribuirse a diferentes limitaciones ambientales que afectan el desarrollo de semillas en diferentes formas de crecimiento y tipos de hábitats. Existen pocos estudios que evalúen la relación entre el tamaño de la semilla y el nivel de germinación para las diferentes formas de crecimiento de las plantas. En general, el tamaño de las semillas y las formas de crecimiento de las especies pueden afectar su modo de dispersión, el lugar de almacenamiento de las semillas y, en consecuencia, pueden determinar el sitio y el destino de las plántulas. En este estudio se evaluamos la relación entre la forma de crecimiento de la planta, el lugar de almacenamiento de la semilla (condiciones de almacenamiento) y la masa de la semilla y los requisitos de luz y temperatura durante la germinación de 23 plantas del desierto de los Emiratos Árabes Unidos (EAU).

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En este estudio se utilizaron semillas de 23 especies con banco de semillas aéreo y, o banco de semilla en el suelo (bajo la planta madre). En estas especies las semillas son almacenadas después de la maduración en la planta madre (14 especies) o en la superficie del suelo (9 especies). Las especies representan tres formas de crecimiento diferentes (6 herbáceas, 11 arbustos pequeños y 6 árboles). Para cada especie se midió la masa promedio de semillas (100 semillas, tres réplicas) y el tamaño promedio de las semillas (longitud de 50 semillas). Las semillas maduras de las 23 especies fueron recolectadas durante mayo-junio de 2015 en cuatro hábitats de los Emiratos Árabes Unidos. Con el fin de evaluar el efecto del almacenamiento en el campo (banco de semillas) (frutos maduros en tallos rastreros) las semillas de la misma especie se recolectaron en febrero de 2016 de plantas madre o de la superficie del suelo. Las semillas de la recolección de mayo-junio de 2015 se dividieron en dos partes; una parte se puso a germinar inmediatamente después de la recolección (semillas frescas) y la segunda parte se almacenó en bolsas de papel oscuro a temperatura ambiente (20 ± 2 ºC) hasta su puesta a germinación en febrero de 2016 (almacenamiento a temperatura ambiente). Se pusieron a germinar semillas almacenadas y semillas frescas recolectadas en el campo a temperatura ambiente en tres cámaras de crecimiento ajustadas a tres temperaturas diferentes de 15/25 °C, 20/30 °C y 25/35 °C y bajo dos regímenes de luz diferentes (12h de luz / 12h de oscuridad). El análisis de varianza unidireccional (ANOVA) se utilizó para evaluar los efectos de los diferentes factores (e.g., forma de crecimiento, almacenamiento de semillas, requisitos de luz y de temperatura de incubación, de germinación final, de RLG (Germinación de Luz Relativa) y de GRI (Índice de Germinación). El coeficiente de correlación de Pearson (*r*) se utilizó para evaluar la relación entre el tamaño (masa) de la semilla y la germinación final, el RLG y el GRI. Todos los métodos estadísticos se realizaron usando SYSTAT 13.

Los resultados del estudio muestran que los árboles poseen semillas significativamente más grandes y pesadas (media: 0.62 cm y 8.64 g). La germinación total de las semillas de los árboles fue de un 46.0%, respecto a las semillas de las especies herbáceas (42.6%) y de los arbustos (23.0%). La germinación a la luz fue de un 40.3% mayor que en la oscuridad (29.0%) y a temperaturas moderadas (20/30 °C, 36.0%) respecto a temperaturas más altas (25/35 °C, 33.2%). Para en las plantas herbáceas, la germinación fue significativamente mayor en la luz que en la oscuridad en las semillas almacenadas. El almacenamiento a temperatura ambiente mejoró la germinación final en todos los casos. La germinación de las semillas frescas y almacenadas a temperatura ambiente para las plantas herbáceas fue significativamente mayor a la luz en comparación con la de las otras dos formas de crecimiento. La germinación de las semillas almacenadas de los árboles fue significativamente mayor tanto en la luz como en la oscuridad respecto a las otras dos formas de crecimiento. En las especies herbáceas y arbustivas, las semillas almacenadas a temperatura ambiente germinaron más rápido que las semillas frescas (puestas a germinar directamente tras su recolección) y las semillas almacenadas. En general, las especies con semillas de mayor tamaño germinaron mejor en condiciones de oscuridad. En las plantas herbáceas, sin embargo, las especies con semillas de mayor tamaño germinaron mejor tanto en la luz como en la oscuridad. En los arbustos, las especies con semillas pequeñas tuvieron una buena germinación tanto en la luz como en la oscuridad y las especies con semillas grandes germinaron principalmente en la luz. En los árboles, las especies de semillas

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pequeñas tienen mayor dormancia en la oscuridad y menor en la luz. El índice de germinación (IRG) fue mayor para las semillas de hierbas y árboles que para los arbustos. La germinación fue más rápida para las semillas más grandes de hierbas, pero a la inversa en el caso de las semillas de los árboles.

En las especies estudiadas, la forma de crecimiento, el tamaño de la semilla y las condiciones de almacenamiento pueden afectar la germinación bajo luz, pero no bajo diferentes temperaturas. Las hierbas con semillas grandes germinaron mejor que las de semilla pequeña. Por lo tanto, las semillas más pequeñas de hierbas contribuyen más a formar un banco de semillas en el suelo bajo la planta madre y consecuentemente distribuyen el riesgo de germinación a lo largo del tiempo. Las semillas de arbustos grandes germinan principalmente a la luz dado que para las especies estudiadas son dispersadas lejos de las planta madre. El almacenamiento y variación en los requisitos de luz y temperatura mejoró la germinación de las semillas de los árboles que en condiciones naturales permanecen en el suelo bajo el árbol o en la planta madre formando un banco de semillas sometido a las fluctuaciones diurnas de humedad y a las variaciones de temperatura diurnas y nocturnas que contribuyen romper su dormancia. El almacenamiento a temperatura ambiente mejoró la germinación de las semillas de las plantas herbáceas a la luz. La temperatura ambiente de las cámaras de germinación pueden imitar las condiciones naturales que se encuentran las semillas bajo la estructura persistente de las plantas herbáceas muertas tras la dispersión y cuyas semillas permanecen in situ bajo ellas.

Capítulo 3: Dispersión tardía de semillas en el desierto hiper-árido de los Emiratos Árabes Unidos (EAU)

Bradicoria (dispersión tardía) es una adaptación a través de la cual las plantas retienen sus semillas maduras dentro del dosel de la planta madre y retrasan su dispersión por períodos variables de tiempo. Se utiliza el termino bradicoria para reemplazar los términos de serotonina y bradisporia en el campo de la dispersión. La bradicoria proporciona a las semillas protección contra depredadores (granívoros) y / o estrés abiótico, como calor, sequía, fuego y falta de nutrientes. Además, en varias especies, la bradicoria retrasa la liberación de semilla de las plantas madres hasta la llegada de condiciones favorables para la germinación de la semilla y el establecimiento de plántulas. Alrededor de 1200 especies bradicoricas (pertenecientes a 40 géneros) han sido identificadas en diferentes regiones del mundo, como el Mediterráneo, el sudoeste de Australia, el sur de África, las regiones de América del Norte y los desiertos áridos. Se ha documentado que la bradicoria está asociada con caracteres vegetales específicos, tales como dispersión de semillas (por ejemplo, dispersión espacial), mecanismos antitelecóricos (por ejemplo, mixospermia y sinaptospermia) y caracteres de la forma de crecimiento de la planta. En el desierto de la Península de Arábia, no hay estudios que evalúen la presencia del bradicoria. Los objetivos de este estudio son: (1) identificar las especies bradicoricas en la Flora de los EAU; (2) evaluar las relaciones entre bradicoria, formas de crecimiento, hábito de la planta, dispersión espacial y mecanismos antitelecóricos.

La incidencia de bradicoria se observó en un total de 307 especies de mayo de 2014 a octubre de 2016 en cuatro hábitats interiores (llanuras de grava, montañas, salinas y planicies de arena) en el desértico desierto hiperárido de los Emiratos Árabes Unidos. Las especies

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seleccionadas representan las especies perennes más comunes y algunas especies raras que caracterizan la vegetación de los EAU. Se guardaron especímenes de testimonio de herbario de las especies estudiadas en el Sharjah Seed Bank and Herbarium (Sharjah Research Academy). Una especie se identificó como bradicórica cuando las semillas se conservan en la planta madre durante más de seis meses. Se clasificaron las especies bradicóricas en grupos sobre la base de las estructuras morfológicas que retienen las diásporas (semillas o frutos) en las plantas, características de dispersión, rasgos de diasporas y temporada de crecimiento. Se evaluaron las relaciones entre el bradicoria y el tipo de hábitat, la forma de crecimiento, el habito de la planta, la dispersión espacial, el tiempo de liberación de la semilla y los mecanismos antitelecóricos (mixospermia, sinaptospermia y tripanocarpia). Las relaciones entre los caracteres se evaluaron con pruebas de Pearson Chi-cuadrado y un análisis de Componentes Principales No Lineales (NLPCA). Todos los análisis estadísticos se realizaron utilizando SPSS 14 y SYSTAT 13. Los grupos de especies bradicóricas fueron los siguientes: especies basicárpicas, especies con frutos persistentes, especies que abren sus capsulas regularmente, especies con frutos esquizocárpicos y especies con frutos lignificados persistentes.

Se identificaron un total de 46 especies bradicóricas (15.0% de las 307 especies estudiadas). La familia Fabaceae tuvo el mayor número de representantes (17.4%). El grupo bradicórico dominante fueron las especie con frutos persistentes (28.3%), y las especie con esquizocarpos las menos representadas (6.5%). Los arbustos pequeños y las hierbas fueron las dos formas de crecimiento con más especies bradicóricas (39.1% y 23.9%, respectivamente). La bradicoria se asoció con una dispersión espacial restringida (67.4%). Las especies basicárpicas (8 especies), las especies que abren gradualmente sus cápsulas y las especies con frutos lignificados persistentes (9 especies para cada uno) presentaron dispersión espacial restringida, mientras que como especies esquizocárpicas presentaron dispersión espacial por vectores abióticos. La bradicoria estuvo sobre representada en las especies perennes (60.9%). Todas las especies de graminoides retienen su semilla en frutos lignificados persistentes y el 63.0% de las especies anuales fueron basárpicas y todas las especies basicárpicas fueron postradas. La bradicoria está estrechamente relacionada con la sinaptospermia, siendo todas las especies con frutos persistentes sinaptospérmicas. La estación de liberación de la semilla para las especies bradicóricas fue en la estación seca, particularmente para especies con frutos persistentes y esquizocarpos. Los hábitats arenosos tienen el mayor número de especies bradicóricas (54.3%), mientras que las salinas tienen las más bajas (23.9%). Las especies bradicóricas están representadas en todos los hábitats, a excepción de las especies con frutos persistentes lignificados y frutos esquizocárpicos que no están presentes en las salinas.

En el desierto hiper-árido de los EAU, la presencia de bradicória es menor que en la vegetación mediterránea árida (por ejemplo, vegetación de matorrales semiáridos del SE de España), pero coincide con la presencia en otras regiones áridas, como el desierto central de Namibia. En los Emiratos Árabes Unidos, la lluvia es temporalmente impredecible y, por lo general, se restringe a un periodo corto del ano. Alrededor del 46.0% de las especies bradicóricas dispersan sus semillas en la estación seca, lo que se explica a la luz de la menor actividad de los granívoros durante esa época del año. Además, la fluctuación diurna en la humedad y las temperaturas en las estaciones secas ayuda a romper la dormancia de la

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semilla. En los desiertos de los EAU, si las semillas se dispersaran y germinan en respuesta a una lluvia ineficaz, pueden morir antes de llegar a las próximas temporadas. Hay un 54.3% de especies bradicóricas en los hábitats de llanuras de arenas fijas, en las que el viento constituye un problema importante pues enterraría las semillas y las plántulas en el suelo. Por lo tanto, retrasar la dispersión de la semilla pospone la germinación de la semilla hasta el final de las estaciones ventosas. Curiosamente, muchas de las especies bradicóricas en las dunas de arena tienen un hábito erguido impidiendo este el ser enterrada en la arena en las dunas activas. Todas las especies bradicóricas identificadas en hábitats de salinas tienen una dispersión espacial restringida que refleja la adaptación espacial de las especies halófitas para sobrevivir solo en un tipo de hábitat muy específico. La presencia de diferentes grupos de especies bradicóricas representa diferentes tipos de adaptación a la supervivencia en los desiertos áridos de los EAU. El grupo de especies bradicóricas con frutos persistentes es predominantemente sinaptospérmico, lo que mejoraría el establecimiento de plántulas y reduciría las pérdidas de diásporas a través de la depredación por hormigas. El grupo de especies basicárpicas está sobre-extendido en todos los hábitats estudiados de los EAU. La basicárpia proporciona anclaje contra la escorrentía superficial y protege la diáspora de los depredadores. En nuestros resultados, el grupo de especies basicárpicas incluye especies anuales y postradas, que concuerdan con los resultados de otros estudios, como los desiertos del Negev y los desiertos de Mojave y Sonora en California.

Capítulo 4: Efecto del tiempo de maduración sobre la dormancia y la germinación de las semillas de *Citrullus colocynthis* (Cucurbitaceae) en el desierto hiper-árido de los Emiratos Árabes Unidos (EAU)

Las condiciones ambientales que prevalecen en el momento de la maduración de la semilla pueden afectar los requisitos de dormancia y germinación. Muchas plantas del desierto producen semillas con diferentes tipos y niveles de dormancia que solo se pueden romper una vez que están expuestas a las señales ambientales adecuadas. Es conocido el efecto inducido por el medio ambiente sobre la expresión fenotípica de los caracteres morfológicos y fisiológicos de las plantas. Por ejemplo, las semillas maduras en diferentes estaciones tienen diferentes requisitos de temperatura y luz durante la germinación. Varios estudios demuestran en el caso de Cucurbitáceas que las semillas maduras en otoño o invierno germinan significativamente más a altas temperaturas y en luz continua, en comparación con las semillas maduras en primavera o verano. La sincronización estacional de la maduración y dispersión de la semilla puede, a su vez, determinar la temporada de germinación de la semilla y la tasa de germinación y, en consecuencia, el ciclo de desarrollo o vida de la planta. El fotoperiodo y la calidad de la luz que prevalecen durante la maduración de la semilla pueden afectar la dormancia de la misma y la posterior germinación. En general, la germinación se promueve con regímenes de días cortos. La temperatura es otro factor muy importante durante la maduración de la semilla y que afecta su dormancia. En varias especies de Cucurbitáceas, las semillas producidas a temperaturas más altas tienen menor dormancia. La luz y las temperaturas afectan en gran medida la germinación de especies de Cucurbitáceas.

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Citrullus colocynthis (L.) Schrad., (Cucurbitaceae) es un pequeña arbusto perenne postrado que crece durante todo el año en los desiertos árabes. Esta especie tiene muchos beneficios medicinales, incluyendo la diabetes tipo I. Además, *C. colocynthis* produce una gran cantidad de semillas oleaginosas que podrían convertirse en biodiesel de bajo costo. Estudios previos muestran que las semillas de *C. colocynthis* tienen una dormancia profunda. En nuestro estudio, analizamos si la dormancia de la semilla y los requisitos de germinación de *C. colocynthis* dependen del tiempo de recolección del fruto (un melón que contiene en su interior las semillas) y evaluamos los factores que podrían desencadenar la germinación, como la luz y la temperatura en los desiertos hiper-áridos de los Emiratos Árabes Unidos (EAU). Además, estudiamos el impacto de diferentes tratamientos, como el almacenamiento en seco, el remojo en agua y la escarificación física en la rotura de la dormancia y los requisitos de germinación de las semillas.

Las semillas maduras se recolectaron en cinco momentos diferentes durante 2014-2015 (mediados de octubre y diciembre de 2014, principios de marzo y mediados de abril y junio de 2015) en una población natural de *C. colocynthis* que crece alrededor de la ciudad de Dubái, al norte de los Emiratos Árabes Unidos. Para cada recolección, se determinó el promedio de la masa de la semilla, el ancho y la altura, y el espesor del recubrimiento de la semilla. Las semillas de marzo y diciembre se almacenaron en bolsas de papel oscuro a temperatura ambiente durante un año (almacenamiento a temperatura ambiente). Las semillas almacenadas a temperatura ambiente y las frescas (puestas a germinar directamente tras su recolección) se pusieron a germinar bajo tres regímenes de temperatura (15/25 °C, 20/30 °C y 25/35 °C) en oscuridad continua y alternancia de 12h de luz / 12h de oscuridad. Se estudió específicamente el efecto del remojo en agua y la escarificación física en la germinación en las semillas recolectadas en marzo que presentaron una dormancia profunda. El análisis de varianza unidireccional (ANOVA) se utilizó para evaluar la importancia de los factores principales (por ejemplo, tiempo de recolección, temperatura y luz en incubación y condición de almacenamiento) sobre la germinación final y el índice de tasa de germinación (GRI). Se usó el coeficiente de correlación de Pearson (r) para evaluar el significado de la relación entre la germinación y las diferentes características de la semilla (por ejemplo, longitud de la semilla, masa y espesor de la cubierta de la semilla). Todos los métodos estadísticos se realizaron usando SYSTAT 13.

Las semillas recolectadas en marzo no germinaron ni a la luz ni en oscuridad bajo ninguno de los tres regímenes de temperaturas. La germinación total de la semilla de la recolección de diciembre (74.0%) fue mayor que las semillas recolectadas en abril, junio y octubre (52.0%, 27.8% y 36.7%, respectivamente). La germinación aumentó con el aumento de la temperatura de incubación (15/25 °C: 13.6%, 20/30 °C: 38.4% y 25/35 °C: 44.0%) y fue mayor en la oscuridad (38.0%) que en la luz (26.0%). A temperaturas más bajas (15/25 °C), las semillas de todas las colecciones no germinaron en la luz y las semillas de la recolección de abril no germinaron en la oscuridad, pero las de junio, octubre y diciembre germinaron en la oscuridad. Curiosamente, para la recolección de diciembre, la germinación alcanzó casi el 100.0% de las semillas totales a 25/35 °C en luz, pero alcanzó el mismo nivel a 15/25 °C en la oscuridad. Estos resultados indican que la germinación a la luz requiere temperaturas más altas, pero la germinación en la oscuridad puede ser independiente del régimen de temperatura y depende más del momento de la recolección de la semilla. La germinación de

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todas las recolecciones de semillas fue significativamente más rápida a 25/35 °C que a 20/30 °C. Los resultados del estudio muestran correlaciones negativas entre la germinación final y la longitud de la semilla, el ancho, la masa y el grosor de la cubierta. Así, las semillas de marzo y junio son más grandes, pesadas y con una cubierta más gruesa y de germinación significativamente menor. La escarificación física, el remojo en agua y el almacenamiento de semillas no interrumpieron la dormancia para las semillas de la recolección de marzo. En general, el almacenamiento dio como resultado la reducción de la germinación (47.8% desde 73.8%). En la oscuridad, la germinación de las semillas almacenadas se redujo a 15/25 °C (39.0% desde 100.0%) y 25/35 °C (28.0% desde 82.0%), en comparación con las semillas frescas. Además, a la luz, la germinación fue significativamente mayor en las semillas frescas (70.0%), en comparación con las almacenadas (31.0%), a 20/30 °C.

La germinación de las semillas de *C. colocynthis* fue muy sensible a la luz, a la temperatura de incubación y a el tiempo de maduración de la semilla. Estos resultados son consistentes con los encontrados en muchas especies de la familia Cucurbitácea, en la cual las semillas germinaron solo a temperaturas cálidas. Además, muchas especies de Cucurbitáceas son negativamente fotoblásticas; es decir, su germinación se inhibe con la luz. La capacidad de las semillas de las diferentes colecciones, excepto marzo y abril, para germinar en la oscuridad indica que el requisito de temperatura tiene una base filogenética así como el efecto inducido por la madre. Varios estudios muestran que una mayor duración del día durante el desarrollo de la semilla produce una estructura de la cubierta de la semilla más gruesa y más dura que reduce la germinación de la semilla en varias especies de Cucurbitáceas. En *C. colocynthis*, el espesor del recubrimiento de la semilla no pudo explicar la variación en la germinación; las semillas maduraron durante los días más cortos (diciembre, cubierta más delgada) así como los días más largos (abril, junio y octubre) alcanzaron una germinación más alta. Las semillas recolectadas en marzo no germinaron desarrollándose y madurando a temperaturas más frías. Esto indica que una temperatura más baja podría ser responsable de una mayor dormancia. El almacenamiento de las semillas de diciembre dio como resultado una reducción significativa en la germinación en oscuridad y a temperaturas bajas y altas, lo que indica que el almacenamiento no afectó la viabilidad de la semilla, pero pudo haber cambiado la sensibilidad del fitocromo en la oscuridad. Algunos estudios atribuyen la dormancia total y la no germinación ante ningún tratamiento al hecho de la presencia de una membrana interna de semilla, pudiéndose ser el caso de nuestro estudio, ya que ni la escarificación física ni el remojo en agua ni su combinación estimularon la germinación de las semillas de la colección de marzo.

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II. INTRODUCTION

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II. INTRODUCTION

II.1. Biodiversity and Conservation

The broadest definition of biodiversity is the diversity of life in all its forms and all its levels of organization (Hunter 1990), including the ecological structures, functions, and processes (Roberts & Gilliam 1995). Biodiversity refers also to the number, abundance, composition and spatial distribution of their entities (genotypes, species, functional units, or communities within ecosystems), as well as the interactions between their components (Diaz et al. 2005, 2006, Hooper et al. 2005). Biodiversity has well-established effects on ecosystem services, that is, the benefits provided by ecosystems to humans, which could contribute to human life (Diaz et al. 2006).

Several studies linked biodiversity to ecosystem functioning and focused on both species richness (Loreau et al. 2002, Lepš 2004, Schmid & Hector 2004) and species diversity (Henry et al. 2005). These studies considered the species diversity increases the space for the functional differences among species to regulate ecosystem processes and functions (Petchey et al. 2004, de Bello et al. 2006).

In the unpredictable arid desert ecosystems, species are threatened and sometimes facing danger of extinction due to both harsh natural conditions and anthropogenic causes (Sudhersan et al. 2003). For many philosophical, cultural and practical reasons, the conservation of species richness deserves the highest priority in ecological agendas (Diaz & Cabido 2001).

II.2. Ecological diversity

Ecological diversity includes the variation in both terrestrial and aquatic ecosystems. It has a great deal of both species and genetic diversity. Ecological diversity mostly depends on variation in the complexity of a biological community which includes number of different niches (e.g., competition and predation), number of trophic levels in food chains and other ecological processes. The ecological diversity on a global scale would be the variation in biome types such as deserts, forests, grasslands, wetlands and oceans. Consequently, the ecological diversity is considered the largest scale of biodiversity. (Heywood 1995, Frosini 2003, Magurran 2004, Lazo et al. 2008, Loreau 2010).

II.3. Plant functional diversity

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Plant functional diversity could be also defined as the type, level and relative abundance of the functional traits that are present in a community (Diaz et al. 2007). Plant diversity is being seriously affected by unprecedented modifications led by human activities on ecosystems (e.g., land use change, destruction and fragmentation of habitats and introducing of exotic species) (MEA 2005). Any changes in the biodiversity have impact, directly or indirectly, on the human well-being, where these changes can affect the functioning of the ecosystems and their capacity for generating essential services for the society (Diaz et al. 2006). Hence, in the scientific community, the concept of functional diversity started to be used for their close links with the ecological processes beside their key role in the maintenance of the vital support systems of the planet (Martín-López et al. 2007).

The mechanisms by which diversity influence on the functioning of ecosystems are more dependant on some functional traits of groups of species rather than the individual species richness (Chapin et al. 2000, Diaz & Cabido 2001). Therefore, in any community, the total functional traits as well as their abundance are among the main factors that affect the functioning of the ecosystems (Chapin et al. 2000, Diaz & Cabido 2001).

In general, the species diversity changes can be expressed by the changes in the functional diversity. For example, the functional traits of dominant species are a key element that determines the success of the conservation practices and biodiversity management (Moonen & Barberi 2008, Andres et al. 2012). In the vegetative community, there is little information about quantitative value of functional traits for the different components of the functional diversity (Petchey & Gaston 2006, Diaz et al. 2007).

Plant functional traits integrate morphological, physiological and phenological features that represent ecological strategies to determine how plant species respond (adapt) to environmental factors and influence ecosystem properties. Variation in plant functional traits has proven to be useful for understanding and tackling many important ecological questions at a range of scales, which leading to a demand for standardised ways to measure ecologically meaningful plant traits (Pérez-Harguindeguy et al 2013).

In this PhD study, we used the plant functional traits. Table (II.1) summarize the relationships among the studied functional traits and ecosystems attributes, such as (1) plant responses to environmental change (climate change, soil resources changes and disturbance), (2) plant competitive strength and plant ‘defense’ against herbivores and pathogens, and (3) plant effects on disturbance regimes (Cornelissen et al. 2003). Soil resources include water and nutrient availability. Disturbance includes any process that destroys major plant biomass (e.g., fire, storm, floods, extreme temperatures, severe herbivory or disease) (Cornelissen et al. 2003).

Table II.1. The relationships between the plant functional traits used in this PhD study and ecosystem attributes. (* relationship).

Traits	Climate response	Response to soil resources	Response to disturbance	Competitive strength	Plant defence/ protection	Effects on disturbance regime
Whole-plant traits						
Growth form	*	*	*	*	*	*
Life form	*	*	*	*	*	*
Plant height	*	*	*	*	*	*
Regenerative traits						
Dispersal mode			*			
Diaspore shape and size			*			
Diaspore mass		*	*	*	*	

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II.3.1. *Core common plant functional traits*

Weiher et al. (1999) described the functional traits that would challenge the plants under different habitat types and identified the primary challenges that are facing them. Such traits include plant dispersal, establishment, and persistence. In most cases, the obvious direct traits are extremely difficult to measure where they often involve quantifying attributes over a long period of time (e.g., measuring relative growth rate or competitive ability). These traits are called 'hard' because they are hard to measure while other traits are easier to be measured (Table II.2) (Weiher et al. 1999). The common "easy" core traits list and their ecological functions include seed mass and shape, dispersal mode, clonality, specific leaf area, leaf water content, height, aboveground biomass, life cycle, onset of flowering, stem density, and resprouting ability. Some of the common core traits are highly correlated (Table II.3) (Weiher et al. 1999). This study uses some of these core functional traits, such as seed mass, dispersal mode, plant height, life cycle and onset of flowering. In addition, the study also covers some "hard" core functional traits, such as longevity, plant habit, dispersal in space and time, and persistence. Among the hard traits is the plant ability to form persistent seed bank (i.e., have dormant seeds).

According to Pérez-Harguindeguy et al. (2013), fewer traits have been universally used; mainly those that are at the core of the plant life cycle (Grime et al. 1997, Westoby 1998). These traits include plant size (e.g., height), seed size (e.g., seed mass and length) and the structure of leaf tissue (e.g., leaf area or leaf dry-matter content) and the traits that are considered important for plant resource use such as regeneration, dispersal and response to widespread disturbances (e.g., Hodgson et al. 1999, McIntyre et al. 1999, Weiher et al. 1999, Lavorel & Garnier 2002, Knevel et al. 2003). The core traits that affect plant life are summarized below.

Table II.2. Challenges faced by plant species and functional traits (Weiher et al. 1999).

Challenge	Hard trait	Easy trait
Dispersal		
Dispersal in space	Dispersal distance	Seed mass, dispersal mode
Dispersal in time	Propagule longevity	Seed mass, seed shape
Establishment		
Seedling growth	Relative growth rate	Seed mass Specific Leaf Area (SLA) Leaf Water Content (LWC)
Persistence		
Seed production	Fecundity	Seed mass, above-ground biomass
Competitive ability	Competitive effect and response	Height, above-ground biomass
Plasticity	Reaction norm	SLA, LWC
Holding space / longevity	Life span	Life cycle, stem density
Acquiring space	Vegetative spread, plant habit	Clonality
Stress and disturbance avoidance	Phenology, palatability	Onset of flowering, SLA, LWC

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Table II.3. Functional traits and related functions used in this PhD study (Weiher et al. 1999).

Trait	Function
Seed mass	Dispersal distance, longevity in seed bank, establishment success and fecundity
Seed shape	Longevity in seed bank
Dispersal type	Dispersal distance and longevity in seed bank
Height	Competitive ability
Life cycle	Plant longevity, space-holding ability and disturbance tolerance
Onset of flowering	Stress avoidance and disturbance avoidance
Seed dormancy	Longevity in seed bank
Establishment	Environmental factors affecting seed germination and dormancy

II.3.1.1. *Vegetative traits (Whole plant traits)*

II.3.1.1.1. *Plant height*

It has been defined as the shortest distance between the upper boundary of the main photosynthetic tissues (excluding inflorescences) on a plant and the ground level; usually expressed in meters. Plant height is associated with growth form, competitive vigor, whole plant fecundity and with the time intervals generally given for plants to grow between disturbances (e.g., fire, storm, and grazing) (Weiher et al. 1999, Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). Plant height is an important trait for species' life cycle strategies, which affect the ability of plant to capture light (Falster & Westoby 2005, Thomson et al. 2011). In the chapter 2, we study the plant height of 23 species with aerial seed bank in the hyper-arid hot desert of the United Arab Emirates (UAE). Plant height has been correlated with plant growth forms.

II.3.1.1.2. *Life cycle*

Plant life cycle is classified on the basis of timing and duration of survival behavior of individual plants. The three types of life cycles; the annual species (a species that produces seeds and dies within one growing season), the biennial species (a species that grows vegetative in the first season, then flowers in the second to produce seed, followed by senescence and dies), and the perennial (a species that grows vegetative for more than one growing season and flowers more than once before dying). In arid environments a large percentage of the plant species are annuals (van Rheede van Oudtshoorn & van Rooyen 1999, Weiher et al. 1999, Pérez-Harguindeguy et al. 2013). In the chapter 3, we assess the relationship between life cycle and bradychoric mechanism of 46 bradychoric species in UAE.

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II.3.1.1.3. *Growth forms*

Growth forms determine the canopy structure (direction and extent of growth, and any branching of the main-shoot axis or axes), canopy height, and both the vertical and horizontal distribution of leaves (Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). Growth forms tend to correlate with other sets of physiological and morphological traits (Leishman & Westoby 1992, Grime et al. 2014). It may be associated with plant strategy, climatic factors and land use. For instance, the height and positioning of the foliage may be both adaptations and responses to grazing by different herbivores; rosettes and prostrate growth forms are associated with heavy grazing pressure by mammalian herbivores (Noy-Meir et al. 1989, Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). Therefore, Growth forms could have a major role in response of plant communities to disturbances (Sala 1988, Belsky 1992, McIntyre et al. 1995).

The main growth forms are herbaceous (i.e., short basal, semi-basal, erect leafy and tussocks), woody (i.e., dwarf shrubs, shrubs and trees) and graminoids (i.e., grasses) (Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). In the chapter 1, we study the relationships between growth forms and the other plant traits such as diaspore size, dispersal traits (dispersal mode and spatial dispersal) in the 302 species of the hyper-arid hot desert of UAE. In the chapter 2, the relationships between seed size and growth forms are assessed for 23 species have aerial seed bank. In addition, in the chapter 3, we describe the relationship between the growth forms and bradychory for 46 species.

II.3.1.2. *Regenerative traits*

II.3.1.2.1. *Dispersal*

Dispersal is the departure of a diaspore (fruit or seed) from the parent plant (Poschlod et al. 2005, Nathan et al. 2008, Clobert 2012). Dispersal is a crucial process for plant species at several scales because it connects the end of the reproductive cycle of adult plants with the offspring establishment (Leiner et al. 2009). Dispersal can occur in both space and time. Dispersal in space is the transfer of diaspores over certain distances whereas dispersal in time means that diaspores are able to survive in the soil over long periods of unsuitable conditions before germinating (e.g., dormancy) (Poschlod et al. 2005). Diaspore dispersal is advantageous to plants for many reasons. Dispersal in space may be important to enable plant to avoid competition with the mother plant and with other seedlings, inbreeding and predation by animals (Howe & Smallwood 1982, Dirzo & Domingues 1986, Bonn & Poschlod 1998, Poschlod et al. 2005). However, dispersal in space enables species to recolonize unoccupied sites and also to colonize new suitable habitats. Dispersal in time maintain diaspore bank, which delay seedling emergence until the conditions are suitable for seedling and establishment (Kalisz & McPeek 1993, Thompson 2000, Poschlod et al. 2005).

II.3.1.2.1.1. *Spatial dispersal*

The different dispersal mechanisms are grouped into the syndromes of dispersal, which may be typically defined by the morphology of the dispersal unit (Ellner & Shmida 1981, Hughes et al. 1994, Higgins et al. 2003, Grime et al. 2014). The dispersal syndromes can be expressed by spatial dispersal which could be distinguished to two main types: developed spatial and restricted spatial dispersal. Species with developed spatial dispersal have diaspores equipped with structures that facilitate diaspore movement such as flyer

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structures (e.g., pappi, barbs, wings). Developed spatial dispersal could be divided to developed dispersal by abiotic vectors in which the diaspore unit dispersed by abiotic vectors (e.g., wind), and the developed dispersal by biotic vectors in which the diaspore unit dispersed by biotic vectors (e.g., vertebrate) (Ellner & Shmida 1981, Venable & Levin 1985, Cain et al. 2000). Species with restricted spatial dispersal have diaspores lack such dispersal-enhancing structures (Willson 1993). Restricted spatial dispersal is prevailing in desert environments because the suitable areas for growth (i.e., safe sites) are usually occupied with maternal plants. Consequently, restricted dispersal limits the loss of diaspores to unpredictable, unsuitable microhabitats (van Rheede van Oudtshoorn & van Rooyen 1999). In the chapter 1, we study the spatial dispersal of 302 species from the hyper-arid hot desert of UAE and its relationship with other functional traits such as diaspore size, dispersal mode and phylogenetic groups. In the chapter 3, we study the relation between spatial dispersal and bradychory of 46 species.

II.3.1.2.1.2. *Dispersal mode*

Dispersal mode is another detailed expression of dispersal syndromes which is related to morphological traits of diaspores. The dispersal mode of the diaspore unit has obvious consequences for the distances that could be covered, the routes of travelling and the final destination. The dispersal mode has qualitative categories that are assumed to give significant potential dispersal. These are: (1) Barochory and semachory dispersal, in which the diaspore unit (seed or fruit) has no obvious aids for long-distance transport and merely falls passively from the plant (by gravity for barochory or movement caused by wind and animal for semachory) (Thomson et al. 2011, Grime et al. 2014). For example, semachory dispersal mode is dominant in most communities of Iberian Peninsula (Guitián & Sánchez 1992), (2) Wind dispersal (known as anemo-meteochory), which is the dispersal of diaspores with characters slowing their terminal velocity of descent. The diaspores may have membranous wings, bracts, perianth, balloon (calyx), hairs, or dust seed (< 0.01 mg). This dispersal mode can be found all over the world in all vegetation communities, but is prominent in open habitats, such as arid deserts (Ulbrich 1928, Collins & Uno 1985, van Rheede van Oudtshoorn & van Rooyen 1999), (3) Zoochory is the dispersal of diaspores by animals. It could be external animal transport (exo-zoochory), which is aided by appendages such as hooks, barbs, awns, burs and sticky substances, or internal animal transport (endo-zoochory), in which the diaspores are eaten by vertebrates and pass through their gut before they enter the soil elsewhere (Ellner & Shmida 1981, Van der Pij11982). This mode is generally associated with forests and tropical and temperate communities. It is also prevalent in desert communities (Tiffney 1984, van Rheede van Oudtshoorn & van Rooyen 1999), (4) Dispersal by launching (known as ballistic). It is confined to seeds that are launched away from the plant by ‘explosion’ as soon as the seed capsule opens. Ballistic dispersal is consistently rare in all vegetation types. It is more commonly associated with smaller plants, which usually produce small seeds, than in trees that usually produce big seeds (Willson et a1. 1990, van Rheede van Oudtshoorn & van Rooyen 1999), (5) Ombro-hydrochory dispersal mode. In this last type diaspores are dispersed by the effect of rain and/or dew. Interestingly, in spite of the fact that water is a limiting factor in deserts plants, the action of rain or dew can be either

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direct or indirect (van Rheede van Oudtshoorn & van Rooyen 1999, Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). In the chapter 1, we study the dominant dispersal modes of 302 species from the hyper-arid hot desert of the UAE and their relation to other different functional traits such as diaspores size, growth forms and dispersal times.

II.3.1.2.2. *Diaspore size (mass) and shape*

The diaspore units mostly correspond with the seed. However, in many species, it constitutes the seed plus surrounding structures (fruit). Diaspore shape is the variance of its three dimensions (length, width and thickness or breadth). Diaspore shape (roundness) and mass are reasonable indicators of longevity (Thompson et al. 1993, Leishman & Westoby 1998).

Seed mass, also called seed size, is the average dry mass of seed for each species, expressed in gram (g). Seed size is one of the most important traits influencing the early phases of the plant life cycle, including seed dispersal, germination, emergence, survival of seedlings growth in plants (Castro 1999, Milberg et al. 2000, Seiwa 2000, Quero et al. 2007). Generally, the environmental conditions during seeds maturation are responsible for variation in diaspore size and mass. For example, in a variety of species, seeds produced early in the growing season were heavier than those produced late in the growing season (Baskin & Baskin 2014). Seed mass is associated with dispersal ability (Leishman et al. 1995, Thompson et al. 1998). For example, wind dispersed seeds tend to be lighter. In general, large seeds producing bigger and stronger seedling with better competitive ability when competing with neighbors' smaller seedlings, especially under resource-limited environment, as seeds provide the seedlings with food reserve (Wulff 1986, Leishman & Westoby 1994, Burke & Grime 1996, Seiwa & Kikuzawa 1996). For most cases, the larger seeds will be less dispersible for longer distance because of their heavier mass (Salisbury 1974, Fenner 1985, Venable & Brown 1988). Majority of small-seeded plants can produce larger numbers of small seeds, which could be buried deeper in the soil, particularly when shape is close to spherical, which aids their longevity in seed banks (Westoby et al. 1996, Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). In arid deserts, some annual species produce tiny dust-like seeds (e.g., *Schismus arabicus* and *Spergularia diandra*), which are dispersed by wind after their maturation. These species adopt the escape strategy by falling into small cracks for few millimeters below the soil surface and then become a part of the long-lasting soil seed banks (Gutterman 2002). Interspecific variation in seed mass also has an important taxonomic component; more closely related taxa being more likely have similar seed mass (Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). In the chapter 1, we study the variation of diaspore size (seed and fruit) among different traits such as growth forms, spatial dispersal, dispersal modes, APG III phylogenetic taxonomic groups, phytogeography and dispersal phenology in different inland habitats of UAE. In addition, in the chapter 2, we study the relationships between the seed size of 23 species with seed bank and plant growth forms, seed storage conditions and germination requirements (light and temperature). In the chapter 4, we study the relation between seed size and seed seasonal production and the germination of *Citrullus colocynthis* in the hyper-arid hot desert of the UAE.

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II.4. Bradychory (delayed seed dispersal)

Bradychory is adopted in some desert plants through which mature seeds are retained within the mother plant canopy. It also delays seed dispersal for varying periods of time (Thompson 1987, Lamont et al. 1991, Gutterman & Ginott 1994, Martínez-Berdeja et al. 2015). The bradychory has been described in many regions such as Mediterranean, south-western Australia, South Africa, and North America (Lamont & Enright 2000, Navarro et al. 2009 a, b, Martínez-Berdeja et al. 2015). The diaspore unit is all or partially retained within the canopy of parent plant and protected by lignified floral structures or dry fruits (Navarro et al. 1993, van Rheede van Oudtshoorn & van Rooyen 1999, Navarro et al. 2009a, b). In the chapter 3, we identify the bradychoric species among the 307 plant species studied in the hyper-arid hot desert of the UAE. We study the relationships between bradychory and myxospermy, synaptospermy, trypanospermy, growth form, plant habit and seasonal dispersal while as their occurrence in four inland habitats from UAE.

II.5. Antitelechoric mechanisms

Antitelechory is a mechanism in which the diaspore units are prevented from long-distance dispersal. It could be considered a form of restricted spatial dispersal. Antitelechory mechanisms include production of diaspores unit at near or below the soil surface, without any morphological characters of diaspores (i.e., atelechory) or mother plant enhancing dispersal, and with morphological characteristics of the diaspores (e.g., weight and shape) (Zohary 1937, Ellner & Schmida 1981, van der Pijl 1982, Willson 1993). Nevertheless, long-distance dispersal is known as telechory; i.e., could be considered a developed spatial dispersal (Ellner & Shmida 1981, Venable & Levin 1985, Willson 1993, van Rheede van Oudtshoorn & van Rooyen 1999, Higgins et al. 2003, Navarro 2009a, b). As far, antitelechory mechanisms are adaptive responses to high mortality of diaspore units in unpredictable deserts and help diaspore to inhabit the maternal sites. In addition, the regulation within season timing of germination help diaspores to spread their dispersal and germination over several years, protect them from predators, anchor seeds and seedlings against surface runoff and enhance water-uptake by seeds and seedlings (Ellner & Shmida 1981, van Rheede van Oudtshoorn & van Rooyen 1999). The antitelechoric mechanisms include the following:

II.5.1. *Myxospermy*

It is an anchorage mechanism, in which mucilage is produced when diaspore exposed to moister. This mechanism is mainly associated with arid environments. The diaspores units of this species ripen and disperse at rainfall to produce mucilage secretion that causes adhesion to the soil surface before the dry season. In some cases, the mucilage increases the floating of diaspore unit on the water surface (nautohydrochorous). In addition, the mucilage may increase the area of contact between seed and soil, which lead to increase the water uptake during limited rainy periods (Ellner & Shmida 1981, van Rooyen et a1.1990, van Rheede van Oudtshoorn & van Rooyen 1999, Liu et al. 2005). In the chapter 3, we study the relation between myxospermy and bradychory.

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II.5.2. *Synaptospermy*

More than one seed is dispersed as one unit (Cheplick 1992). Synaptospermy is associated with arid environments where dispersal units have the ability to absorb more water and can retain it for a longer period (Murbeck 1943, van Rooyen et al. 1990, Kamenetsky & Gutterman 1994). In the chapter 3, we study the relation between synaptospermy and bradychory.

II.5.3. *Trypanospermy*

It is an anchorage mechanism by the appendages of the diaspore, which support its burial in the soil at the point of initial contact (e.g., by drilling or wedging into cracks). Therefore, it is a type of dispersal adaption, in which seeds is placed in a suitable position that could enhance water uptake for germination. Trypanospermy also supports the fixation of diaspore unit against surface runoff, while the risk of predation is decreased as soon as the diaspores are buried (Ellner & Shmida 1981, van Rooyen et al. 1990, van Rheede van Oudtshoorn & van Rooyen 1999). In the chapter 3, we study the relationships between trypanospermy and bradychory.

II.6. Plant diversity conservation in the UAE desert ecosystems

It has been reported that the vegetation of the Arabian Peninsula has been rapidly degraded in most areas and habitats. The principal threats to biodiversity and vegetation cover are overgrazing, urban expansion and agricultural expansion, agricultural practices, the clearance of woody plants for fuel wood, desertification, and introduction of the alien invasive and natural threats (e.g., climate change and drought). However, still the main threat comes from overgrazing, which has resulted from an increase in livestock numbers (i.e. goats, camels, cattle and feral donkey) (Miller & Cope 1996, Ghabbour 1997, Ghazanfar & Fisher 1998, El-Keblawy et al. 2009, El-Keblawy 2017a).

The United Arab Emirates (UAE), like other oil producing countries, is developing rapidly which lead to human population activities expansion that threatened wildlife populations (Vine 1996, Böer 1998, El-Keblawy & Ksiksi 2005). The overgrazing in addition to agriculture and urbanization has been recognized as the most common anthropogenic threats to the biodiversity in the UAE (Oatham et al. 1995, Böer 1998, El-Keblawy 2003a). To overcome such threats, the government applied several legislative federal (Aspinall 2001).

There are different conservation policies in the Arabian Peninsula such as the establishment of nature conservation areas (*in-situ* conservation) and seed banking for saving the seeds of important plants (*ex-situ* conservation). These policies are variable from one country to another where most of the protected areas have been established within the last 25 years and all countries still actively considering the establishment of new reserves. However, some of the areas of high diversity and endemism which urgently require conservation (Socotra and in mainland Yemen, south-western and north-western highlands of Saudi Arabia, southern region of Oman and UAE) currently receive little or no formal protection (Ghazanfar & Fisher 1998, El-Keblawy 2014).

In-situ conservation is considered as one of the main conservation strategies. The UAE declared several areas as protectorates with different conservation targets (Ghazanfar &

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Fisher 1998). In one year (2006), UAE has declared a total of 14 areas with a total surface area 4.406 km^2 to be protected (UAE Ministry of Energy 2006). A concrete example for results of protection strategies against overgrazing in two regions of Abu Dhabi Emirate, a significant increase in richness and diversity of species and plant density and cover (El-Keblawy 2003a).

The seed bank is one of the most widespread and effective *ex-situ* approaches to conserve and store seeds, which can assist in conservation of native plant diversity. Currently, the Ruler of Sharjah established Sharjah Seed Bank and Herbarium (SSBH), which aims to collect and bank seeds and herbarium samples for entire flora of the UAE (Gairola et al. 2013, Gairola et al. 2017).

II.7. Study area

Deserts are arid regions with very low annual rainfall (less than 300 mm) with extensive areas of sands, rock or salt. In the desert regions, the evaporation rates are higher than the annual amount of precipitation. The world’s deserts are divided into four categories (subtropical, cool coastal, cold winter and polar deserts). Subtropical deserts are the hottest one with parched terrain, rapid evaporation and cold winter. These deserts are marked by stark temperature differences from season to season where the temperatures are ranging from 38 °C in the summer to -12 °C in the winter. Subtropical deserts include Sahara, Arabian, Kalahari, Australian, Mojave, Sonoran and Thar deserts.

II.7.1. *Arabian desert*

Arabian Desert covers about one million square miles, and covers several countries (e.g., Saudi Arabia, Kuwait, Qatar, UAE, Oman and Yemen) (Huggett 2007, Bahadur et al. 2015). It is the second largest on earth after Sahara in northern Africa. Arabian deserts occupy almost the entire Arabian Peninsula (Fig. II.1). The Arabian desert is bordered to the north by the Syrian desert, to the north-east and east by the Arabian Gulf and the Gulf of Oman, to the south-east and south by the Arabian Sea and the Gulf of Aden, and to the west by the Red Sea. The United Arab Emirates and Qatar stretch along the southern coast of the Arabian Gulf at the desert’s north-eastern limit (Miller & Cope 1996, Huggett 2007, Bahadur et al. 2015).

The Arabian Peninsula comprises seven countries of the Gulf countries: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE, and Yemen. This region has some of the most extreme climatic conditions found on the Earth; e.g., low rainfall, high evaporation rates, highest temperatures and high levels of soil and water salinity (Fig. II.1) (Miller & Cope 1996, Böer 1997, Ghazanfar & Fisher 1998, Zahran 1998, Peacock et al. 2003).

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II.7.2. *UAE desert ecosystem*

II.7.2.1. *UAE location and land description*

The UAE is located in the south-eastern part of the Arabian Peninsula between latitudes 22° 40' and 26° 00' north and longitudes 51° 00' and 56°00' east. It is bounded from the north by the Arabian Gulf, from the east by Oman and the Gulf of Oman, and from the

Figure II.1. The Arabian Peninsula and its desert.

South and the west by the Saudi Arabia. The total area of the UAE is about 83.600 km^2. The UAE consists of seven Emirates: Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Fujairah, Ajman and Umm Al Quwain (Fig. II.2) (El-Keblawy et al. 2005, Sherif et al. 2009). Most of the UAE land is desert characterized by the predominance of Aeolian landform system. UAE geomorphologic features include mountains, gravel plains, sand sheets and saline flats (Böer & Chaudhary 1999, Karim & Fawzi 2007a, b). Generally, the land of UAE is divided into two distinct zones; the larger low-lying zone and the mountains zone. The sandy desert covers over 90.0% of the country’s surface area, extending from the north-west to the eastern part of the country where it is truncated by the mountains zone (El-Keblawy et al. 2005, Sherif et al. 2009). The sandy desert zone ranges in altitude from sea level up to 300 m. Its major part is characterized by the presence of sand dunes that rise gradually from the coastal plain reaching elevations up to 250 m above sea level (asl). Along the coast of the Arabian Gulf, the low-lying land is punctuated by ancient raised beaches and isolated hills which may reach up to 40 m asl in some locations (El-Keblawy et al. 2005, Sherif et al. 2009). The mountainous zone of the UAE consists of north-south mountain ranges parallel to the east coast, which extends north-south about 150 km and about 50 km east-west. The mountains peak reaches up to 2000 m asl. The mountains are dissected by several networks of wadis (El-Keblawy et al. 2005).

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Figure II.2. Location of the United Arab Emirates (UAE) in the Arabian Peninsula.

II.7.2.2. *UAE climate*

The Arabian Peninsula is characterized by low relative humidity and high evaporation rates which being maximum daytime temperature of 50 °C and among the hottest areas on earth. In many parts of the region, the diurnal temperature range is enormous sometimes as much as 33 °C. The varied topography and latitude of the Arabian Peninsula means that its climate is affected by a number of different processes and in consequence climatic conditions vary considerably over the region. However, in general there are hot summers and cold or warm winters with winter and spring rainfall in the north and east, and both spring and summer rainfall in the south. Throughout the Peninsula, rainfall is erratic and unpredictable in time and quantity. In some years, certain areas may not receive rainfall (Miller & Cope 1996, Böer 1997, Almazroui et al. 2012). For example, Feulner (2006) reported that the long term annual average rainfall in Sharjah (1934 - 2004), UAE, is 102.8 mm. However, out of the 71 years of rainfall records, only 27 years received 50 mm or less and eight years received less than 10 mm (Feulner 2006).

The UAE is a hyper-arid hot (subtropical) desert ecosystem, in which there are two main seasons: a long hot summer and a short mild winter. The rain falls in winter season between November and March, with maximum intensity during February and March. Rainfall is very scarce, random, and infrequent. The mean annual rainfall is about 110 mm with extreme variability in space and time. The lowest annual precipitation was found in Abu

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Dhabi (about 45 mm/year), inland desert (28 - 90.7 mm/year) and western coast (97.7 - 105 mm/year). The highest annual precipitation found in the north-east mountainous region of the country ranges between 125.6 and 172 mm/year. The annual average temperature is approximately 27 °C and humidity 45.0%. For the winter, the mean temperature is around 20 °C, while mean temperature of summer ranges between 35 - 40 °C that can reach above 50 °C. In addition, humidity could reach more than 90.0% (Miller & Cope 1996, Böer 1997, Zahran 1998, El-Keblawy et al. 2005, Sherif et al. 2009, UAE Ministry of Energy 2012, UAE Ministry of environment & water 2015).

II.7.2.3. *UAE vegetation and flora*

The flora of the Arabian Peninsula consists of ca. 3.500 species of vascular plants, with approximately 600 endemic species (Ghazanfar & Fisher 1998). The Arabian Peninsula has six main vegetation ecosystems that could be distinguished according to the geomorphological diversity, phytogeography, climate, and the vegetated landscape. These are the coastal and sabkha vegetation, gravel desert and the scarcely vegetated areas, sand deserts, northern plains and the northern coastal lowlands, montane woodlands and xeromorphic shrublands and wadi vegetation, which is a zonal type dependent on the water regime (Miller & Cope 1996, Ghazanfar & Fisher 1998).

It has been documented that the UAE flora comprises about 830 species (Gairola et al. 2017). These species show specific physiological, behavioral and morphological adaptations to survive in the harsh environmental conditions (Tourenq & Launay 2008, Gairola et al. 2017). Actually, the flora of the UAE has not been fully discovered till now (Al-Ansari & EL-Keblawy 2003, EL-Keblawy et al. 2005, Gairola et al. 2017). Over the last five years, about 30 new records have been added to the country’s flora, which is considered around four percent more than those recorded in Jongbloed (2003), Karim & Fawzi (2007a, b) and Gairola et al. (2017). The mountains area occupies only 10.0% of UAE total area, however, it receives the highest rainfall and it has more than 50 percent of the identified plant species so far (Al-Ansari & El-Keblawy 2003, Gairola et al. 2017).

The UAE have four vegetation ecosystems (Jongbloed 2003, El-Keblawy et al. 2005, Karim & Fawzi 2007a). Costal lowlands region is characterized by mangrove vegetation, which is represented by *Avicennia marina* and halophytic plant communities dominated by *Arthrocnemum macrostachyum*, *Halopeplies perfoliate*, *Salsola imbricata*, *Sporobolus ioclados*, and Z*ygophyllum qatarense*. Desert regions occupy the most of the land surface of the country, especially the south of the coastal region that has salt marches and saline depressions. These desert regions include two areas: a- western dunes which dominated by *Cyperus conglomeratus*, *Haloxylon salicornicum*, and *Prosopis cineraria* and *Tribulus omanense*. b- central desert which dominated by *Acacia tortilis, Citrullus colocynthis, Haloxylon persicum, Leptadenia pyrotechnica* and *Stipagrostis plumose.* Mountainous region corresponds to the Hajar Mountains series that extend from the UAE to the neighboring Oman. Their elevations can reach more than 1000 m asl. The common shrubby species in the mountains is *Euphorbia larica*. On the lower hills and wadies, the most dominant species are *Acacia tortilis*, *Fagonia indica*, *Moringa* peregrina, *Ochradenus aucheri*, *Prosopis cineraria* and *Pulicaria glutinosa*. The other region of mountain is the high mountain (The Ru’us al-

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Jibal) corresponds to the North Mountains and is geologically distinct from the Hajar Mountains. Peaks of this mountains reach up to 2000 m asl. *Ficus johannis* grow in the Ru'us al-Jibal, while the high plateau is covered with bushes of *Cymbopogon* sp. and *Seriphidium herba-alba*. Some annual species, such as *Campanula erinus* and *Pentanema divaricatum* grow in silt among the rocks. Alluvial plains region is run westwards from the mountainous slopes until they meet the central desert. This region dominated by some species such as *Aerva javanica*, *Asphodelus tenuifolius, Crotalaria aegyptiaca*, *Cyperus conglomeratus* and *Tephrosia apollinea*.

II.7.2.4. *Key plant species in the UAE ecosystems*

From 307 plant species included in the different chapters of the PhD, we described in detail six typical species from UAE ecosystems. We selected these species for their great ecological and natural value. They belong to different families, two species from Fabaceae and the rest from Aizoaceae, Amaranthaceae, Brassicaceae and Cucurbitaceae. Fabaceae, Amaranthaceae and Brassicaceae are from the most representative families of the 307 species (12.4%, 7.5% and 4.6%, respectively), but only 1.0% is represented by Aizoaceae, despite of being mainly distributed in tropical and subtropical regions specially in tropical deserts which is adapted to the extreme conditions (Hartmann 2002). Cucurbitaceae family comprises one of the most important species in UAE studied in the chapter 4, *Citrullus colocynthis*. Most of these species can be used for restoration and rehabilitation of some degraded areas. The six key plant species are as following:

II.7.2.4.1. *Aizoon canariense* L. (Aizoaceae)

Aizoon canariense is annual short basal (prostrate) plant. The branches are zig-zagging which radiating from center and often growing in star-shape. The leaves are alternate, fleshy and bright green. The flowers are tiny and yellow-green. The seeds are black and kidney-shaped (ca. 0.1 cm) in woody star-shaped capsule that remain on plant (Jongbloed 2003, Karim & Fawzi 2007a). It is distributed in tropical and North Africa, Arabian Peninsula, Macaronesia, west and east Mediterranean, Iran, Afghanistan, and Pakistan (Boulos 2009, flora of Pakistan 2016). In the UAE, it is a common species in the northern part of the country, growing in compact sand, gravel plains, offshore islands and road side (Jongbloed 2003, Karim & Fawzi 2007a). The Flowering time is during January to June (Jongbloed 2003). The dispersal mode is ombro-hydrochory and the dispersal time is in the rainy season (October - May). *A. canariense* is a studied species in the first, second and third chapters.

II.7.2.4.2. *Arthrocnemum macrostachyum* (Moric.) K.Koch (Amaranthaceae)

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Arthrocnemum macrostachyum is a perennial halophyte, dwarf shrub, 125 cm height. Stems are much-branched, the old stems are woody structured while the young branches are succulent. Its seedlings characterized by being multi-colored where three colors (red, yellow, green) may be found in the same seedling. The leaves are reduced to tiny cup-like structures at the stem-joints. The flowers are minute and yellow and be in 3-flowerd spikes in leaf nodes. The seeds are black and glossy. It is the most common extremely salt tolerant species.

It is distributed in the Mediterranean coast of Europe, North Africa, Saudi Arabia, Middle East, Iran and Pakistan (Boulos 2009, flora of Pakistan 2016). In UAE, it occurs mainly at costal sand, at or just above high tide line. It is common and widespread distributed on both coasts of the country (Ghazanfar & Fisher 1998, Jongbloed 2003, Khan et al. 2005, Karim & Fawzi 2007a). The whole plant used as medicine for alexipharmic and antimicrobial activity (Al-Saleh et al. 1997, Agoramoorthy et al. 2008). The Flowering time is from September to December (Jongbloed 2003). The dispersal mode is semachory and the dispersal time is through all the year. *A. macrostachyum* is a studied species in the first, second and third chapters.

II.7.2.4.3. *Anastatica hierochuntica* L. (Brassicaceae)

Anastatica hierochuntica is an annual prostate plant, 5 - 15 cm height, branched from the base with ascending branches. The leaves are haired and oval to spoon-shaped with small stalk. The flowers are tiny, white and without stalk in leaf nodes. Fruits are small and contain ovoid, flat, orange seeds. This is a common desert plant and occurs in North Africa, Arabian Peninsula, Jordan, Iraq, Iran and Pakistan (Gutterman & Shem-Tov 1997, Boulos 2009, flora of Pakistan 2016). In UAE, it has a scattered distribution, it occurs mainly in sandy and limestone hills habitats and it is a well-known “resurrection plant”, well resistant to hyper-dehydration (Jongbloed 2003, Karim & Fawzi 2007a, Bhatt et al. 2016). It is one of the most famous folk medicine plants where used as medicine to ease childbirth also, smoke of burning stems inhaled to treat colds in children. (Jongbloed 2003, Hellyer & Aspinall 2005, Sakkir et al. 2012). Flowering time is during February to May (Jongbloed 2003). When the fruit matures, the branches curl in to enclose fruit forming woody ball and open when the plant becomes wet during rains, the dispersal mode is ombro-hydrochory. The main dispersal time is in the rainy season (October - May). *A. hierochuntica* is a studied species in the first, second and third chapters.

II.7.2.4.4. *Citrullus colocynthis* (L.) Schrad. (Cucurbitaceae)

Citrullus colocynthis is a perennial small shrub (with a woody base) with prostrate or climbing stems reachs up to 150 cm producing adventitious roots. The stems are haired. The leaves are alternate, triangular and deeply lobed into 3 - 7 lobes with long stalks. It is monoecious; has male and female flowers separate. The flowers are solitary and yellow (Jongbloed 2003, Karim & Fawzi 2007a). It has smooth spherical fruits which are mottled green when young and yellow when ripe, with about 6 - 12 cm in diameter. Each fruit has numerous light brown-dark brown seeds. It is commonly known as bitter apple or cucumber (Abdel-Hassan et al. 2000, Gharehmatrossian et al. 2014). The species is distributed in dry regions of northern tropical Africa, eastward through Iran to India and other parts of tropical Asia and Australia (Sen & Bhandari 1974, Gharehmatrossian et al. 2014, flora of Pakistan 2016, Menon et al. 2016). In the Arabian Peninsula, *C. colocynthis* often grows in sandy soils, covering large areas (Menon et al. 2016). In the UAE, it is common and widespread in sand and gravel habitats, except in the western and southern regions of the country (Jongbloed 2003, shahid & Rao 2014).

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C. Colocynthis is naturally adapted to arid and hyper-arid environments and could be grown in marginal habitats that are not suitable for other plants (Saberi et al. 2011). It is a typical phreatophytes; i.e., roots can reach very deep to the water table (Sen & Bhandari 1974, Hellyer & Aspinall 2005). It has large leaves that are laid on the very hot soil surface throughout the summer months. The plants compensate for the high temperatures by an increased transpiration rate which cools the leaf temperature to less than ambient temperatures; this should prevent tissue damage (Hellyer & Aspinall 2005, Menon et al. 2014). *C. colocynthis* produce an adventitious root at older nodes, so it could propagate by both the vegetative buds on the rootstocks and seeds (Sen & Bhandari 1974). It is a soil fertilizer species and its extract could be used as bio-pesticide for controlling soil borne insect pests (Jongbloed 2003, Mahajan & Kumawat 2013, Menon et al. 2014). Ecologically, it is an excellent sand binder; it fixes the sand by its adventitious root covers it by the large leaves (Sen & Bhandari 1974). In Saudi Arabia, researchers suggested that this plant can be used as a bio-indicator of available nutrients (N, Ca) and contaminating heavy metals (Cd, Fe) in soil (Menon et al. 2014).

C. colocynthis has multiple benefits (ecological, economical and medicinal) and could be a panacea to sustain life of desert dwellers (Kumawat et al. 2009, Mahajan & Kumawat 2013). The seeds are rich in oil and proteins and consequently could be used as food (roasted as an edible, bread and soup thickener). Its edible oil could be used for cooking (Akubor 2004, Mahajan & Kumawat 2013). The leaves, roots and seeds of *C. colocynthis* contain effective medicinal substances (Al-Yahya et al. 2000, Tannin-Spitz et al. 2007, Gharehmatrossian et al. 2014). These substances could be used in the treatment of cancer (Tannin-Spitz et al. 2007), especially breast cancer (Tannin-Spitz et al. 2007), as anti-oxidant (Kumar et al. 2008, Gurudeeban et al. 2010) and anti-bacterial (Khatibi & Teymorri 2011). In some areas, *C. colocynthis* is used in folk medicine by local people as a purgative, antirheumatic, antidiabetic, and skin infections, jaundice, ascites, liver problems, rheumatism, fever, urinary disease and stomach pain (Jongbloed 2003, Mohammed et al. 2004, Tannin-Spitz et al. 2007, Huseini et al. 2009, Gurudeeban et al. 2010, Menon et al. 2014).

Several studies have reported that the oil of *C. colocynthis* is very rich in unsaturated fatty acids, high linoleic fatty acid content that make it resemble that of safflower, corn, cottonseed, sunflower, soybean and sesame oil (Giwa et al. 2010). Nehdi et al. (2013) revealed that *C. colocynthis* seed oil possessed physicochemical properties, antioxidant properties, fatty acids and tocopherol compositions that may be of interest for food and non-food applications. Those authors also indicated that *C. colocynthis* seed oil is desirable in terms of nutritional values, and might be an acceptable substitute for conventional oils such sun- flower seed oil. The oil of *C. colocynthis* can also be used for medicinal and soap production. Once the oil has been extracted, the byproducts can be used for many purposes (Giwa et al. 2014). Interestingly, the low peroxide and free fatty acid values and the absence of disagreeable flavour and odour in *C. colocynthis* seed oil indicates that this seed is not susceptible to oxidation in its intact form (O'brien 2008) and can be stored for a long time without deterioration until further use in both food and oleochemical industry (Nehdi et al. 2013).

Citrullus colocynthis has the ability to substitute the requirement of low cost feedstock with the potential of high oil seed production and the added benefit of an ability to

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grow on marginal land. These properties support the suitability of this plant for large-scale vegetable oil production needed for a sustainable biodiesel industry. In addition, the high oil yield coupled with the ease of cultivation and seed collection make *C. colocynthis* a good candidate for commercial exploitation.

The dispersal unit is the seed with ballistic dispersal mode and its dispersal times are through all the year. The mature seed coat is dark brown, thick, and lignified (Koller et al. 1963). The average 50 seed weight is about 1.5 g. In the UAE, several researchers reported the flowering time of *C. colocynthis* in the period from November to July (Jongbloed 2003, Karim & Fawzi 2007a). However, our extensive surveys in the UAE showed that the plants of this species are evergreen and can flower and produce fruits all over the year in some places.

It has been reported that the seed germination of *C. colocynthis* under natural field conditions is highly variable, erratic and very poor (i.e., seeds have deep dormancy), in spite of the large number of seeds produced (Koller et al. 1963, Sen & Bhandari 1974, Al-Ghamdi et al. 2009, Mahajan & Kumawat 2013). Matured non-treated seeds of *C. colocynthis* did not germinate for collections from Negev Desert (Koller et al. 1963), UAE desert (Menon et al. 2014) and Iranian desert (Saberi et al. 2011, Gharehmatrossian et al. 2014). Such dormancy was attributed to the mechanical barrier of testa, not to the presence of allelochemical in seed testa that might inhibit the germination. None of these studies mentioned the time of seed maturation and collection. As *C. colocynthis* is fruiting all over the year in some habitats of the UAE, the present study (chapter 4) aimed to assess the impacts of time of fruit collection on germination level and rate.

As *C. colocynthis* has several ecological and medicinal applications and has very deep dormancy, we selected it to examine dormancy and germination requirements for seeds collected at different times of the year. This is especially important as most of the earlier studies assessed germination for one collection (more likely those from winter time) and found deep dormancy. *C. colocynthis* is a very common, widespread species with great medical and economic applications. This necessitates understanding its dormancy, how to break it and germination requirements. This is also especially important as there is a great potential to domesticate this plant as a cash crop to be grown in the marginal lands of the deserts. *C. colocynthis* is a studied species in the four chapters.

II.7.2.4.5. *Acacia tortilis* Hayne (Fabaceae)

Acacia tortilis is umbrella shaped tree, 4 - 6 m height, with a single stem or several stems branching from the base. It is characterized by paired straight white spines up to 8 cm alternating with shorter (ca. 0.5 cm) at base of leaf. Leaves with 5 - 11 pairs of pinnae and each pinnae with 6 - 20 pairs of leaflets. The flowers are creamy-white spherical. The fruits are a pod 3 - 9 cm length, contorted or spirally twisted. It is distributed in northern and eastern Africa, Arabian Peninsula and southward to southern Africa (El Amin1976, Brenan 1983, Kennenni & Maarel 1990, flora of Pakistan 2016). In UAE, it grows in sand plains and mountain habitats and it is common and widespread in the eastern part of the country (Jongbloed 2003, Karim & Fawzi 2007a). The flowering time is from April to June (Jongbloed 2003, Karim & Fawzi 2007a). *A. tortilisis* is considered as a ‘‘Keystone species’’

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(Mills et al. 1993) with the positive influence of soil enrichment in arid ecosystems such as soil organic matter, total N, P and Ca^{2+} which are significantly higher under tree canopies, in addition, tree canopy has positive influence on the herbaceous species composition and dry matter yield (Abdallah et al. 2008) and has a great effect on sand stabilization (Kennenni & Maarel 1990). *A. tortilisis* provides food and shelter to many desert animals such as camels and goats. This species is a major source of fuel, fodder and remedies for local (Bedouin) people and also, its gum used in the manufacture of mucilage (Ashkenazi 1995, Jongbloed 2003, Noumi et al. 2010, flora of Pakistan 2016). The dispersal mode is barochory and the dispersal time is the dry season. *A. tortilis* is a studied species in the first and second chapters.

II.7.2.4.6. *Prosopis cineraria* (L.) Druce (Fabaceae)

Prosopis cineraria is a tree of 10 m height, with rounded canopy. The branches may drop all the way to the ground. The leaves are grey-green which divided into two pinnae and each pinna has 7 - 16 pairs of leaflets. The flowers are tiny on cylindrical spikes from leaf nodes. The fruits are the cylindrical pods slightly curved and yellow to reddish-brown. It grows extensively in arid and dry regions including western region of India, Pakistan, Afghanistan, Iran, and Arabian Peninsula (Sharma et al. 2011, flora of Pakistan 2016). In UAE, it is common and widespread in the north-eastern part of the country. The distribution varies from open forests in gravelly wadi beds to tight clusters in low sand dunes and sand plains (Jongbloed 2003, Gallacher & Hill 2005, Karim & Fawzi 2007a, Gallacher & El-Keblawy 2013). *P. cineraria* has been reduced over the last few decades due to overgrazing, coppicing urban and reducing access to ground water and habitats fragmentation (Gallacher & Hill 2005). *P. cineraria* has an important ecological role because it increases the organic matter, total N, P and S, and available N, P and K contents in soils (Aggarwal et al. 1993, El-Keblawy & Abdelfatah 2014). The “Ghaf” plant (Arabic name of *P. cineraria*) is an integral part of the cultural heritage of UAE and to natural desert ecology (Lemons et al. 2003, Gallacher & El-Keblawy 2013). It has a lot of traditional uses as a good fodder and shade in desert. Seed pods and young leaves are eaten by local people. Wood used for fuel and construction. Furthermore, it is considering a medicinal plant. For example, the extract of leaves is used as eye drops, extract of crushed pods used as ear drops and also bark used for rheumatism and applied to scorpion stings and the branches sap used as an antiseptic (Jongbloed 2003, Hellyer & Aspinall 2005, Sakkir et al. 2012, flora of Pakistan 2016). It has two times of flowering, one during March to May and the other is October to January (Jongbloed 2003, Karim & Fawzi 2007a). The dispersal mode is barochory and the dispersal time is in the dry season (May - October). *P. cineraria* is a studied species in the first and second chapters.

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II.8. Relationships between functional, seed and germination traits

The community structure might be determined by different trade-offs and relationships among seed and plant traits such as growth forms, dispersal characters, seed size, dormancy and germination requirements (Westoby et al. 1996, Wang et al. 2017). The distribution of different plant species is the result of strategies of their seed dispersal, dormancy and germination behavior (Kos et al. 2012). Under the unpredictable heterogeneous environments, such arid deserts, plants develop multiple strategies through producing offspring that differ in time and place of germination, and tolerance to environmental stresses (El-Keblawy 2003b, Baskin & Baskin 2014). For example, seeds of desert plants developed different types of dormancies that could be broken once they exposed to the proper environmental signals that enhance the seedling establishment (Finch-Savage & Footitt 2012). In addition, place of seed storage determines the level of dormancy and germination responses to light and temperature conditions and consequently the time and place of germination. Seeds stored in soil seed bank differ in their germination responses from those with aerial seed bank (bradychory); i.e., stored inside maternal tissues on the maternal plants or under the canopies (Uhl & Clark 1983, Pons 2000, Ooi et al. 2009).

Growth form, which is one of the important functional traits, can affect dispersal mode, position of diaspore storage and consequently affect place of seedling establishment, growth and survival, which in turn could shape community structure (Saatkamp et al. 2014, Jiménez-Alfaro et al. 2016). Plant size, which is another important functional trait, can affect seed size, which in turn affects dormancy and germination traits. For example, Baker (1972) examined the possible relationships between seed weight of different growth forms with different environmental conditions in the flora of California, including deserts, and concluded that seed size is proportionally correlated with both plant size and length of generation time (life cycle); smallest seeds were for herbaceous and largest for trees. However, fewer studies assessed the relationship between seed size and germination level among different growth forms in desert communities. The next few sections describe important seed and germination traits and these traits affect survival in the arid deserts of the Gulf region. In the chapter 2, we assessed the relationship between functional traits like growth forms, and seed and germination traits for 23 species having aerial seed bank.

II.8.1. ***Dormancy and germination responses***

Dormancy is a temporary failure of a viable seed to complete germination under conditions that are favorable for germination of non-dormant seeds (Baskin & Baskin 2014). Seed dormancy enhances seedling survival by preventing germination under unfavorable conditions or ephemerally favourable conditions (Bewley 1997, Auge et al. 2015). Some desert plants depend more on dormancy than dispersal for survival. Under unsuitable condition (e.g., dry season), the plants tend to delay germination until the occurrence of a favorable condition rather than relying on dispersal (Liu et al. 2014). The delay in germination (i.e., seed dormancy) was considered as ‘bet-hedging strategy’ that spreads the risk of germination failure over time (Rees 1996, Gremer & Venable 2014). It has been reported that plants that are subjected to high risks of mortality during early life stages develop dormancy and dispersal strategies that offset fluctuations in habitat suitability (Fenner & Thompson 2005). Such strategies are usually linked to seed size (Larson et al. 2016).

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The level and type of dormancy can be determined by environmental factors prevailing during seed maturation on mother plants (Gutterman 2000) as well as by conditions experienced directly by seeds during their storage in natural habitats

(Finch-Savage & Leubner-Metzger 2006, El-Keblawy 2013). In addition, dormancy and germination responses can be determined by environmental conditions during seed soaking (Baskin & Baskin 2014). Thus, germination timing under natural ecological conditions is determined by the interaction between factors of the environment of the mother plant and post-dispersal environments (Gutterman 2002).

Several studies have reported that mechanisms of releasing dormancy or inducing germination under harsh environmental conditions is influenced by several factors, including alternating temperatures, light, and dormancy regulating chemicals (El-Keblawy et al. 2010, El-Keblawy 2013). Soil temperature is an important environmental signal in the top soil layer that can modulate time of seed germination, which control seedling emergence and survival. Several studies have reported that temperature plays an important role in controlling germination, establishment and regeneration of desert species (Budelsky & Galatowitsch 1999). For example, germination response of desert halophytes depends on the temperature of incubation (Gul et al. 2000, Khan et al. 2001), but depends on both temperature and light and their interaction in other halophytes (El-Keblawy & Al-Rawai 2006, El-Keblawy et al. 2007). The temperature requirements for germination may play a role in determining the distribution and microhabitat in which the species grown (Bewley et al. 2012, Baskin & Baskin 2014). Seeds exposed to alternating temperatures (e.g., stored on soil surface) prefer to germinate at fluctuating rather than constant temperatures (Baskin & Baskin 2014). Conversely, other species germinate better at constant temperatures, if they are buried or stored under canopies (Conner & Conner 1988, Kumar et al. 2013). It has been recommended that, to get high percentage of seed germination, the difference between the high and low temperatures (alternative temperature) must be 10℃ or more (Morinaga 1926, Pons & Schroder 1986).

Light is another important signal for the seed germination, especially in desert plants. The effect of light on seed germination could be positive, negative, or neutral (Gutterman 1993, Baskin & Baskin 2014). Many plant species have seeds germinate to high percentages in both light and darkness (Baskin & Baskin 2014). However, seeds of some species germinate only in light (Attims & Come 1978, Baskin & Baskin 2003) or in darkness (Morgan & Lunt 1994). The germination response of desert plants in light conditions depends on seed size and growth form (El-Keblawy 2017b). In some species, the light sensitivity of seeds depends on phytochrome action and this sensitivity changes with temperature (Smith 1975). In addition, the induction of dark dormancy has been reported to depend on temperature of incubation (Wesson & Wareing 1969, Pons 1991). For example, induction of dark dormancy was observed to be faster at higher than at lower temperatures in species that are well known to form persistent soil seed banks (Pons 1991).

Light is an important signal, especially for small seeded plants, in soils frequently exposed to natural disturbance, e.g., mobile sand dunes (Huang & Gutterman 1998, Koutsovoulou et al. 2013), or to man-made disturbances, such as farms (Milberg et al. 2000, Batlla & Benech-Arnold 2014). Light signal could interact with internal factors to regulate dormancy release and germination process. Once dispersed in soil, the small seeds of this species have a high chance of being buried and consequently undergo dark induction and could become a part of the soil seed bank (Bliss & Smith 1985, Pons 2000). Thus, germination at a soil depth is likely to be fatal for the resulting small seedlings, which cannot easily reach the soil surface (Pons 1991). In the chapter 2, the dormancy and germination

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responses to light and temperature during seed soaking has been studied for 23 species beloning to different growth forms. In addition, in the chapter 4, the effect of mother environment prevailing during seed maturation on germination response to light and temperature has been assessed for *Citrullus colocynthis*.

II.8.2. *Relation between dormancy, seed storage and response to environmental conditions*

Each desert plant species has its own complex of survival strategies that enable it to persist to appear in a certain desert habitat in which exhibit a complementary set of adaptations during the different stages of its life cycle. These enable the species to survive despite the presence of selective biotic factors (e.g., seed consumption) and abiotic factors (extreme, unpredictable amounts and distribution of rain). The main survival strategies are “dispersal strategies” which reduce massive seed consumption, “bradychory” which acts as a long-term protected aerial seed bank, and “seed germination strategy” in which only a portion of the seed population germinates after even one small rainfall (Gutterman 1994, 2002, Liu et al. 2014).

Seeds storage after maturation can be divided to two types. The first is soil seed banks, which is formed in the soil and the other is bradychory, in which seeds retained on the mother plant canopy and gradually released over the time as a response to germination cues like rain (Thompson 1987, Gutterman & Ginott 1994, Gao et al. 2014). In arid and semi-arid deserts, the soil seed bank can play a major role in plant recruitments and population dynamics (Kemp 1989, El-Keblawy & Bhatt 2015). Several studies have reported that seeds stored in soil seed bank (i.e., buried) are exposed to less fluctuations in daily temperature (Gutterman 2000). However, seeds from bradychoric species are exposed to diurnal fluctuations in temperature and to full light during storage (El-Keblawy & Bhatt 2015). Small seeds can bury and consequently become part of seed bank (El-Keblawy & Bhatt 2015).

There is a relationship between persistent seed bank and seed size and shape (Thompson & Grime 1979, Thompson 1987, Leck 1989, Thompson et al. 1993). Persistent seeds tend to be smaller and compacted, while short-lived seeds are normally larger and either flattened or elongate (Thompson et al. 1993). In addition, the environmental factors associated with seed in the soil seed bank differ from those in the aerial seed bank. Seeds in a soil seed bank are either buried at different depths or stored on the soil surface. Seeds stored on the soil surface are exposed to light and face diurnal fluctuations in the temperatures. Conversely, seeds buried in the soil are stored in darkness and face less diurnal temperature fluctuations. In the aerial seed bank, however, seeds are exposed to light and experience less fluctuation in diurnal temperatures.

The light-requirement of seed germination decrease with increased seed size of species (Milberg et al. 2000, El-Keblawy 2017b). In the soil, small-seeded species might have a light requirement for germination, while the large-seeded species might be independent on light. Therefore, the seed bank with small seeds has light-sensitive germination (Thompson et al. 1993, Milberg et al. 2000). In many small-seeded species, exposure to light can break the dormancy of seeds (Cochrane et al. 2002). It has been reported that, species with heavier seeds (> 10 mg) can germinate under a wider range of conditions than lighter seed (< 10 mg) (Bell et al. 1995, Cochrane et al. 2002). In the chapter

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2, the effect of storage conditions in field and at room temperature on germination response to light and temperatures have been assessed for 23 species with aerial seed bank (i.e., bradychory). These species produce a wide range of seed sizes. Consequently, the relationship between seed mass and germination response to environmental factors have been assessed.

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II.9. Objectives

For all of the above, the main objective of this PhD is as follows: Plant dispersal strategies of different ecological desert habitats of UAE. In this study, attention will be paid mainly to the study of functional characters related to reproduction and regeneration, such as the characteristics of the diaspore, the different dispersion strategies, the presence of a persistent seed bank as well as the germination requirements of the seeds of a typical species and characteristic of desert habitats, *Citrullus colocynthis* (L.) Schrad., (Cucurbitaceae) as a model study for further studies of functional ecology. The study focuses on the 307 most common species of the flora that characterizes the five main types of inland ecosystems of the hyper-arid hot desert of the UAE.

II.9.1. The specific objectives of the PhD study:

1. To describe the dispersal spectrum, seed characteristics, variation of dispersal traits and dispersal strategies of the 307 species among the major inland habitats of the hyper-arid hot (subtropical) desert of the UAE. The major habitats that will be compared are: sandy, salty, gravel, and low and high mountains.

2. To analyze the seed germination characteristics of 23 species with aerial seed bank (seed stored in plant canopy or under plant for more than 9 months) belong to different plant growth forms and their relationships with seed size (mass), seed storage conditions, and light and temperature of incubation.

3. To identify and classify into groups, the bradyoric species out of a total of 307 studied species, from four inland habitats from the hyper-arid hot desert of the UAE and analyze their relationships with growth forms, spatial dispersal and antitelechoric mechanisms.

4. To study the germination characteristics of the seeds of the *Citrullus colocynthis* (L.) Schrad., a key species from the hyper-arid hot desert of the UAE in order to examine the variations of seed germination under different seed storage types, seeds maturation time, treatments to break dormancy, and light and temperature requirements.

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II.10. PhD structure and organization

This PhD report “Plant dispersal strategies of different ecological desert habitats of UAE” is structured in four chapters have been written in English to publish in scientific journals. The following are the names of the co-authors and their state of publication.

The title of the publications including the authors and the reference of the journal are presented below:

Chapter 1: Shabana H.A., Navarro T., El-Keblawy A. (2018) Dispersal traits in the hyperarid hot desert of the United Arab Emirates. Plant Ecology and Evolution 151(2): 194-208.
https://doi.org/10.5091/plecevo.2018.1359

Abstract: This study describes the dispersal traits of 302 species in five Afro-Arabian habitats from the hyper-arid hot desert of United Arabian Emirates (UAE). Diaspore size (diaspora length) was studied in relation to growth forms, dispersal modes, presence of structures for long distance dispersal, APG IV groups, phytogeography and dispersal phenology using ANOVA and Pearson χ^2 test-statistical analyses. Small diaspores were predominant (six orders of magnitude from 10^{-4} to 10^{2}). The major diaspores were found in Fabids phylogenetic APG IV group (1.80±0.41 cm) mainly trees and the minor in Commelinids (0.30±0.08 cm). The most dominant dispersal mode was semachory (43.7% of the total and 67.5% of the herbaceous species), followed by anemo-meteochory (28.8%) and barochory (23.8%). Semachores/barochores (67.5%) formed the largest groups from the Fabaceae, Poaceae, Boraginaceae, Brassicaceae and Amaranthaceae families. Savanna trees such as *Acacia*, *Prosopis*, *Ziziphus* sp. and *Indigofera* sp. produced large diaspores secondarily dispersed by vertebrates. Anemo-meteochoric species with small diaspores were predominantly semi-shrubs such as *Haloxylon* sp. Graminoids such as *Stipa* sp. and *Stipagrostis* sp., without structures for long-distance dispersal had diaspore appendages acted as "active drills" in soil cracks. Dryness (dry season) favours the efficient dispersion by the wind for the small shrub species with haired capsule (e.g. *Aerva javanica*), winged calyx (e.g. *Astragalus squarrosus*) or wings (e.g. *Tribulus qatarensis*). Most of the species studied (64.2%) dispersed in the dry season according to what was found in other arid region from the world. The longer dispersal phenology corresponded to Saharo-Arabian and Sudano-Decanian species which is related to the floristic richness of the study area. Species dispersal throughout the year indicates an

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important seed resource e.g. barochoric species with fleshy fruits or pods with nutrient structures (e.g. *Senna italica* and *Indigofera* sp.).
In the hyper-arid hot desert of UAE, the dispersal spectra are close to those recorded in other arid environments but with particularities due to the presence of African floristic elements.

Chapter 2: El-Keblawy A., Shabana H.A., Navarro T. (2018) Seed mass and germination traits relationships among different plant growth forms with aerial seed bank in the subtropical arid Arabian deserts. Plant Ecology & Diversity 11(3):393-404.
https://doi.org/10.1080/17550874.2018.1496365”

Abstract: Seed mass and plant growth forms can affect dispersal syndrome that determines where seed is stored until germination, which can consequently determine germination requirements and the fate of emerged seedlings. This study aimed to assess the relationships between seed mass, germination rate and light and temperature requirements during germination of 23 desert plants with an aerial seed bank. Freshly collected seeds and those stored for 9 months at room temperature and enclosed within plant parts in the field were germinated in three growth chambers adjusted to three temperatures and two light regimes. Trees and shrubs had significantly heavier seeds with greater dormancy compared to herbs. Germination at all storage conditions responded positively to light in herbs and germinated in both light and dark in shrubs and trees. Field storage enhanced light germination in trees, but not in shrubs and herbs. Germination rate index was greater for seeds of herbs and trees compared to those of shrubs. The relationships between seed mass and final germination in both light and dark regimes were positive in herbs but negative in shrubs. Growth form, seed size, storage condition can affect light, but not temperature, requirement of the studied plants.

Chapter 3: Delayed seed dispersal in the hyper-arid hot desert of the United Arab Emirates (UAE). Not pubished.

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Chapter 4: El-Keblawy A., Shabana H.A., Navarro T., Soliman S. (2017) Effect of maturation time on dormancy and germination of *Citrullus colocynthis* (Cucurbitaceae) seeds from the Arabian hyper-arid deserts. BMC Plant Biology 17(1): 1-10.
https://doi.org/10.1186/s12870-017-1209-x

Abstract: Light and temperatures of germination greatly affect germination of several Cucurbitaceae species. Environmental conditions prevailing at seed maturation time can affect dormancy and germination requirements. *Citrullus colocynthis* seeds have a deep dormancy. This perennial prostrate shrub grows all over the year in the arid Arabian deserts. We explored if seed dormancy and germination requirements of *C. colocynthis* depend on time of fruit collection. Matured seeds were collected at five different times during 2014/2015 year from a population around Dubai city. Fresh seeds were germinated at three temperature regimes in both continuous darkness and alternating 12 h light/12 h darkness. Impacts of seed storage and other treatments on germination were applied on seeds collected in March and exhibited deep dormancy. March collected seeds almost did not germinate in both light and dark at the three temperatures, but those of the other collections responded differently to both light and temperatures. At the lowest temperatures, seeds of all collections did not germinate in light, but those of June, October and December collections germinated in dark. There were negative correlations between final germination and seed length, width, mass and coat thickness. Physical scarification, water soaking and seed storage did not break dormancy of March collection. Germination of *C. colocynthis* is very sensitive to light and incubation temperature as well as to the environmental conditions associated with the time of seed maturation. It is important to investigate the effects of environmental factors prevailing during seed maturation under controlled conditions to understand exact reasons for unusual seed dormancy and germination requirements of *C. colocynthis*, which seems to be very sensitive to maternal environment.

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III. RESULTS

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III. RESULTS

The general results of the PhD study have been structured following the order of different chapters. These results correspond to the objectives presented in the PhD introduction.

The main results of the dispersal traits in 302 studied species from the hyper-arid hot desert of the United Arab Emirates (UAE) (Chapter 1) show us that among the 51 studied families, Fabaceae, Asteraceae and Poaceae (12.6%, 9.9% and 9.6%, respectively) were the richest in species number and from the eight phylogenetic APG IV groups; Fabids and Basal Asterids were the predominant (22.2% and 20.5%, respectively). Concerning the growth forms, the dwarf shrubs (41.1%) were the most dominant followed by semi-basal herbs (21.9%). In relation to dispersal traits and diaspore types, fruits (69.7%) were the dominant dispersal unit (diaspore type). Small diaspores were more common; the diaspore size (diaspore length) covered six orders of magnitude from 10^{-4} to 10^{2}. The diaspores mean size 0.8 cm and ranged from 0.02 cm (*Sporobolus spicatus*) to 19.5 cm (*Prosopis juliflora*). Species lacking structures for long-distance dispersal (restricted spatial dispersal) were more represented (58.6%) followed by species with developed structures for dispersal by abiotic vectors (29.1%) and by biotic vectors (12.3%). The main dispersal mode was semachory (43.7%) followed by anemo-meteochory (28.8%) and barochory (23.8%). The anemo-meteochoric species with wings were dominant in sand sheets habitat (33.3%). The dispersal phenology was concentrated in the dry season, from April to October, which represents 63.9% of the total studied species in dispersal.

The diaspore size differed significantly among APG IV phylogenetic taxonomic groups, growth forms, dispersal mode and spatial dispersal ($P < 0.001$). Fabids and Malvids had the largest diaspores (mean size: 1.8 cm and 0.9 cm, respectively) while smallest were Commelinids (mean size: 0.3 cm). The trees had the largest diaspore (mean size: 3.9 cm) while tussocks had the smallest (mean size: 0.3 cm). Barochoric species (mean size: 1.8 cm) were the largest while semachoric (mean size: 0.4 cm) were the smallest. Species dispersed by biotic vectors (mean size: 2.9 cm) had bigger diaspore than those dispersed by abiotic vectors (mean size: 0.7 cm) and restricted dispersal (mean size: 0.5 cm).

There were significant relationships between dispersal modes and each of APG IV phylogenetic taxonomic groups, growth forms ($P < 0.001$) and dispersal phenology ($P < 0.01$). Barochory was over-represented in Fabids (62.9% of total species) and absent in Campanulids. However, anemo-meteochory was predominant in Campanulids (76.5%). Semachory was predominant in Commelinids (82.4%). Semachory was more represented in herbaceous species, such as tussock graminoids (82.4%). Barochory was predominant in trees (71.0%). Anemo-meteochory was over-represented only in dwarf shrubs (39.7%).

Spatial dispersal had significant relationships with each of APG IV phylogenetic taxonomic groups, growth forms, species phytogeographical distribution ($P < 0.001$) and dispersal phenology ($P < 0.01$). Restricted dispersal was the most common in all APG IV except for Campanulids, in which dispersal by abiotic vectors was over-represented (76.5%). Restricted dispersal was over-represented in herbaceous species such as Tussocks (91.4%). Dispersal by biotic vectors was prevalent in trees (64.3%), while dispersal by abiotic vectors

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was over-represented in shrubs (47.3%). Dispersal by biotic vectors were mainly associated with Sudano-Decanian species (56.8%), which are species forming part of Saharan-African vegetation in the study area. Semachoric species and species with developed spatial dispersal synchronize their dispersal time with the dry season (72.7% for semachoric species and 63.6% for developed spatial dispersal species).

The most relevant results obtained from the study of relationships of seed mass (seed size) and germination traits among different plant growth forms in the hot hyper-arid desert of the UAE (Chapter 2), are related with 23 selected species (7.6% from the 302 species included in the chapter 1). They are belonging to 15 families and three growth forms (six herbaceous, 11 small shrubs and six trees). These species were selected based on the storage of seed in aerial seed bank (on maternal plants or soil surface). Growth forms had significantly affected ($P < 0.001$) seed size (length) and mass. Trees had larger and heavier seeds (mean: 0.62 cm and 8.64 g) as compared with both shrubs (mean: 0.32 cm and 0.93 g) and herbs (mean: 0.10 cm and 0.03 g).

There were significant effects ($P < 0.05$) for storage condition, growth form and light and temperature of incubation on final germination. Room temperature storage improved final germination (45.1%) compared to field storage (31.0%) and fresh seeds (30.9%). The overall germination of seeds of trees (46.0%) and herbaceous seeds (42.6%) were significantly greater than that of shrubs (23.0%). Overall germination in light (40.3%) was greater than it in darkness (29.0%). Moreover, germination for the 23 species was greater at moderate temperatures (20/30 °C: 36.0%) than at higher temperatures (25/35 °C: 33.2%).

The interaction between storage condition, growth form and light of incubation was significant ($P < 0.001$). Germination of fresh and room temperature-stored seeds of herbaceous plants was greater in light (52.6% and 87.2%, respectively) compared to that of the other two growth forms. However, germination of field-stored seeds of trees was significantly greater in both light and dark (60.9% and 47.4%, respectively) than in the other two growth forms.

Generally, in herbaceous plants, germination was significantly greater in light than in dark in seeds stored at different conditions. In both shrubs and trees, germination was greater in light (25.3% and 60.9%, respectively) than it in dark (18.1% and 47.4%, respectively) for field-stored seeds.

The interactive effect of storage condition and growth forms on GRI (germination rate index) was significant ($P < 0.01$). In trees, field-stored seeds germinated faster than both fresh and room temperature-stored seeds (GRI: 40.7, 35.3 and 35.0, respectively). In both herbaceous and shrub species, room temperature seeds germinated faster (GRI: 44.2 and 39.4, respectively) than fresh seeds (GRI: 32.4 and 28.3, respectively) and field-stored seeds (GRI: 38.6 and 35.6, respectively).

The relationship between seed mass and final germination was significantly positive in dark and negative in light conditions ($P < 0.01$). This means that large-seeded species germinated better in dark. In herbaceous plants, however, final germination had positive significant relationships with seed mass in both light and darkness ($P < 0.001$). Nevertheless, this relationship was significantly negative for shrubs ($P < 0.01$). In trees, this relation was

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significantly negative in light ($P < 0.001$), but not in dark. In trees, small-seeded species had higher dormancy in dark and lower dormancy in light.

Seed mass had significant negative relation with RLG (relative light germination) ($P < 0.001$) for seeds of both herbaceous and trees species but significant positive ($P < 0.001$) for seeds of small shrubs. Consequently, the small seeds of herbaceous and trees plants require more light for germination (RLG: 0.63 and 0.54, respectively), but small-seeded shrubs don't require light to germinate. In addition, there were significant positive relationships ($P < 0.001$) between GRI and seed mass of seeds of herbaceous plants but was negative for seeds of trees ($P < 0.01$). Therefore, germination speed was faster for bigger seeds of herbs but the reverse was true for the seeds of trees.

The results of the presence of bradychory (delayed seed dispersal) in the hyper-arid hot desert of the UAE (Chapter 3) showed that only 46 species out of 307 studies (15.0% of the total) were bradychoric species. Between the bradychoric species, we identified five bradychoric groups; species with persistent fruits which was predominant (28.3% of total species), followed by basicarpic species, gradually open capsules species, species with persistent lignified fruits (each of the last three groups were represented by 21.7% of total studied species) and species with schizocarpic fruits (6.5% of total species).

Among antitelechoric mechanisms, synaptospermy was the most common (37.0%) in bradychoric species followed by myxospermy (21.7%) and trypanocarpy (6.5%). In addition, bradychory was strongly related with myxospermy and synaptospermy ($P < 0.05$). All species with persistent fruits were synaptospermic species (13 species). Bradychoric species were mainly restricted dispersal species (31 species), 80.0% of basicarpic species and 90.0% of gradually open capsules species and 90.0% of species with persistent lignified fruits were restricted dispersal. However, within the 13 species with persistent fruits; six species were dispersed by biotic vectors and two by abiotic vectors. All schizocarpic species were developed spatial dispersal by abiotic vectors.

Bradychory was more common in perennial species (28), compared to annuals (11) and graminoids (7). Bradychory was related significantly with the growth form. All graminoids species had persistent lignified fruits. Among 28 perennials species; 13 species had persistent fruits and 8 were species open gradually their capsules. The annuals were mainly basicarpic species (63.0%).

Twenty-one species released their seeds in the dry season, compared to those released their seeds in rainy season (9 species) and through the year (16 species). The dry season was the main release time of species with persistent and schizocarpic fruits (53.7% and 100.0%, respectively).

The frequency of bradychoric species in the different habitats were 25, 23, 22 and 11 species in sand sheets, gravel plains, mountains and salt flats, respectively. The distribution of five bradychoric species groups was related significantly to habitat type ($P > 0.05$). All bradychoric species groups were represented in all habitats, except for species with persistent and schizocarpic fruits which were not present in salt flats. Species with persistent fruits were the most common in sandy sheets, mountains and gravel plains (36.0%, 36.4% and 43.5%, respectively). In salt flats, species retain their seed in dry persistent lignified fruits and those open gradually their capsules were predominant (45.5% and 36.4%, respectively).

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The results of the study of the effect of maturation time on dormancy and germination of *Citrullus colocynthis* (L.) Schrad. Seeds, a keystone species in the hot hyper-arid desert of the UAE (Chapter 4) indicated that there were significant effects (*P* < 0.001) of time of seed collection, temperature and light of incubation, and their interactions on final germination of *C. colocynthis* fresh seeds. Seeds collected in March didn't germinate at all. The overall germination of December collection (74.0%) was greater than it for seeds collected in April, June and October (52.0%, 27.8% and 36.7%, respectively). In addition, the germination increased with the increase in incubation temperature (15/25 °C: 13.6%, 20/30 °C: 38.4% and 25/35 °C: 44.0%) and was greater in dark (38.0% of total seeds) than in light (26.0%).

At 15/25 °C, seeds of all time collections didn't germinate in light and seeds of April collection didn't germinate in dark. In addition, seeds of June, October and December collections germinated to 22.0%, 34.0% and 100.0% in dark, respectively. In light, germination at 25/35 °C was significantly greater than at 20/30 °C for seeds collected in April, October and December by 150.0%, 43.0% and 41.0%, respectively. Interestingly, for December collection, germination reached almost 100.0% of total seeds at 25/35 °C in light but reached to the same level at 15/25 °C in dark. These results indicate that germination in light requires higher temperatures, but germination in darkness might be independent on temperature regime and depends more on the time of seed collection.

The effects of seed collection time and incubation temperature in addition to their interaction on germination rate index were significant (*P* < 0.001). Germination of all seed collections was significantly faster at 25/35 °C than at 20/30 °C for seeds of April, June, October and December collection by about 13.0%, 11.0%, 9.0% and 42.0%, respectively.

For seeds of all collections, there were negative correlations between final germination in light (*P* < 0.05) and dark (*P* > 0.05) and different seed traits, including seed length, width, mass and coat thickness. Seeds of March and June were bigger (0.80 cm and 0.78 cm), heavier (2.21 g and 2.38 g) and with thicker seed coat (0.31 mm and 0.30 mm) but attained significantly lower germination.

For seeds matured in March, storage for one year did not affect the dormancy; no germination occurred in both fresh seeds and those stored for one year (almost 0.0%). For seeds matured in December, there were significant effects for the main factors (seed storage, incubation temperature and light condition) and their interactions on final germination (*P* < 0.001). In general, storage resulted in the reduction of the germination (47.8% from 73.8%). In dark, germination of the stored seeds was reduced at 15/25 °C (39.0% from 100.0%) and at 25/35 °C (28.0% from 82.0%), compared to that of fresh seeds. Also, in light, germination was significantly greater in fresh (70.0%), compared to stored seeds (31.0%), at 20/30 °C. Neither physical scarification (scars in seed coat) nor water soaking resulted in any improvement in germination of March seeds.

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IV. DISCUSSION

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IV. DISCUSSION

The general discussion of the PhD study has been structured following the order of different chapters.

The general discussion begins with the discussion of the most relevant results of the study of dispersal traits in UAE hyper-arid hot deserts (Chapter 1). The results of this study show that the average and range of seed size variation in the 302 studied species are coincided with those reported in other studies in arid and semi-arid ecosystems (Jurado et al. 1991). In our study, the small diaspores were predominant. However, there were neither very small (log, 10^{-4}) nor very large diaspores (log, 10^{2}). Smaller diaspores have the ability to fall into soil cracks and avoid detection by predators (Gutterman 2002). Consequently, these seeds could form a long-lived seed bank in the desert, which enable species survival under the heterogeneous and unpredictable desert conditions (El-Keblawy et al. 2015b, El-Keblawy & Gairola 2017).

In temperate regions, barochoric species (species dispersal by barochory) are more frequent (Wang et al. 2009). However, in our study, semachoric species that lack dispersal structures that facilitate long-dispersal were most abundant (43.7% of the total species). Semachory help the seeds to stay near the mother plants, which in turn keep them in “safe sites” close to their maternal plant. Such strategy ensures seedling establishment (Rodriguez et al. 2017).

Many studies documented the relationship between dispersal modes and plant growth forms (Griz & Machado 2001, Navarro et al. 2009a, b). In the present study, the trees and large shrubs were barochoric species that produce large fleshy fruits or pods with nutritive structures. Around 68.5% of the semachoric species were herbaceous plants, which is consistent with the results found in other desert ecosystems (van Rheede van Oudtshoornand & van Rooyen 1999).

In present study, the restricted spatial dispersal was predominant (58.6% of total species). The species with restricted spatial dispersal were over-represented in herbaceous growth form (63.8%) and this result is consistent with what has been reported in other deserts (Ellner & Shmida 1981).

Dispersal mechanisms can be associated with climatic factors, especially water availability which could affect seed germination and seedling establishment in hyper-arid hot deserts (Jara-Guerrero et al. 2011). In our study, 25.1% of species disperse in the rainy seasons and they are mainly Sudano-Decanian barochoric species (Afro-Arabian species).

In the present study, the species dispersed by abiotic vectors (wind) were mainly dispersed in the dry season which is consistent with results reported in other climatic regions such as desert and Mediterranean regions (van Rooyen et al. 1990, Navarro et al. 2009a, b). Notably, most species that can disperse throughout the year were barochoric species. Generally, the species dispersed throughout the year have lower dormancy and can germinate at a wider range of environmental conditions that help seedling establishment at any time of the year (El-Keblawy 2017).

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Chapter 2, represents the main results of the study of seed mass (size) and germination traits related with different plant growth forms. The results of this chapter allow discussing the relationships between both seed mass and size, and germination among 23 studied species that have aerial or soil seed bank and belong to three growth forms. The tree species had biggest and heaviest seeds followed by the small shrubs then the herbaceous. However, fresh seeds of small shrubs and trees had lower germination than herbaceous plants. This means that the smaller-seeded species germinate more than larger-seeded species (Rees 1996). The small seeds of herbs were dispersed easily by wind to explore new sites that might be suitable for their seedling establishment in the unpredictable and heterogeneous deserts (El-Keblawy & Gairola 2017).

In herbaceous, large-seeded plants can germinate greater and faster in both light and dark more than small-seeded plants. This indicates that small-seeded herbs contribute their seeds to soil seed bank and distribute the risk of germination along time. However, the relatively more food reservoirs of larger seeds would encourage granivores to consume them, if they are stored in a soil seed bank (Wright et al. 2007). In addition, small-seeded herbs were germinated better in light, while large-seeded in darkness. Small seeds have little resources that limit seedling emerge from a deep soil (Bewley & Black 1994). However, food reserves in larger seeds enable them to emerge even from a deep soil (El-Keblawy 2017a).

In small shrubs, large-seeded species germinated less than small-seeded ones in both light and dark, and the large seeds germinated mainly in light. This indicates that larger seeds cannot germinate in the shade of their maternal plants and should be dispersed away from them (Venier et al. 2016). This mechanism would reduce the production of larger seedlings that could compete with the maternal shrubs.

In trees, the studied species adopted a strategy intermediate between small shrubs and herbs where species with large seeds germinated more in dark, but those with small seeds germinated better in light (Grime 1979). Five of the six trees had large seeds that are enclosed within fruit structures and have long distance zoochory dispersal. These species would disperse within the feces of grazing animals and consequently germinate in darkness within the feces or when feces buried in soil.

Many studies documented the significant effect of dry storage on seed dormancy of desert plants (Gutterman 2000). In the present study, the field storage didn’t improve seed germination of herb and shrub plants but improved it in seeds of trees. Four of the six studied trees belong to Fabaceae, which have seeds with physical dormancy. Under field conditions, physical dormancy of many species is broken down by sand drift scarification in addition to diurnal fluctuations in day and night moisture and temperatures (Moreno-Casasola et al. 1994).

Room temperature storage increased germination of seeds of herbaceous plants in light more than dark. In general, room temperature storage could mimic the natural conditions under litters and dead plants (El-Keblawy & Al-Rawai 2006). Greater light requirement of smaller seeds of herbs would ensure their germination after their dispersal away from the litters. The little resources available in small seeds could not be enough to secure seedling emergence from under the litters. Conversely, large resources available in larger seeds could help seedling establishment under such conditions (Wright et al. 2007).

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The more relevant results of the study of the species with delayed seed dispersal (bradychory) in the hot hyper-arid desert of the UAE (Chapter 3) agree with the importance of seed retention in desert plants (Gunster 1992, 1994). In our study, 15.0% of examined species were bradychorics. A similar proportion was reported in the central Namib Desert (13.0%) (Gunster 1992). However, bradychory reached 52.9% in the Moroccan High Atlas arid mountains and 33.5% in the SE Spain semi-arid shrublands vegetation (Navarro et al. 2009a, b). This indicates that the representation of bradychory is less in the hyper-arid hot desert than in the arid Mediterranean vegetation.

In the unpredictable arid deserts, bradychory can delay seed release until occurrence of favourable conditions (mostly rainfalls) for seed germination and seedling establishment (Gutterman & Ginott 1994). In the UAE, the rainfall is temporally unpredictable and usually restricted to short season. A total of 21 bradychoric species (46.0%) disperse their seeds in the dry season. These results could be explained in the light of the activity of granivores, which be less in the dry hot seasons than in moist cooler seasons of the year (Molokwu et al. 2010). In addition, the diurnal fluctuation in moisture and temperatures in the dry seasons would help in breaking seed dormancy (El-Keblawy & Bhatt 2015).

In the Negev Deserts, all bradychoric species (40 species) disperse their seeds in response to rainfalls (Gutterman & Ginott 1994). In our study, only nine species released their seeds in rainfall time. In Mediterranean climate of the Negev, rainfalls are more predictable and hence germination is predicted to happen in response to rainfalls (Gutterman 2002). In UAE deserts, however, if seeds dispersed and germinated in response to ineffective rainfall they might die before reaching the next seasons (El-Keblawy et al. 1997).

We recorded 25 bradychoric species in sandy sheets habitats which reflect the importance of bradychory in this habitat type (Liu et al. 2005). In sand habitat, sand drifts by winds are a major problem that would bury seeds and seedling deep in the soil (Glennie & Evamy 1968). Consequently, delaying seed dispersal in species of sand sheets would postpones seed dispersal till the end of windy seasons (Ma et al. 2010). Interestingly, many of the bradychoric species on sand dunes have erect habit that can adapt the sand burial on active sand dunes (Gunster 1992).

All the recorded bradychoric species in salt flats habitats had restricted spatial dispersal. This reflects the spatial adaptation of the halophytes to survive only in a very specific habitat type.

The bradychoric species group with persistent fruits was predominantly synaptospermics, which would improve seedling establishment and reduce diaspore losses through ant predation (Gutterman 2000, 2001).

Basicarpic species group was overspread in all studied habitats of the UAE. The basicarpy provide anchorage against surface run-off and protect diaspore from predators (Ellner & Shmida 1981). In our results, basicarpic species group includes annual and prostrate species, which agree with the results of other studies, such as Ellner & Shmida (1981), Navarro et al. (2009a) and Martínez-Berdeja et al. (2015).

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Finally, the main results of the study of the effect of maturation time on dormancy and germination of *Citrullus colocynthis* (L.) Schrad. seeds (Chapter 4) indicate that *C. colocynthis* seeds had good germination in both light and dark at high temperatures “20/30 °C and 25/35 °C”. At low temperature (15/25 °C), germination of all collections (October, December, March, April and June) was completely inhibited in light but ranged between 1.0% in dark for seeds of April collection to 100.0% for seeds of December collection. This result is coherent with many species of the Cucurbitaceae family, in which their seeds succeed to germinate at warm temperatures but fail to germinate at lower temperatures. In addition, seeds of Cucurbitaceae are negatively photoblastic as their germination is inhibited in light (Thanos & Mitrakos 1992). In *C. colocynthis*, seeds of June, October and December collections, but not those of March and April, were able to germinate in dark at the low temperature. This indicates that temperature requirement has a phylogenetic basis as well as maternally induced effect (Edelstein et al. 2001).

Time of seed development and maturation affects seed dormancy and germination of several species (Gutterman 2000). In *C. colocynthis*, seeds collected in March didn't germinate at all but seeds of December and April collections had highest germination among the other seed collections. The average temperatures during fruit development and maturation was cooler for fruits collected at early March (average minimum and maximum temperatures of January and February was 17.9 °C and 26.4 °C, respectively), compared to seeds matured at December (average minimum and maximum temperatures of November and December was 22.1 °C and 29.7 °C, respectively) and those matured at April (average minimum and maximum temperatures of March and April was 22.1 °C and 31.3 ºC, respectively). This indicates that the lower temperatures might be responsible for the great dormancy that has been observed in seeds of March collection. El-Keblawy et al. (2018) reached to a similar conclusion when they allowed seeds of *C. colocynthis* to mature under different light and temperature treatments. Their results indicated that seeds matured at lower temperatures had lower germinations, as compared with those matured at warmer temperatures.

Day length during seed development can affect seed coat structure and thickness (Giwa et al. 2010). In *C. colocynthis*, seeds matured during shortest days (December) and those matured at longer days (April, June and October) attained higher germination, whereas seeds of March that matured at day lengths intermediate between the other collections didn't germinate at all. This indicates that seed coat characters cannot explain the germination variation in *C. colocynthis*. However, in their experimental manipulation to the maturation day lengths, El-Keblawy et al. (2018) indicated that seeds matured in dark conditions germinated significantly greater than germinated under day/night light regimes.

In UAE, the physical scarification followed by soaking for 48 hours of *C. colocynthis* seeds increased the germination (Menon et al. 2014). However, in Negev Desert did not germinate under a wide range of experimental conditions (Koller et al. 1963). Koller et al. (1963) attribute the lower germination to the presence of an inner seed membrane. Similarly, our study indicated that neither physical scarification nor water soaking and their combination succeeded to stimulate the germination of dormant seeds of March collection.

In India, storage of *C. colocynthis* fresh seed reduced the germination after one year. This result might be related to the increasing of seed coat hardening that limited the gas exchange between the embryo and surrounding atmosphere (Mahajan & Kumawat 2013). In the present study, storage of December seeds resulted in a significant reduction in the dark germination at both low and high temperatures. Such result indicates that storage didn't affect seed viability but might change phytochrome sensitivity in dark (Casal & Sánchez 1998).

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CHAPTER 1

Dispersal traits in the hyper-arid hot desert of the United Arab Emirates (UAE)

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CHAPTER 1

Dispersal traits in the hyper-arid hot desert of the United Arab Emirates (UAE)

1.1. Introduction

Plant dispersal has an essential role in the colonization of new habitats, population dynamics as well as in species interactions and community structure and floral diversity (van der Pijl 1969, Howe & Smallwood 1982, Willson et al. 1990, Hughes et al. 1994, Morales & Carlo 2006). Plant dispersal mechanisms or dispersal modes (the movement or transport of seeds away from the parent plant) could also be considered as a key factor in conservation biology and restoration management (Strykstra et al. 2002, Navarro et al. 2009b, Jara-Guerrero et al. 2011). Seed size is an important ecological trait for seedling establishment, formation of a persistent seed bank, and dispersal. In addition, seed size variation between or within species has important ecological and evolutionary significance in plant dispersal (Westoby et al. 1992). Generally, large seeds increase the chance of seedling survival and establishment, while small seeds contribute more to forming seed bank (Thompson et al. 1993). Likewise, large seed tends to be desiccation-tolerant under climate constraints in drylands (Pritchard et al. 2004). Seed size is often associated with growth forms (Mazer 1989, Jurado et al. 1991, Lord et al. 1997), and dispersal mode (Ellner & Shmida 1981, Jurado et al. 1991, Navarro et al. 2009a, b). For example, large-seeded species are more likely to be animal dispersed, while small-seeded species are more likely to have unassisted seed dispersal (Leishman et al. 1995, Jurado et al. 2001, Navarro et al. 2009b).

The 'dispersal spectrum' is the frequency distribution of dispersal modes in a particular vegetation type (Howe & Smallwood 1982, Hughes et al. 1994). For several decades, researchers have been interested in studying of the dispersal spectra in different ecosystems (van der Pijl 1969, Frankie et al. 1974, Gentry 1982, Howe & Smallwood 1982, Navarro et al. 2006). In most studies, researchers are interested in assessing the relationship between the relative presence of dispersal modes in a particular site and the prevailing environmental conditions, such as temperature, precipitation, soil nutrient status or canopy structure (Willson et al. 1990, Bullock 1995).

Anthropogenic disturbance has negative effects on forests and the activity of animal dispersers (Daniels et al. 1995). The dominance of species with structures that facilitate spatial dispersal by abiotic vectors (e.g., wind) tends to increase with growing disturbances (Ganeshaiah et al. 1998, Nama & Kiran 2013). In addition, it has been commonly reported that long-distance seed dispersal is less frequent in arid and semi-arid habitats than in mesic habitats and traits constraining seed dispersal are common in arid and semi-arid floras (van der Pijl 1972, Ellner & Shmida 1981, van Rheede van Oudtshoorn & van Rooyen 1999, Navarro et al. 2009a). In this way, restrictions to seed dispersal have been widely used to explain the origin and maintenance of patches in arid vegetation (Kefi et al. 2008).

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Seed size is correlated with flowering time (Mazer 1989, Navarro et al. 2009a) and consequently, with dispersal phenology (Navarro et al. 2009a). In hyper-arid hot deserts, phenological events are mainly related to the amount and time of annual rainfall and soil moisture condition (El-Keblawy et al. 2015a). The earlier flowering allows for a longer development time of seeds, which would promote larger seeds (Mazer 1990). Conversely, the later flowering gives a good chance for using more resources (moisture conditions) for seed development, but shorter time available for seed maturation and dispersal (Roux et al. 2006).

To our knowledge, no studies exist that assess dispersal traits and dispersal phenology in the Arabian desert. This kind of studies is particularly important for comparative ecological studies and for developing scientific conservation initiatives (Finckh 2006). We expect that dispersal spectrum could be similar to those recorded in other arid floras with the particularity of the presence of Afro-Arabian floristic elements. We also expect variation of the dispersal traits in the different studied habitats. The aims of this study are to examine the variation of diaspore size (seed and fruit length) among: (1) growth forms, (2) absence/presence of structures facilitating long distance dispersal (spatial dispersal) (3) dispersal modes (4) APG IV phylogenetic taxonomic groups (5) phytogeography and (6) dispersal phenology in different habitats studied from the United Arab Emirates.

1.2. Material and Methods

1.2.1 *Study area*

The United Arab Emirates (UAE) are located in the south-eastern part of the Arabian Peninsula, between latitudes 22° 40' and 26° 00' north and longitudes 51° 00' and 56° 00' east, covering a total surface of 83.600 km^2. The UAE has a hyper-arid hot climate. The annual average temperature is approximately 27 °C and humidity 45.0%. There are two main seasons; a rainy season with mild temperatures from November to March, with a mean temperature around 20 °C and a dry hot season from April to October, with a mean temperature range between 35 - 40 °C that can reach 47 °C and humidity levels reaching more than 90.0%. The average amount of annual rainfall is around 110 mm with extreme variability in space and time and most of the rainfall occurring from January to April when temperatures are lowest (Böer 1997, UAE Ministry of Energy 2006, 2012, Sherif et al. 2009, UAE Ministry of Environment & Water 2015).

Our study is focused in inland forest and shrubland vegetation. Five different habitats were selected for this study: salt flats, gravel plains, sand sheets, mountains and high mountains (Jongbloed 2003, El-Keblawy et al. 2005, Karim & Fawzi 2007a, b). The sites were selected to cover the main geomorphologic conditions characterizing the UAE (Böer & Gliddon 1997, Jongbloed 2003). Salt flats (“sabkha”) separate the inland sandy areas and low Arabian Gulf coast. The salt flats region is dominated by *Zygophyllum qatarense* and *Salsola imbricata* with some frequent species such as *Heliotropium kotschyi*, *Fagonia ovalifolia*, *Arthrocnemum macrostachyum*, *Suaeda vermiculata*, *Halopeplis perfoliata* and *Anabasis setifera*. The gravel plains habitats are characterized by coarse sand and small rocky soils generally are dominated by *Acacia tortilis* mixed sometimes with *Prosopis cineraria* and *Calotropis procera*. Most of the land surface of the UAE desert is covered with sand, which consists of a mixture of low dunes, high dunes and intervening sand flats. Sand sheets are

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dominated by *Cyperus conglomeratus*, *Haloxylon salicornicum*, *Prosopis cineraria*, *Tribulus omanense* and *Zygophyllum qatarense*. In the central desert, which is dominated by low sand dunes, the water table is deep and abounds in *Citrullus colocynthis*, *Haloxylon persicum*, graminoids and some seasonal herbaceous plants such as *Stipagrostis plumosa*, *Cleome amblyocarpa* and *Eremobium aegyptiacum*. East of Dubai region, the sand sheets abound in *Leptadenia pyrotechnica*, *Calligonum comosum* and *Calotropis procera*.

The mountain habitats correspond to the Hajar Mountains series that extend from the UAE to the neighbouring Oman. Their elevations can reach more than 1000 m asl. The common shrubby species in the mountains is *Euphorbia larica*. In the running wadis, trees such as *Acacia tortilis* and *Prosopis cineraria* are dominant. On rocky hillsides (mountain), *Moringa peregrina*, *Pulicaria glutinosa* and *Ochradenus aucheri* grow in addition to other graminoids and annuals (e.g., *Cymbopogon commutatus* and *Reichardia tingitana*).

The high mountain habitats correspond to the North Mountains and are geologically distinct from the Hajar Mountains. They are sedimentary rocks, mostly carbonate with a peak at 2000 m asl. *Ficus johannis* grow in these mountains, while the high plateaux are covered with bushes (e.g., *Seriphidium herba-alba*). Some annual species, such as *Campanula erinus* grow in silt among the rocks.

1.2.2 *Species selection*

Field sampling and phenological observations were carried out monthly between May 2014 and October 2016. The selected species represent a cross-section of the flora of the arid/hyper-arid hot desert with xeric shrubland vegetation; importance was given to cover the most common and some rare species that characterize the vegetation (Jongbloed 2003, El-Keblawy et al. 2005, Karim & Fawzi 2007a, b).

We selected 30 sampling points (quadrates) per studied habitat which represent a total of 150 quadrates (Fig. 1.1, Appendix 1.1). The quadrate size was 200 m^2, in each quadrate the species dominance had been previously assessed with the relative importance values in which the abundance of the species has been estimated according to the Braun Blanquet scale (Braun-Blanquet 1928). We discarded all the species that were present in less than 10.0% of all the relevés available. The selected dominant species probably represent ca. 80.0% of the total cover in the five studied habitats. Voucher specimens of the most studied species were kept in the Sharjah Seed Bank and Herbarium, Sharjah Research Academy. Botanical nomenclature follows The International Plant Names Index (IPNI 2016). The family and class affiliation of each species used APG IV (Angiosperm Phylogenetic Group 2016).

1.2.3 *Dispersal, phenological and phytogeographical traits' measurements*

Seven easily measured dispersal traits were analysed: (1) dispersal mode which include anemo-meteochory, ombro-hydrochory, semachory, ballistic and barochory, (2) diaspore size (diaspore length), (3) dispersal unit (fruit or seed) (4) spatial dispersal (5) diaspore appendages (6) diaspore color, and (7) dispersal phenology (Appendix 1.2).

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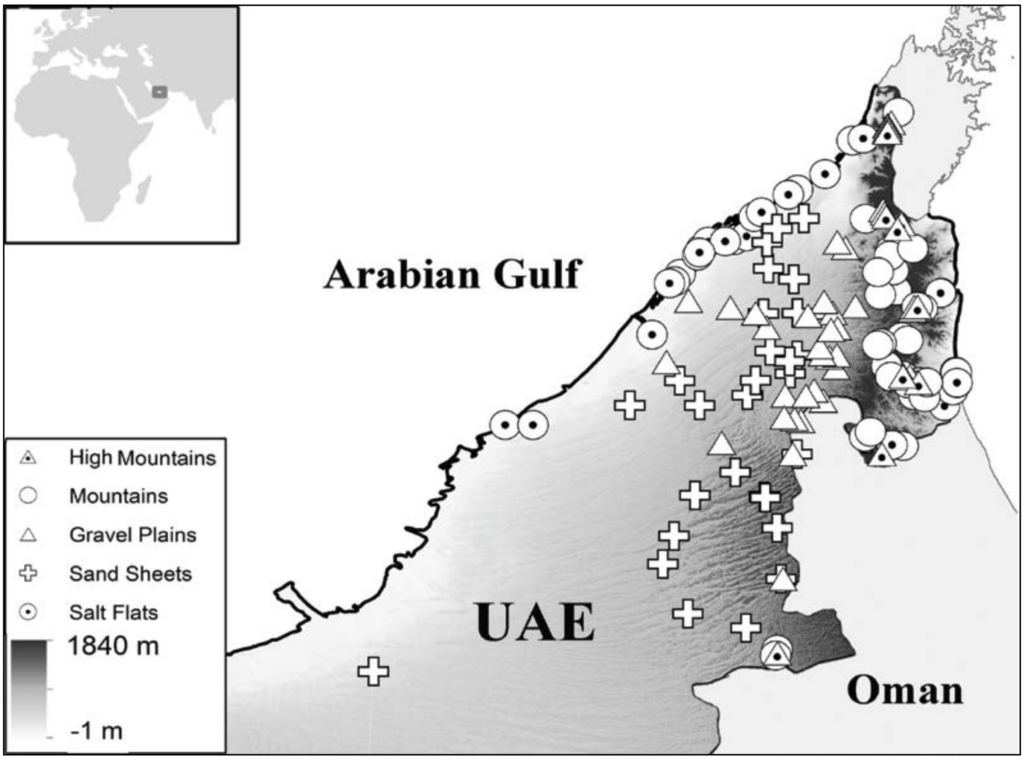
Among dispersal traits, the dispersal mode and diaspore size (diaspore length) constitute the main regenerative traits according to Cornelissen et al. (2003) and Pérez-Harguindeguy et al. (2013). Dispersal modes follow van der Pijl (1982). Whenever a diaspore

Figure 1.1. Illustration map for the 150 sampled quadrates in the study area from the hyper-arid hot desert of United Arab Emirates.



lent itself to more than one type of dispersal mode, the predominant form observed in more than 80.0% of sampling quadrates was generally used.

To measure diaspore size (diaspore length), diaspores were collected when ripe but before they started to fall off the plant. For each individual species, 100 diaspores were air-dried and their mean size was measured as the longest dimension (Cornelissen et al. 2003, Pérez-Harguindeguy et al. 2013). The achenes of Asteraceae were measured with the pappus. Exceptionally, when they were not available in the necessary quantities, the data were completed based on Flora databases (e.g., Flora of Pakistan 2016) and references (Miller & Cope 1996, Jongbloed, 2003, Boulos 2009).

The term diaspore was used to name the dispersal unit (Weiher et al. 1999). We scored whether species had diaspores equipped with structures that facilitate spatial dispersal (developed spatial dispersal), such as pappi, barbs or wings for dispersal by abiotic vectors (e.g., wind, developed dispersal by abiotic vectors) or fleshy fruits for dispersal by biotic vectors (e.g., vertebrates, developed dispersal by biotic vectors) (Ellner & Shmida 1981, Venable & Levin 1985, Cain et al. 2000). Species were considered as having restricted dispersal if diaspores lacked such dispersal-enhancing characters (restricted spatial dispersal) (Willson 1993). Anemo-meteochoric species have structures facilitating long-distance dispersal by abiotic vectors (e.g., wind); barochory species have fleshy fruits or pods with nutrients structures facilitating long-distance dispersal by biotic vectors (e.g., vertebrates);

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ombro-hydrochory, semachory and ballistic species lack structures facilitating long-distance dispersal. Diaspore appendage types were determined following Thomson et al. (2018) and based on the field observations. The color categories follow (Wheelwright & Janson 1985); black (including dark red), red (including pink), yellow, orange, brown, grey, green, white and blue (including purple).

To establish dispersal phenology (rainy or dry season), phenological surveys were performed for at least 2.5 years. In each year, the units of vegetation from each site were observed 10 - 12 times at approximately 30 - 45-day intervals. The onset of dispersal (the beginning of dispersal time) was described (Appendix 1.2).

Species were classified in ten growth forms following Cornelissen et al. (2003) and Pérez-Harguindeguy et al. (2013) (Appendix 1.2).

Species were classified on the basis of their biogeographical distribution in desert regions of the world (Good 1964, Evenari et al. 1985). The major phytogeographical regions were: the central Australian region, the western and central Asian region (Irano-Turanian region) (Eig 1931, 1932, Zohary 1973) and the African-Indian region (Saharo-Sindian region) (Eig 1931, 1932), where our study area is located. Following these authors nine phytogeographical regions were recognized in order to establish relationships between dispersal traits and species biogeography. Species, family, habitats, dispersal traits, phytogeography and dispersal phenology of the studied species are presented in the appendix 1.2.

1.2.4 *Data analyses*

One-way analysis of variance (ANOVA), followed by the post hoc comparisons (Tukey HSD test), were used to test the significance of differences ($P < 0.01$) of log diaspore size among APG IV groups and dispersal traits. Categories with less than seven species were excluded from the analyses. The association between nominal traits was determined with the Pearson χ^2 test-statistic. All statistical analyses were performed with SPSS 14 and SYSTAT 13.

1.3. Results

A total of 302 species, belonging to 51 families and 192 genera, were studied (Appendix 1.2). Fabaceae (12.6% of total species), Asteraceae (9.9% of total species), Poaceae (9.6% of total species) and Amaranthaceae (7.6% of total species) were the richest families. Fabaceae species were recorded in all habitats. Asteraceae were absent in salt flats and Poaceae and Amaranthaceae were absent from high mountains.

Eight phylogenetic APG IV groups were represented: Fabids (67 species, 22.2%), Basal Asterids (20.5%), Lamiids (17.5%), Malvids (14.6%), Commelinids (11.6%), Campanulids (11.3%), Monocots (1.7%) and Basal Rosids (0.7%). 82 species (27.2%) were exclusively Saharo-Arabian (SA) and Sudano-Deccanian (SD) species and were present in all habitats (Appendix 1.2).

A percentage of 53.6% of the studied species were woody species, 34.8% herbaceous and 11.6% graminoids species. The dominant growth form was dwarf shrubs (41.1%) followed by semi-basal herbs (21.9%) and tussocks (11.6%). The dispersal phenology of

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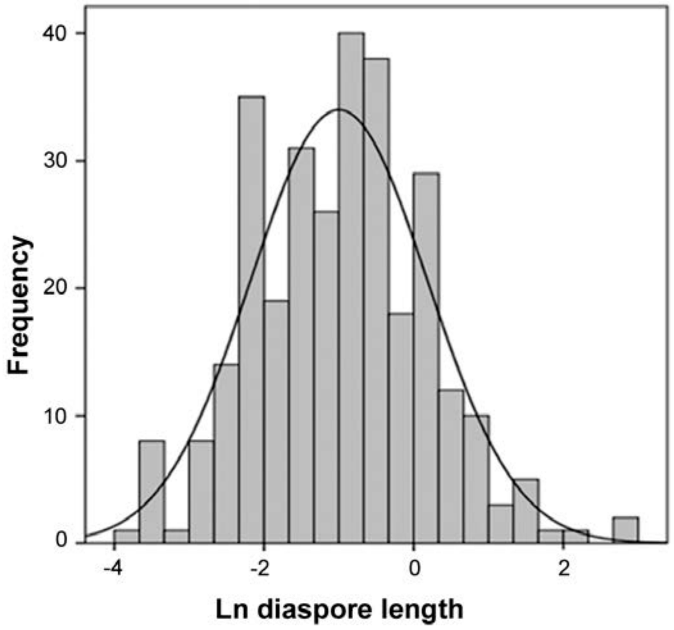
studied species was in the dry season (from April to October) (63.9% of total species) followed by the rainy season (from November to March) (32.1% of total species), and throughout the year (4.0% of total species) (Appendix 1.2).

The range of diaspore size (diaspore length) spanned six orders of magnitude from 10^{-4} to 10^{2} (Fig. 1.2). The diaspores mean size (length) 0.8 cm and ranged from 0.02 cm in *Sporobolus spicatus* (Poaceae) to 19.5 cm in *Prosopis juliflora* (Fabaceae).

Figure 1.2. Frequency of diaspore length (Ln) of studied species in the hyper-arid hot desert of United Arab Emirates.



1.3.1 *Dispersal spectrum*

Fruits (69.7%) were the dominant dispersal unit. Species with restricted spatial dispersal were more represented (58.6%), compared to species with developed dispersal by abiotic vectors (29.1%) or by biotic vectors (12.3%). The main dispersal mode was semachory (43.7%), followed by anemo-meteochory (28.8%), and barochory (23.8%).

Semachory was predominant in all studied habitats followed by anemo-meteochory and barochory, respectively (Fig. 1.3). Ballistic species were absent in salt flats, ombro-hydrochorics were absent in high mountains and zoochoric species were represented only in mountains, sand sheets and gravel plains.

The predominant diaspore color was brown (51.0%), followed by black (17.5%), green (11.9%), white (7.6%), yellow (6.3%), and reddish (4.0%).

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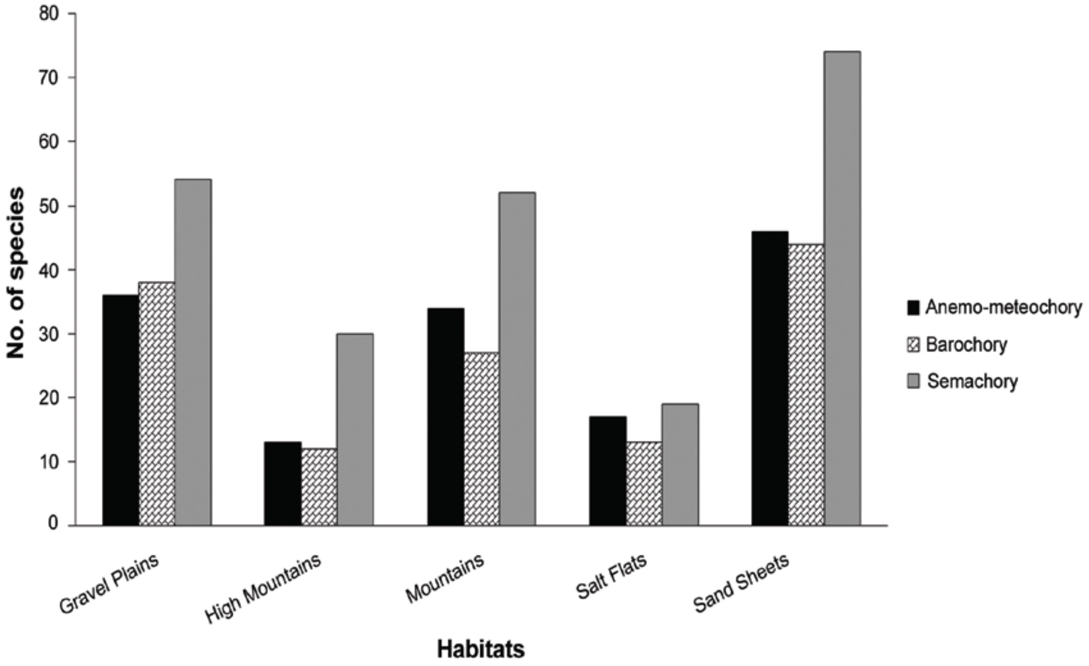
Figure 1.3. Frequency distribution of dispersal modes among species in the five studied habitats from the hyper-arid hot desert of United Arab Emirates.



A total of 60.0% of studied species lacked diaspore appendages. 48.0% of anemo-meteochoric species had winged appendages and 46.6% of them pappus. The anemo-meteochoric species with wings were dominant in sand sheets (33.3%) while species with pappus were dominant in gravel plains, mountains and sand sheets (27.6% in each habitat).

1.3.2. *Variation of diaspore size (diaspore length) among APG IV phylogenetic groups and dispersal traits*

The diaspore length differed significantly among the different APG IV phylogenetic taxonomic groups (F (5, 289) = 17.052; $P < 0.001$). The post hoc comparisons (Tukey HSD test) shows that the mean of diaspore length of Fabids (1.80 ± 0.41 cm) was significantly longer than Malvids (0.87 ± 0.20 cm), Campanulids (0.55 ± 0.05 cm), Lamiids (0.45 ± 0.07 cm), Basal Asterids (0.42 ± 0.06 cm) and Commelinids (0.30 ± 0.08 cm). Fabids and Malvids had the largest diaspores (e.g., *Prosopis juliflora*, 19.5 cm and *Cleome amblyocarpa*, 6.0 cm), while Commelinids had the smallest diaspores (e.g., *Sporobolus spicatus*, 0.02 cm) (Fig. 1.4A, Table 1.1).

Diaspore length differed significantly among growth forms (F (6, 289) = 13.012; $P < 0.001$). The post hoc comparisons (Tukey HSD test) shows that the mean of diaspore length of tussocks (0.30 ± 0.08 cm) was significantly lower than that of dwarf shrubs (0.74 ± 0.07 cm), short basal (prostrate) (0.77 ± 0.20 cm), shrubs (1.40 ± 0.43 cm) and trees (3.85 ± 1.76 cm). This means, trees had the largest diaspore size (e.g., *Prosopis juliflora*, 19.5 cm), while tussocks had the smallest sizes (e.g., *Sporobolus spicatus*, 0.02 cm and *Cenchrus ciliaris*, 0.03 cm) (Fig. 1.4B, Table 1.1).

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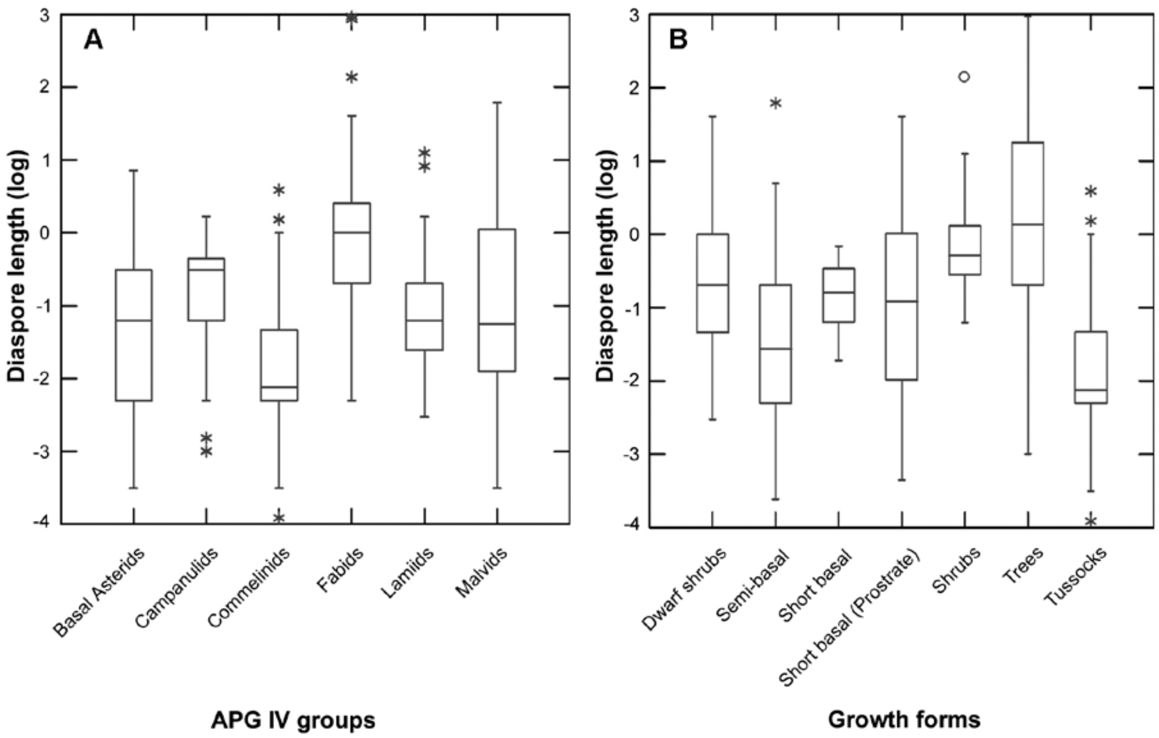
Figure 1.4. Diaspore length variation among A, APG IV phylogenetic taxonomic groups and B, growth forms of studied species from the hyper-arid hot desert of United Arab Emirates. (Cornelissen et al. 2003 and Pérez-Harguindeguy et al. 2013).



Diaspore length differed significantly among the different dispersal modes (F (2, 288) = 39.720; *P* < 0.001). The post hoc comparisons (Tukey HSD test) shows that the mean of diaspore length of semachoric species (0.37 ± 0.04 cm) was significantly lower than that of the anemo-meteochoric (0.69 ± 0.07 cm) and barochoric species (1.77 ± 0.39 cm). Barochoric species (e.g., *Prosopis cineraria*, 18.8 cm) were the largest, while semachoric species (e.g., *Tillaea alata*, 0.027 cm) were the smallest (Fig. 1.5A, Table 1.1).

Diaspore length differed significantly according spatial dispersal (F (2, 299) = 42.590; *P* < 0.001). The post hoc comparisons (Tukey HSD test) shows that the mean of diaspore length of species dispersed by developed biotic vectors (2.52 ± 0.71 cm) was significantly longer from the species dispersed by developed abiotic vectors (0.68 ± 0.07 cm) and species with restricted spatial dispersal (0.47 ± 0.06 cm). Species dispersed by biotic vectors (e.g., *Prosopis cineraria*, 18.8 cm and *Calligonum comosum*, 1.2 cm) had the larger diaspore size than those dispersed by abiotic vectors (e.g., *Pulicaria undulata*, 0.3 cm) and species with restricted spatial dispersal (e.g., *Reseda aucheri*, 0.08 cm) (Fig. 1.5B, Table 1.1).

Diaspore length differed significantly according absence or presence of appendages (F (3, 271) = 2.956; *P* < 0.05). Species lacking appendages facilitating long-distance dispersal had longer diaspores (Fig. 1.5C, Table 1.1).

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Table 1.1. Mean and standard error (SE) of nine traits studied in the 302 plant species from the hyper-arid hot desert of United Arab Emirates. Nine traits are: APG IV, growth forms, spatial dispersal, dispersal mode, absence/presence of appendage types, diaspore color, phytogeographical regions, habitats and dispersal phenology.

Trait	**Category**	**Mean ± SE**	**Trait**	**Category**	**Mean ± SE**
APG IV	Basal Asterids	0.42 ± 0.06	Diaspore color	Black	0.20 ± 0.02
	Campanulids	0.55 ± 0.05		Brown	0.80 ± 0.09
	Commelinids	0.30 ± 0.08		Green	0.67 ± 0.09
	Fabids	1.80 ± 0.41		Red	0.65 ± 0.12
	Lamiids	0.45 ± 0.07		White	0.73 ± 0.21
	Malvids	0.87 ± 0.20		Yellow	2.74 ± 1.34
Growth forms	Dwarf shrubs	0.74 ± 0.07	Phytogeographical regions	Cosm	0.40 ± 0.17
	Semi-basal	0.41 ± 0.10		SA	0.35 ± 0.06
	Short basal (prostrate)	0.77 ± 0.20		SA, IT	0.67 ± 0.09
	Trees	3.85 ± 1.76		SA, IT, Med	0.43 ± 0.07
	Shrubs	1.40 ± 0.43		SA, IT, SD, Med	0.68 ± 0.14
	Short basal	0.47 ± 0.06		SA, Med	0.51 ± 0.08
	Tussocks	0.30 ± 0.08		SA, SD	1.24 ± 0.27
Spatial dispersal	Restricted spatial dispersal	0.47 ± 0.06		SA, SD, IT	1.27 ± 0.71
	Developed dispersal by abiotic vectors	0.68 ± 0.07		SA, SD, Med	0.65 ± 0.22
	Developed dispersal by biotic vectors	2.52 ± 0.71	Habitats	Mountains	0.64 ± 0.08
Dispersal mode	Semachory	0.37 ± 0.04		Gravel Plains	0.86 ± 0.17
	Anemo-meteochory	0.69 ± 0.07		Sand Sheets	0.96 ± 0.17
	Barochory	1.77 ± 0.39		Salt Flats	0.83 ± 0.39
Absence/presence of appendage types	Absence	0.85 ± 0.15		High Mountains	0.65 ± 0.10
	Pappus	0.57 ± 0.05	Dispersal phenology	Dry	0.78 ± 0.12
	Spine	0.60 ± 0.09		Rainy	0.61 ± 0.09
	Wings	0.68 ± 0.08		All the year	2.34 ± 1.58

Diaspore length differed significantly according to diaspore color (F (5, 289) = 9.408; *P* < 0.001). The post hoc comparisons (Tukey HSD test) shows that the mean diaspore length of black diaspores (0.20 ± 0.02 cm) was significantly lower than the red (0.65 ± 0.12 cm), green (0.67 ± 0.09 cm), white (0.73 ± 0.21 cm), brown (0.80 ± 0.09 cm) and yellow diaspores (2.74 ± 1.34 cm). Species with green and yellow diaspores (e.g., *Prosopis juliflora*, 19.5 cm and *Rhynchosia schimperi*, 2.1 cm, respectively) were the largest, while black diaspores (e.g., *Polycarpaea repens*, 0.03 cm) were the smallest (Fig. 1.5D, Table 1.1).

Diaspore length differed significantly among the different phytogeographical regions (F (8, 293) = 3.672; *P* < 0.001). The post hoc comparison (Tukey HSD test) shows that the

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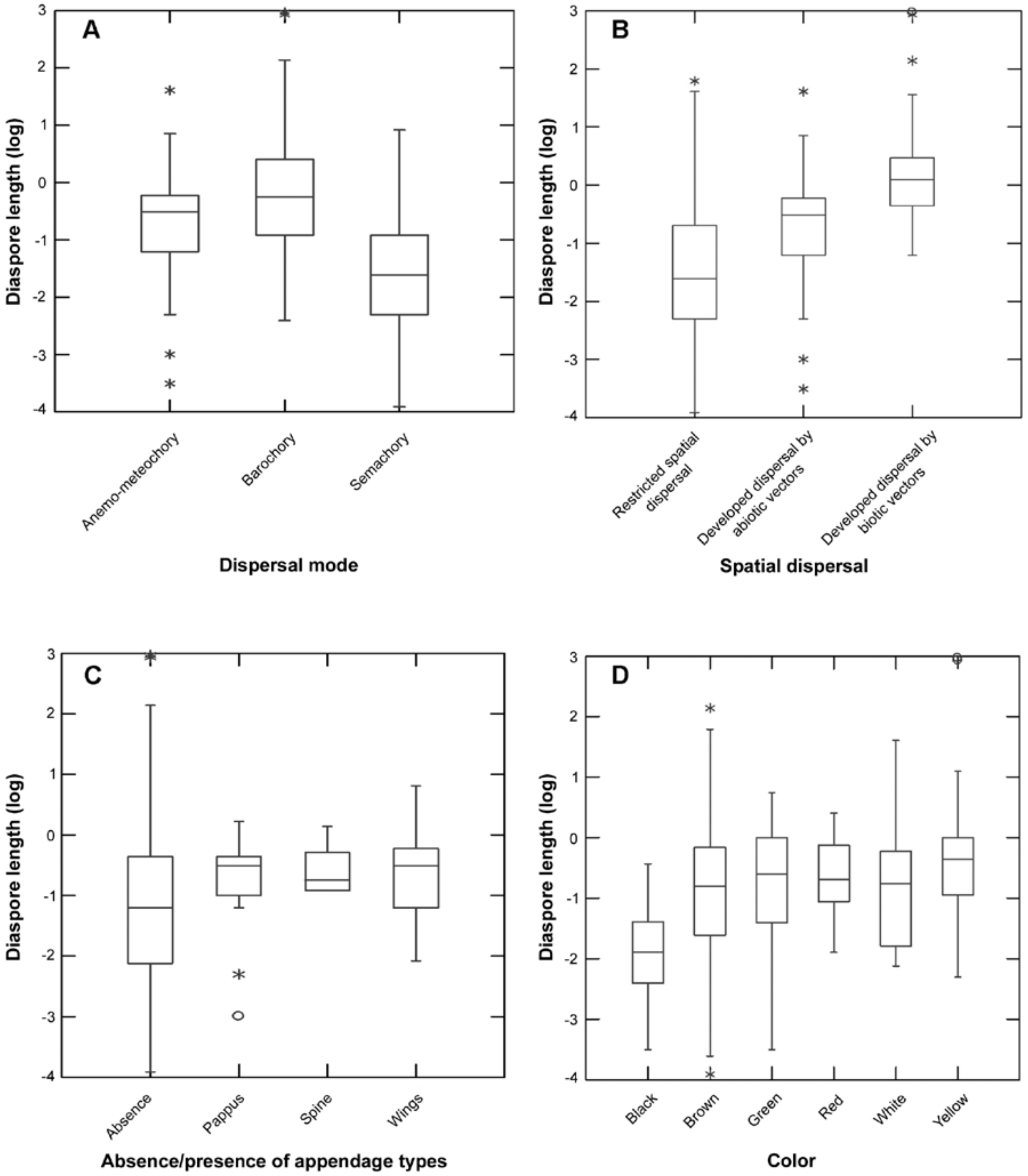
Figure 1.5. Diaspore length variation among dispersal traits in the studied species from the hyper-arid hot desert of United Arab Emirates. A, dispersal mode; B, spatial dispersal; C, absence/presence of appendage types; D, diaspore color.



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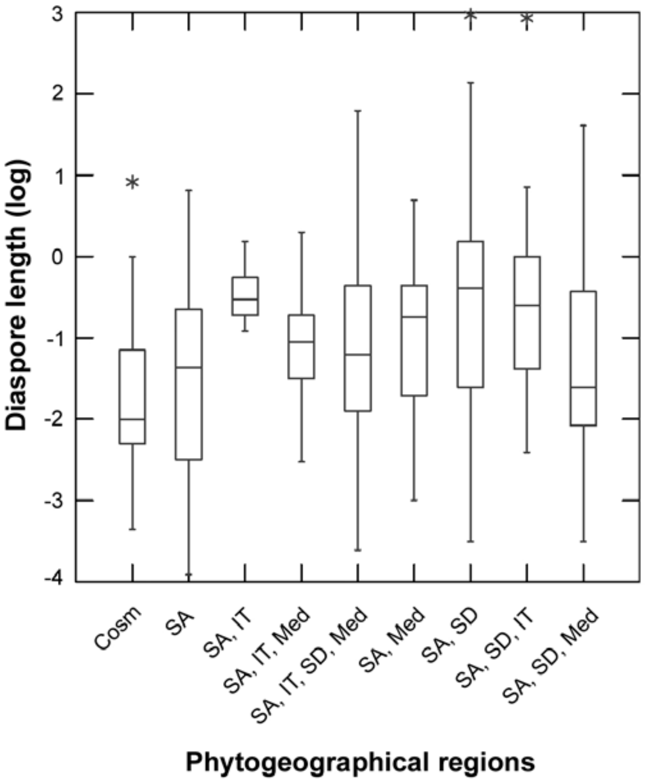
mean of diaspore length of species belongs to Saharo-Arabian and a Sudano-Deccanian region (1.24 ± 0.27 cm) was significantly bigger than to Cosmopolitan (0.40 ± 0.17 cm) and Saharo-Arabian species (0.35 ± 0.06 cm). Saharo-Arabian and Sudano-Deccanian species (e.g., *Acacia ehrenbergiana*, 8.5 cm) had the largest seeds, while Saharo-Arabian and *Cosmopolitan species* had the smallest (e.g., *Limeum indicum*, 0.02 cm) (Fig. 1.6, Table 1.1).

Figure 1.6. Diaspore length variation among phytogeographical regions of studied species from the hyper-arid hot desert of United Arab Emirates. Phytogeographical regions: Cosm, Cosmopolitan; IT, Irano-Turanian; Med, Mediterranean; SA, Saharo-Arabian; SD, Sudano-Deccanian.



No significant difference was observed in diaspore length among habitat types (F (4, 527) = 0.581; $P < 0.676$) or among dispersal phenology (F (2, 299) = 1.233; $P < 0.293$).

1.3.3. *Relationships between dispersal modes, APG IV phylogenetic groups, growth forms and dispersal phenology*

There were significant relationships between APG IV phylogenetic taxonomic groups and dispersal modes ($\chi^2 = 119.354$; df = 10; $P < 0.001$) (Fig. 1.7A). Barochory was more common in Fabids and absent in Campanulids (Fig. 1.7A). In addition, anemo-meteochory was over-represented in Basal Asterids and Campanulids (Fig. 1.7A). Semachory was predominant in Lamiids, Commelinids and Malvids (Fig. 1.7A).

Significant relationships were detected between dispersal modes and growth forms ($\chi^2 = 79.427$; df = 12; $P < 0.001$, Fig. 1.7B). Semachory was more represented in herbaceous species, such as semi-basal, prostrate herbs and tussock graminoids. Barochory was predominant in trees and shrubs (Fig. 1.7B). Anemo-meteochory was over-represented only in dwarf shrubs (Fig. 1.7B).

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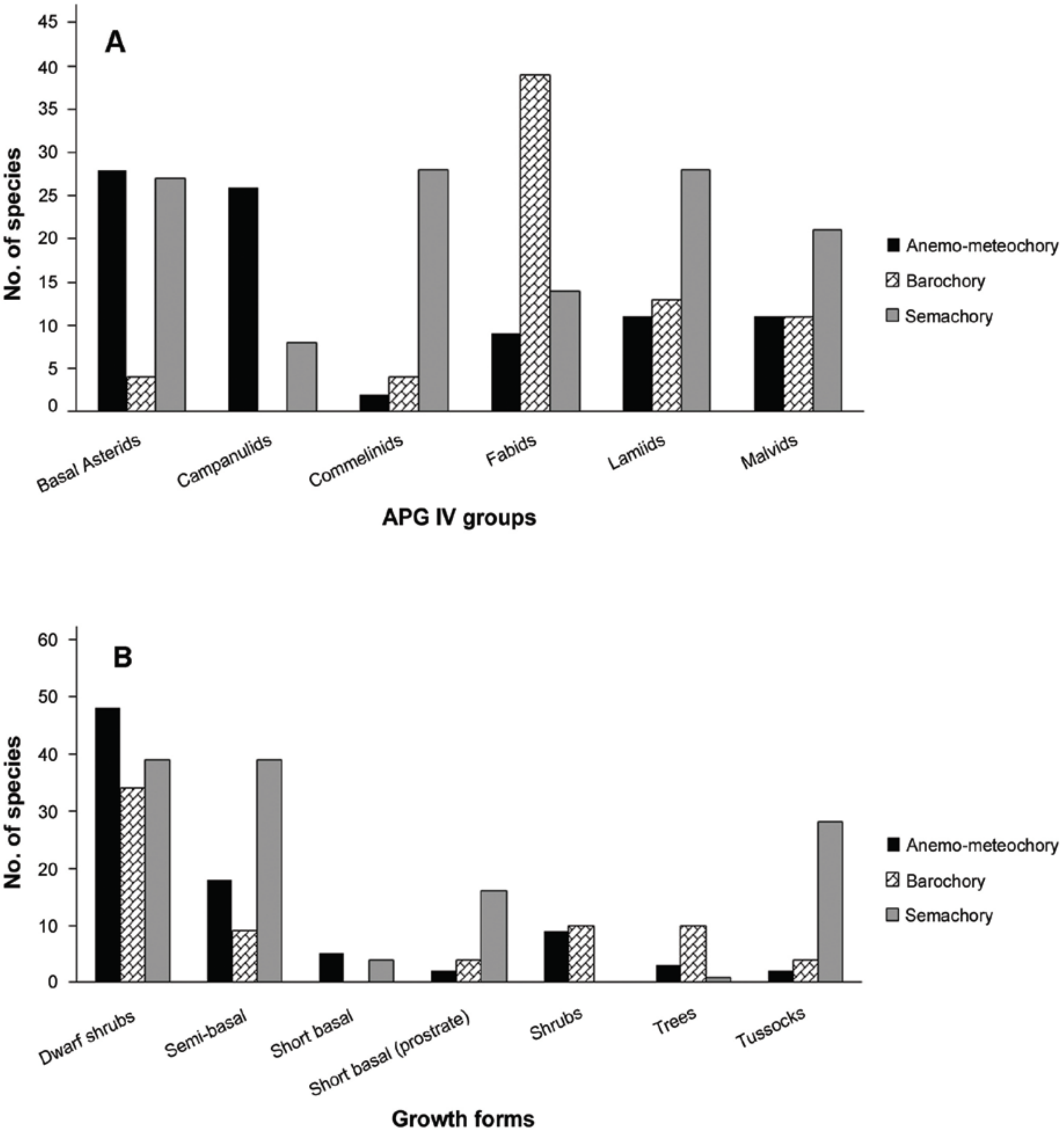
Figure 1.7. Frequency distribution of dispersal modes among APG IV phylogenetic groups and growth forms of studied species from the hyper-arid hot desert of United Arab Emirates.



Significant relationships were detected between dispersal modes and dispersal phenology ($\chi^2 = 15.506$; df = 4; $P < 0.01$). Dispersal was concentrated in dry season (Fig. 1.8, Appendix 1.2).

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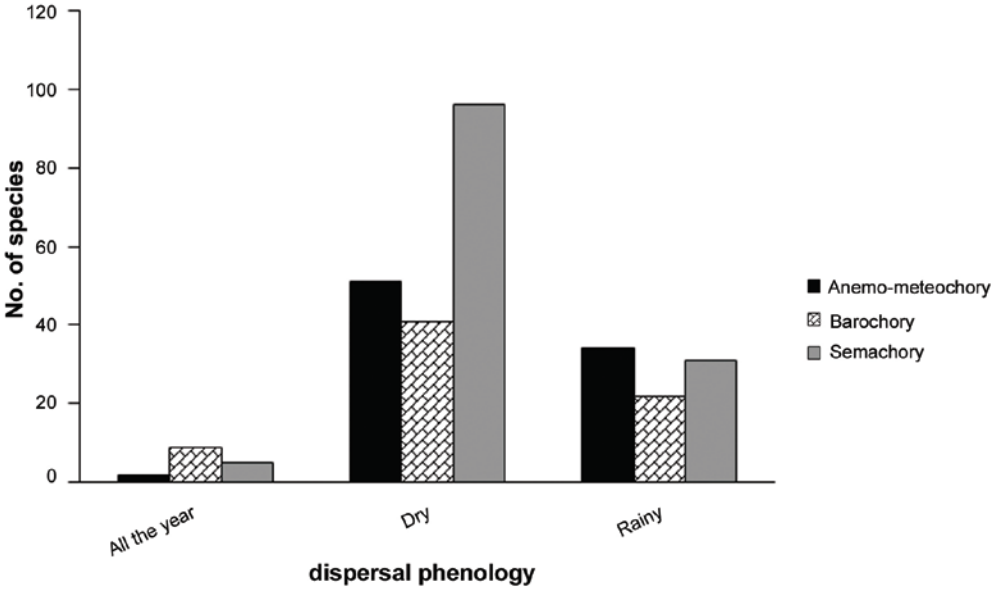
Figure 1.8. Frequency distribution of dispersal modes among dispersal phenology of studied species from the hyper-arid hot desert of United Arab Emirates.



1.3.4. *Relationships between spatial dispersal, APG IV phylogenetic groups, growth forms, phytogeography and dispersal phenology*

There were significant relationships between APG IV phylogenetic taxonomic groups and the spatial dispersal ($\chi^2 = 119.998$; df = 10; $P < 0.001$) (Fig. 1.9A). Restricted spatial dispersal was the most common in all phylogenetic taxonomic groups except for Campanulids, in which developed dispersal by abiotic vectors was over-represented (Fig. 1.9A). Developed dispersal by biotic vectors was present only in Lamids, Malvids and Fabids (Fig. 1.9A).

Significant relationships were detected between the spatial dispersal and growth forms ($\chi^2 = 92.054$; df = 12; $P < 0.001$) (Fig. 1.9B). Restricted spatial dispersal was overrepresented in herbaceous species and dwarf shrubs (Fig. 1.9B). Developed dispersal by biotic vectors was mainly prevalent in trees (Fig. 1.9B), while developed dispersal by abiotic vectors was over represented only in shrubs (Fig. 1.9B).

Significant relationships were detected between the spatial dispersal and species phytogeographical distribution ($\chi^2 = 48.268$; df = 16; $P < 0.001$) (Fig. 1.10). Developed dispersal by biotic vectors were mainly associated with Sudano-Decanian species (Fig. 1.10), which are species forming part of African vegetation in the study area. Saharo-Arabian species were exclusively restricted dispersal and they were dominant species in all regions except in the Saharo-Arabian and Irano-Turanian region.

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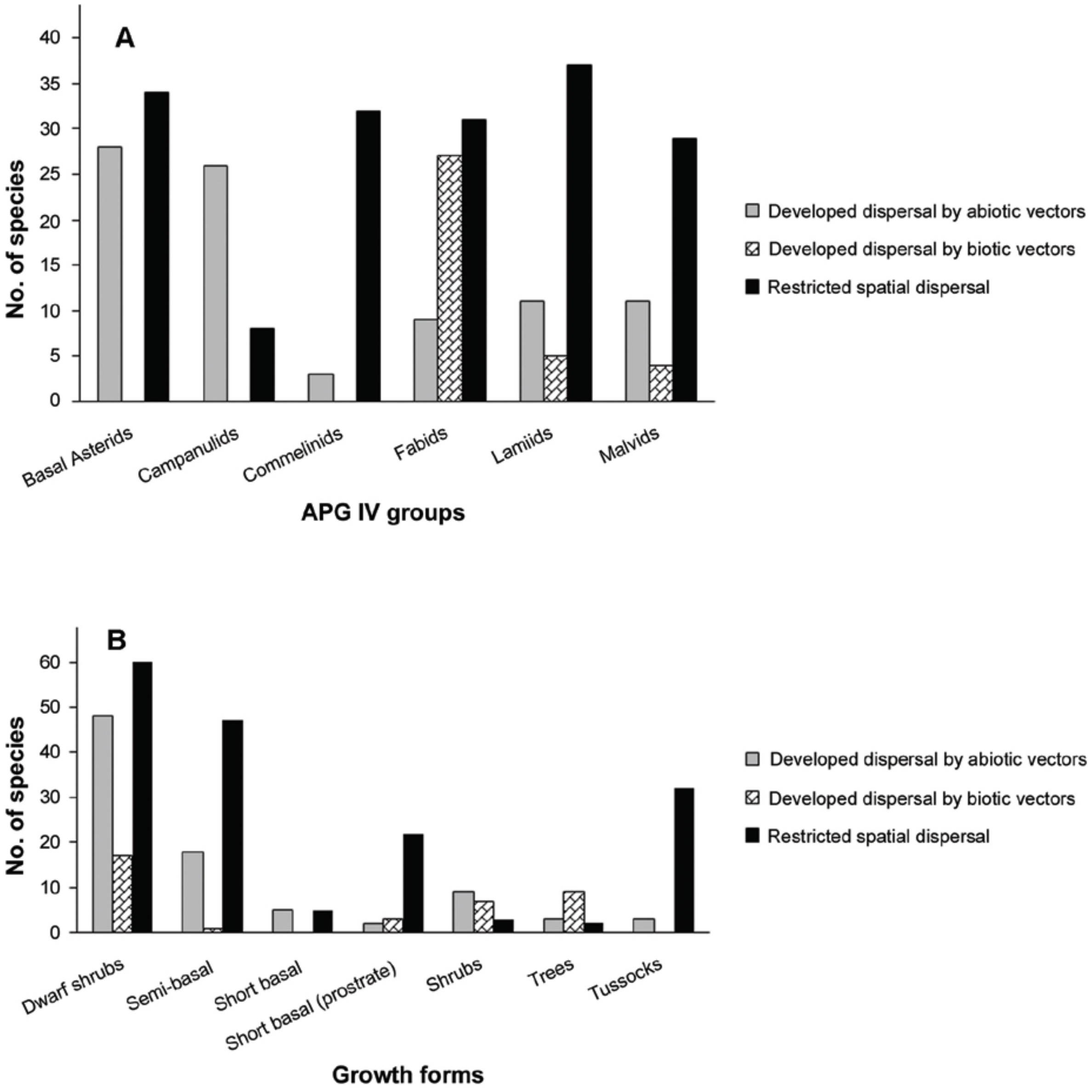
Figure 1.9. Frequency distribution of spatial dispersal among APG IV phylogenetic groups and growth forms of studied species from the hyper-arid hot desert of United Arab Emirates.



Significant relationships were detected between the spatial dispersal and dispersal phenology ($\chi^2 = 15.644$; df = 4; $P < 0.004$). A total of 63.6% of the species with developed spatial dispersal dispersed in the dry season from April to October (Fig. 1.11).

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Figure 1.10. Frequency distribution of spatial dispersal among phytogeographical regions of studied species from the hyper-arid hot desert of United Arab Emirates. Phytogeographical regions: Cosm, Cosmopolitan; IT, Irano-Turanian; Med, Mediterranean; SA, Saharo-Arabian; SD, Sudano-Deccanian.

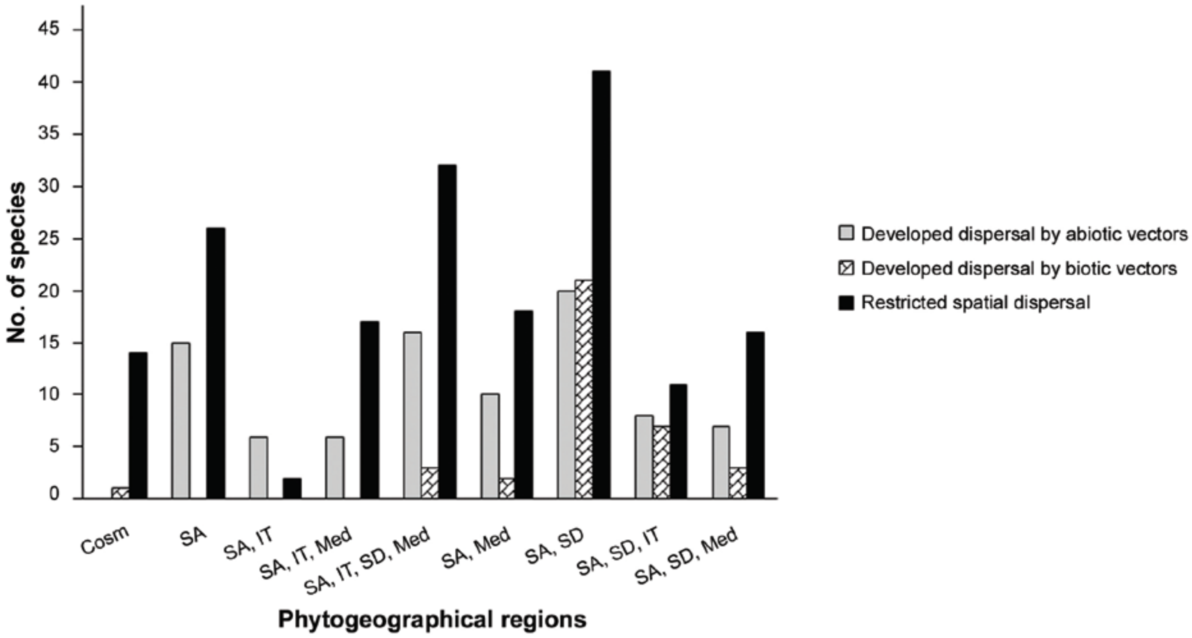
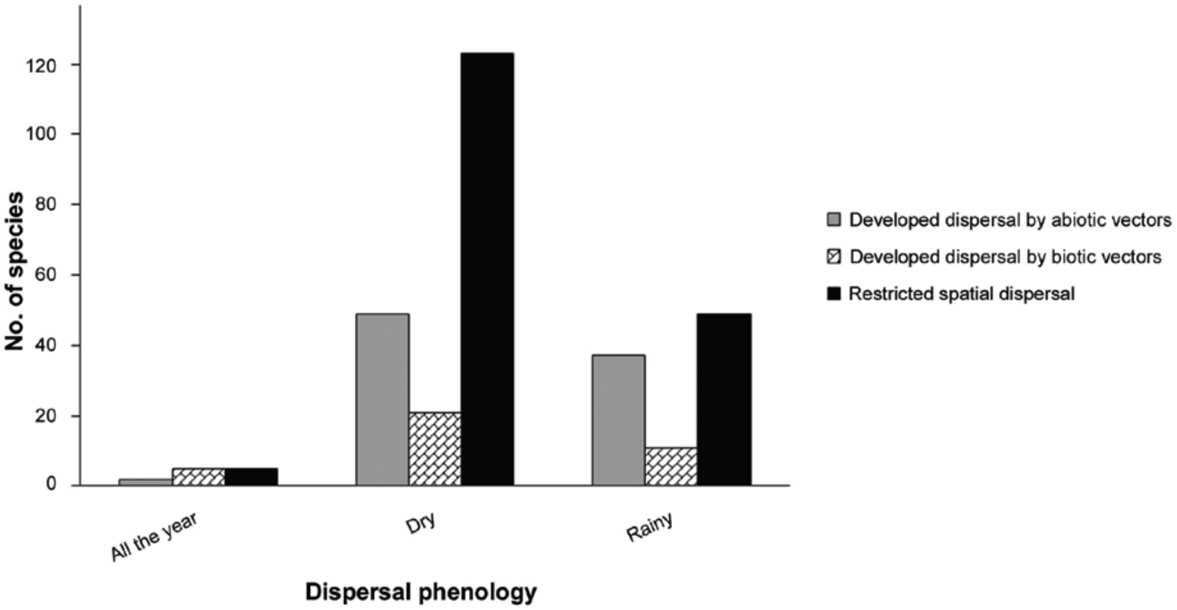


Figure 1.11. Frequency distribution of spatial dispersal among dispersal phenology of studied species from the hyper-arid hot desert of United Arab Emirates.



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1.4. Discussion

The range of seed size variation in the studied species in the hyper-arid hot UAE deserts coincides with that found in other arid and semi-arid ecosystems (Jurado et al. 1991, 2001, Leishman et al. 2000, Navarro et al. 2006, 2009b). However, in the UAE deserts, there were no very small (log, 10^{-4}) or very large diaspores (log, 10^{2}). Harel et al. (2011) reported that seed size significantly decreased with increasing aridity and rainfall variability in seven out of fifteen sites in the hot Negev Desert. Our results are in agreement with previous studies that indicate that the largest diaspores were represented in the Fabaceae family while the smallest diaspores were found in Poaceae (Mazer 1989, Liu et al. 2014). The advantage of small seeds is a lower risk of being eaten by predators (Hulme 1994, van Rheede van Oudtshoorn & van Rooyen 1999); their small size enables them to fall into soil cracks and consequently avoid detection by predators (Gutterman 2002). This indicates that small seeds could form a long-lived seed bank in the desert, which ensures species survival under the heterogeneous and unpredictable desert conditions. However, the small reserves in the small seeds would not help them to emerge from deep soil unless some kind of disturbance happens (El-Keblawy et al. 2015b, El-Keblawy & Gairola 2017, El-Keblawy 2017). On the other hand, small seeds tend to be desiccation-sensitive seeds that germinate rapidly because delayed germination can induce seed death (Pritchard et al. 2004), as is the case of the ombro-hydrochoric species.

The seed dispersal spectrum of the studied hyper-arid hot desert in the UAE was characterized by the dominance of semachory (43.7%), followed by anemo-meteochory (28.8%) and barochory (23.8%). Nevertheless, semachory/barochory is the largest group (67.5%). Other species in the Amaranthaceae, Zygophyllaceae, Brassicaeae and Poaceae families were semachores, just like other species in the Fabaceae and Zygophyllacae families were barochores with larger seeds that can take full advantage of the favorable surrounding conditions and germinate fast and to high levels (Liu et al. 2014). About 68.5% of the semachoric species were herbaceous, which is consistent with other desert ecosystems (van Rheede van Oudtshoorn & van Rooyen 1999). Zoochory has been described as the most dominant mechanism (more than 80.0%) in humid and dry tropical forests (Fleming 1979, Gentry 1982), but its presence decreases in ecosystems with dryer climates (Gentry 1982). In temperate areas, barochoric species are significantly more frequent than anemo-meteochoric and zoochoric species (Leishman et al. 1995, Wang et al. 2009). However, semachoric species lacking long-dispersal structures, are more frequent in our study area helping the seeds to stay near the mother plants, which could be considered as “safe sites” for seedling establishment (van Rheede van Oudtshoorn & van Rooyen 1999, Rodriguez et al. 2017). Only three of the studied species were zoochoric (the epizoochoric *Tragus racemosus* and *Medicago* sp.). The low frequency of epizoochory could reflect the low presence of mammals in the harsh desert conditions .

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Several studies have reported a relationship between dispersal syndromes and plant growth forms (van der Pijl 1969, Frantzen & Bouman 1989, Willson et al. 1990, Griz & Machado 2001, Navarro et al. 2009a, b). Anemo-meteochory was predominant in dwarf shrubs and shrubs in the tropical dry forest (Griz & Machado 2001) and in the Mediterranean dry shrublands (Navarro et al. 2009b). In our study, trees and large shrubs are barochoric species that produce large fleshy fruits or pods with nutritive structures (e.g., *Acacia* sp., *Indigofera* sp., *Prosopis* sp. and *Ziziphus* sp.) dispersed secondarily by vertebrates (Jurado et al. 1991, 2001, Leishman & Westoby 1994). Westoby et al. (1992) have proposed that diaspore size tends to be associated with plant size and the longevity of trees and large shrubs of unfavorable habitats (Puigdefábregas & Pugnaire 1999) with desiccation-tolerant seeds (Pritchard et al. 2004).

In the desert region, restricted spatial dispersal is more dominant than developed spatial dispersal and was more represented in herbaceous and graminoids than woody species (Ellner & Shmida 1981). These species can survive in situ, with regeneration and plant recovery in extreme and hard climatic conditions (Gutterman & Shem-Tov 1997, van Rheede van Oudtshoorn & van Rooyen 1999). The graminoids living preferably in the gravel plains and mountains having appendages which enable them to be effectively dispersed by the wind, pass through the cracks of the biological soil crusts, and settle down, such as *Stipa* sp., *Stipagrostis* sp. and *Aristida* sp., which could take a special way named “active drill” into soil cracks using mucrons (Schöning et al. 2004, García-Fayos et al. 2013). Brassicaceae, Lamiaceae and Scrophulariaceae herbaceous species are mainly restricted spatial dispersal species with relatively small seeds, as found in other arid regions (Navarro et al. 2009a, b). Efficient spatial dispersal is associated with the presence of morphological structures favors long-distance dispersal by the wind such as hairy capsules (e.g., *Aerva javanica*), winged calyx (e.g., *Astragalus squarrosus*), wings (e.g., *Tribulus* sp.) or pappus in the Asteraceae species .

Dispersal mechanisms can be associated with climatic factors (Gentry 1982, Wikander 1984, Griz & Machado 2001, Navarro et al. 2009b, Jara-Guerrero et al. 2011), and most probably with the temporal patterns of water availability. These factors have the largest impact on plant propagation in hyper-arid hot desert as in other hot dry regions (Griz & Machado 2001). In the savannas of west Africa, strong relationships were found between fruiting and soil moisture, which may reflect a selection of dispersal periods that maximizes seed dispersion and germination (Seghieri et al. 2009). In our study, 25.1% of species disperse in the rainy seasons and they are mainly Sudano-Decanian barochoric species (Afro-Arabian species) (Appendix 1.2), which form part of the savanna vegetation.

The results of our study showed that species dispersed by abiotic vectors (wind) have a dispersal peak in synchronization with the dry season, as found in other regions with climatic restrictions, such as Mediterranean (Navarro et al. 2009a, b), desert (van Rooyen et al. 1990) and dry tropical regions (Machado et al. 1997, Griz & Machado 2001).

Continuous patterns of dispersal throughout the year were observed in some of the studied species (e.g., *Citrullus colocynthis*). This indicates an important seed supply to occur in the ecosystems that are characterized by seasonal variation and where a rainfall could be expected at any time of the year (Machado et al. 1997). These species correspond to barochoric species with large fleshy fruits (e.g., *Ziziphus* sp., *Solanum* sp.) or pods with nutrient structures (e.g., *Senna italica*, *Indigofera* sp., *Tephrasia* sp.). Interestingly, species that can disperse throughout the year have lower dormancy and are able to germinate at a wider range of environmental conditions; consequently, they can contribute to seedling recruitment at any time of the year (El-Keblawy 2017).

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1.4.1. *Conclusions*

To conclude, the observed patterns suggest that the seed dispersal spectrum of the hyper-arid hot desert of UAE follows the general patterns of arid and desert ecosystems with some particularities due to the UAE floristic richness explained by the presence of African floristic elements. Seed/fruit availability is limited by fruiting seasonality in altered habitats. In general, diaspore characteristics were closely related to phylogeny, dispersal modes and growth forms and these characteristics allowed the plants to adapt to extreme hot desert environments.

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1.6. Appendices

Appendix 1.1. List of the habitats studied including the geographical references for the 150 sampled quadrates from the hyper-arid hot desert of the United Arab Emirates. Habitats (gravel plains, high mountains, mountains, salt flats, sand sheets); Latitude (decimal degrees); Longitude (decimal degrees); Altitude meters above sea level (m asl).

Habitat/ area name	**Latitude (decimal degrees)**	**Longitude (decimal degrees)**	**Altitude (m asl)**
Gravel plains			
Academic City, Dubai	25.105673	55.392484	26
Adhen Village, Ras Al Khaimah	25.508693	55.990141	81
Al Bassmah, Sharjah	24.988290	55.788764	165
Al Bataeh, Sharjah	25.277472	55.690605	59
Al Batayeh - Al Faya Rd, Sharjah	25.227215	55.727477	124
Al Dhaid, Sharjah	25.299148	55.915059	162
Al Dhaid, Sharjah	25.268374	55.865457	159
Al Dhaid, Sharjah	25.279193	55.949070	153
Al Dhaid, Sharjah	25.225665	55.964097	148
Al Dhaid, Sharjah	25.219770	55.941080	140
Al Dhaid, Sharjah	25.318403	55.918868	135
Al Dhaid, Sharjah	25.268780	55.865110	103
Al dhaid-Masafi Rd, Fujairah	25.302763	56.023531	226
Al Foah, Abu Dhabi	24.343647	55.781454	179
Al Madam, Sharjah	24.899487	55.841744	304
Al Madam, Sharjah	24.971062	55.915998	219
Al Madam, Sharjah	24.904556	55.820210	197
Al Madam, Sharjah	24.910859	55.785546	133
Al Saja'a Industrial Suburb, Sharjah	25.297329	55.605918	95
Al Shuwaib, Abu Dhabi	24.781994	55.813473	151
Maleha, Sharjah	25.085634	55.959479	229
Maleha, Sharjah	25.122452	55.936745	190
Maleha, Sharjah	25.129470	55.961062	183
Maleha, Sharjah	25.133980	55.913050	163
Maleha, Sharjah	25.159178	55.904242	146
Maleha, Sharjah	24.987053	55.858082	179
Mudfak, Ras Al Khaimah	25.527215	55.962310	64
Murqquab, Dubai	24.821320	55.577350	170
Thameed, Sharjah	25.006415	55.885329	175
University City, Sharjah	25.322084	55.466400	9
High mountains			
Fujairah	25.629864	56.121565	995

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Habitat/ area name	**Latitude (decimal degrees)**	**Longitude (decimal degrees)**	**Altitude (m asl)**
High mountains (Continued)			
Fujairah	25.055909	56.204203	843
Fujairah	25.618477	56.126237	815
Fujairah	25.050720	56.188090	732
Fujairah	25.033635	56.234707	725
Fujairah	25.055959	56.182217	714
Ghub, Fujairah	25.593000	56.177400	725
Ghub, Fujairah	25.575200	56.164000	716
Htta, Dubai	24.782959	56.111523	706
Jabel Hafeet, Abu Dhabi	24.081392	55.763314	801
Jebel Jais, Ras Al Khaimah	25.949473	56.142042	1448
Jebel Jais, Ras Al Khaimah	25.939546	56.131062	1271
Jebel Jais, Ras Al Khaimah	25.937014	56.129693	1219
Jebel Jais, Ras Al Khaimah	25.936500	56.129252	1184
Jebel Jais, Ras Al Khaimah	25.936622	56.129611	1153
Jebel Jais, Ras Al Khaimah	25.934922	56.130778	1113
Jebel Jais, Ras Al Khaimah	25.917808	56.127333	946
Jebel Jais, Ras Al Khaimah	25.925575	56.131460	909
Jebel Jais, Ras Al Khaimah	25.914669	56.129409	830
Jebel Jais, Ras Al Khaimah	25.914746	56.130628	814
Jebel Jais, Ras Al Khaimah	25.914087	56.130524	810
North Ras Al Khaimah	25.641498	56.114922	1221
North Ras Al Khaimah	25.641667	56.115184	1212
North Ras Al Khaimah	25.924213	56.130680	955
Wadi Shees, Fujairah	25.296000	56.221300	841
Wadi Shees, Fujairah	25.289700	56.213700	802
Wadi Shees, Fujairah	25.300335	56.220005	780
Wadi Shees, Fujairah	25.300337	56.219995	779
Wadi Shees, Fujairah	25.299654	56.220340	725
Wadi Shees, Fujairah	25.299917	56.230996	711
Mountains			
Al Aqdah, Fujairah	25.033442	56.262675	201
Al Bithnah, Fujairah	25.193474	56.177911	674
Al Bithnah, Fujairah	25.181743	56.197855	414
Al Halah, Fujairah	25.498894	56.142387	534
Al Halah, Fujairah	25.479483	56.137699	366
Asimah, Fujairah	25.421792	56.098209	306
Dibba - Masafi Rd, Fujairah	25.505066	56.214793	216
Dibba - Masafi Rd, Ras Al Khaimah	25.356755	56.158780	546
Diftah Shis Tunnel, Fujairah	24.981113	56.253842	484
Diftah Shis Tunnel, Fujairah	24.988739	56.218983	502
Fujairah	25.056974	56.180962	596

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Habitat/ area name	**Latitude (decimal degrees)**	**Longitude (decimal degrees)**	**Altitude (m asl)**
Mountains (Continued)			
Fujairah	25.034495	56.235277	537
Fujairah	25.030340	56.198500	457
Fujairah	25.342139	56.105245	430
Jabel Hafeet, Abu Dhabi	24.093275	55.761913	604
Jabel Hafeet, Abu Dhabi	24.071792	55.756360	470
Khatt, Ras Al Khaimah	25.609487	56.056445	517
Najd abyad, Ras Al Khaimah	25.071200	56.139898	539
Sayh Mudayrah, Ajman	24.841545	56.054797	458
Sayh Mudayrah, Ajman	24.860134	56.073154	475
Sharjah-Kalba Rd, Fujairah	24.986938	56.239118	503
Sharjah-Kalba Rd, Fujairah	24.981507	56.254062	443
Sifuni, Ras Al Khaimah	25.171760	56.108487	324
Sifuni, Ras Al Khaimah	25.164832	56.096815	313
South Ras Al Khaimah	25.054172	56.141671	457
Tawi Mayd Sharqiyin, Fujairah	25.427108	56.149439	467
Wadi Litibah, Ras Al Khaimah	25.984245	56.166569	223
Wadi shawqa, Ras Al Khaimah	25.091801	56.126501	470
Wadi Shees, Fujairah	25.292700	56.246190	585
Wadi Shees, Fujairah	25.300767	56.229497	524
Salt flats			
Al Hamriya, Sharjah	25.503084	55.509512	-6
Al Hamriya, Sharjah	25.479779	55.497522	-9
Al Hamriya, Sharjah	25.490419	55.503809	-11
Al Jazirah Al Hamra, Ras Al Khaimah	25.694586	55.799331	-2
Al Muntazah, Sharjah	25.381917	55.403890	-10
Al Owan, Ajman	25.416182	55.438797	34
Al Rafaah, Umm Al Quawain	25.616036	55.685210	-10
Al Rifa'ah, Sharjah	25.389197	55.419797	0
Al Riffa, Ras Al Khaimah	25.712070	55.830253	10
Ayn ul Ghamur, Fujairah	24.949852	56.320991	61
Dafan Al Khor, Ras Al Khaimah	25.766524	55.922528	9
Ghantoot, Abu Dhabi	24.883688	54.854834	4
Green Belt, Umm Al Quawain	25.528169	55.531882	-11
Hatta, Dubai	24.813030	56.146153	292
Hawd al Bid`ah, Fujairah	25.349030	56.310420	183
Hawd al Bid`ah, Fujairah	25.348192	56.308321	183
Kalba, Sharjah	25.004987	56.348748	32
Kalba, Sharjah	25.071360	56.357450	21
Kalba, Sharjah	25.069622	56.359740	10
Kalba, Sharjah	25.031406	56.362949	8
Kalba, Sharjah	25.031942	56.362758	-2

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Habitat/ area name	**Latitude (decimal degrees)**	**Longitude (decimal degrees)**	**Altitude (m asl)**
Salt flats (Continued)			
Ras Al-Khaimah	25.891826	56.049860	-1
Saih Sheib, Abu Dhabi	24.883549	54.947686	-8
Saraya Islands, Ras Al Khaimah	25.884235	56.012972	0
Sufayri, Dubai	24.809958	56.182756	267
The Lagoons, Dubai	25.201940	55.344640	74
Umm Al Quawain	25.534290	55.620441	-5
Umm Al Quawain	25.547335	55.660495	-6
Umm Al Quawain	25.530092	55.588974	-11
Umm Al Quawain	25.631997	55.710511	-15
Sand sheets			
Maleha, Sharjah	25.064465	55.805889	141
Maleha, Sharjah	25.107216	55.803236	130
Al Agabiyya, Abu Dhabi	24.169242	55.658084	236
Al Ajban, Abu Dhabi	24.635820	55.488190	205
Al Bataeh, Sharjah	25.276186	55.716033	79
Al Dhaid, Sharjah	25.278031	55.828796	166
Al Dhaid, Sharjah	25.278190	55.828914	112
Al Faqa, Dubai	24.716728	55.622135	220
Al Foah, Abu Dhabi	24.341551	55.774478	293
Al Hayer, Abu Dhabi	24.521721	55.761845	303
Al Hayer, Abu Dhabi	24.633095	55.718702	294
Al Hayer, Abu Dhabi	24.627716	55.721896	276
Al Lisaili, Dubai	24.952647	55.503025	136
Al Rashidiya, Umm Al Quawain	25.396352	55.817279	65
Al Saad, Abu Dhabi	24.218952	55.463914	184
Al Shohadaa Rd, Ras Al Khaimah	25.610801	55.851472	44
Al Shuwaib, Abu Dhabi	24.781742	55.828357	136
Jebel Ali - Lehbab Rd, Dubai	24.952110	55.269583	29
Mahafiz, Sharjah	25.144091	55.739257	111
Maharqah Waste Landfill, Abu Dhabi	24.015505	54.413955	58
Maleha, Sharjah	25.129410	55.828609	193
Nazwa, Sharjah	24.988769	55.662290	190
Nazwa, Sharjah	25.041049	55.689653	129
Sayh Mudayrah, Ajman	24.836600	56.060772	390
Sweihan, Abu Dhabi	24.394956	55.381345	175
Sweihan, Abu Dhabi	24.493432	55.417747	165
Tijarah Town, Dubai	25.039707	55.436703	43
Umm Al Quawain	25.435312	55.732967	44
Umm Al Quawain	25.526576	55.728377	12
Umm Al Quawain	25.575696	55.761215	-1

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Appendix 1.2. The species, family, habitats, APG IV phylogenetic group, growth form, phytogeography and dispersal traits (diaspore unit, diaspore size “diaspore length in cm”, diaspore color, absence/presence of diaspore appendage types “diaspore appendage”, spatial dispersal, dispersal mode and dispersal phenology) of 302 species from hyper-arid hot desert of the United Arab Emirates. Habitats: GP, gravel plains; HM, high mountains; M, mountains; SF, salt flats; SS, sand sheets. Growth forms (Cornelissen et al. 2003 and Pérez-Harguindeguy et al. 2013): DSh, dwarf shrubs; EL, erect leafy; SB, semi-basal; ShBp, short basal (prostrate); ShB, short basal (subrosette); ShBr, short basal (rosette); Sh, shrubs; Tr, trees; Tu, tussocks. Spatial dispersal: Dav, dispersal by abiotic vectors; Dbv, dispersal by biotic vectors; Rsd, restricted spatial dispersal. Diaspore unit: F, fruit; S, seed. Color: Bl, black; Br, brown; Gr, green; Or, orange; Re, red; Vi, violet; Wh, white; Ye, Yellow. Phytogeographical regions (Phytogeograph.): Cosm, Cosmopolitan; IT, Irano-Turanian; Med, Mediterranean; SA, Saharo-Arabian; SD, Sudano-Deccanian. *: Bradychoric species (aerial seed bank).

Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Acanthaceae											
**Blepharis ciliaris* (L.) B.L.Burtt	GP, M, SS	Lamiids	DSh	S	0.70	Br	Absence	Rsd	Ballistic	Rainy	SA, SD
Aizoaceae											
**Aizoon canariense* L.	GP, M, SS	Basal Asterids	ShBp	S	0.09	Bl	Absence	Rsd	Ombro-hydrochory	Rainy	SA
Sesuvium verrucosum Raf.	SF, SS	Basal Asterids	ShBp	S	0.10	Bl	Absence	Rsd	Ombro-hydrochory	Dry	SA, SD
Zaleya pentandra (L.) C.Jeffrey	GP, SS	Basal Asterids	ShBp	S	0.15	Bl	Absence	Rsd	Ombro-hydrochory	Rainy	SA, IT, SD, Med
Amaranthaceae											
**Aerva javanica* Juss.	GP, M, SS	Basal Asterids	DSh	F	0.13	Wh	Absence	Dav	Anemo-meteochory	All the year	SA, SD
Anabasis setifera Moq.	SF	Basal Asterids	DSh	F	0.50	Ye	Wings	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
**Arthrocnemum macrostachyum* (Moric.) K.Koch	SF	Basal Asterids	DSh	F	0.30	Bl	Absence	Rsd	Semachory	All the year	SA
Atriplex canescens (Pursh) Nutt.	SF	Basal Asterids	DSh	F	0.75	Br	Wings	Dav	Anemo-meteochory	Rainy	SA, IT
Atriplex leucoclada Boiss.	SF	Basal Asterids	DSh	F	0.40	Br	Bracts	Rsd	Semachory	Dry	SA, IT

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Family and species	**Habitats**	**AP G IV**	**Growth form**	**Diaspore unit**	**Diaspore size (cm)**	**Diaspore color**	**Diaspore appendage**	**Spatial dispersal**	**Dispersal mode**	**Dispersal phenology (month)**	**Phytogeograph.**
Amaranthaceae (Continued)											
Beta vulgaris L. subsp. *maritima* (L.) Arcang.	SF	Basal Asterids	SB	F	0.50	Gr	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Bienertia cycloptera Bunge	SF	Basal Asterids	SB	F	0.80	Ye	Wings	Dav	Anemo-meteochory	Rainy	SA, SD, IT
Chenopodium album L.	SS	Basal Asterids	SB	F	0.13	Wh	Absence	Rsd	Barochory	Dry	Cosm
Cornulaca aucheri Moq.	SF, SS	Basal Asterids	DSh	F	0.25	Wh	Wings	Dav	Anemo-meteochory	Rainy	SA, SD, IT
Cornulaca monacantha Delile	SF, SS	Basal Asterids	DSh	F	0.30	Ye	Wings	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
**Halocnemum strobilaceum* M.Bieb.	SF	Basal Asterids	DSh	F	0.15	Ye	Absence	Rsd	Barochory	Rainy	SA, IT, SD, Med
**Halopeplis perfoliata* Bunge ex Schweinf. & Asch.	SF	Basal Asterids	DSh	F	0.30	Re	Absence	Rsd	Barochory	Rainy	SA, SD, Med
Halothamnus bottae Jaub. & Spach	GP, SS	Basal Asterids	DSh	F	0.60	Ye	Wings	Dav	Anemo-meteochory	Dry	SA
Haloxylon persicum Bunge ex Boiss. & Buhse	SS	Basal Asterids	Sh	F	0.80	Ye	Wings	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Haloxylon salicornicum Bunge ex Boiss.	GP, SF, SS	Basal Asterids	DSh	F	0.70	Wh	Wings	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Salsola cyclophylla Baker	GP, SF, SS	Basal Asterids	DSh	F	0.47	Wh	Wings	Dav	Anemo-meteochory	Rainy	SA, IT
Salsola drummondii Ulbr.	SF	Basal Asterids	DSh	F	0.70	Ye	Wings	Dav	Anemo-meteochory	Rainy	SA, IT
Salsola imbricata Forssk.	SF	Basal Asterids	DSh	F	0.80	Wh	Wings	Dav	Anemo-meteochory	Rainy	SA, IT
Salsola rubescens Franch.	GP, M, SS	Basal Asterids	DSh	F	0.50	Re	Wings	Dav	Anemo-meteochory	Rainy	SA, IT
Salsola tetrandra Forssk.	GP, SF, SS	Basal Asterids	DSh	F	0.50	Re	Wings	Dav	Anemo-meteochory	Rainy	SA, IT

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Amaranthaceae (Continued)											
Seidlitzia rosmarinus Bunge ex Boiss.	SF, SS	Basal Asterids	DSh	F	1.00	Ye	Wings	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Suaeda aegyptiaca (Hasselq.) Zohary	SF, SS	Basal Asterids	SB	F	0.30	Br	Spongy perianth	Rsd	Barochory	Rainy	SA, SD
Suaeda vermiculata Forssk. ex J.F.Gmel.	SF, SS	Basal Asterids	DSh	F	0.30	Re	Absence	Dav	Anemo-meteochory	Rainy	SA, SD
Apocynaceae											
Rhazya stricta Decne.	GP, M, SS	Lamiids	DSh	S	0.70	Br	Absence	Rsd	Semachory	Dry	SA, SD, IT
Asclepiadaceae											
Calotropis procera (Aiton) W.T.Aiton	GP, SS	Lamiids	Sh	S	0.70	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, IT, SD, Med
*Glossonema varians Benth. ex Hook.f.	GP, M	Lamiids	DSh	S	0.60	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, SD, IT
Leptadenia pyrotechnica Decne.	SS	Lamiids	Sh	S	0.80	Br	Pappus	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Pentatropis nivalis (J.F.Gmel.) D.V.Field & J.R.I.Wood	GP, M, SS	Lamiids	Sh	S	0.45	Br	Pappus	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Pergularia tomentosa L.	GP, M, SS	Lamiids	DSh	S	0.45	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, IT, SD, Med
Asteraceae											
Anthemis odontostephana Boiss.	HM	Campanulids	SB	F	0.15	Br	Absence	Rsd	Semachory	Dry	SA, SD, IT
Atractylis carduus C.Chr.	GP, M, SS	Campanulids	DSh	F	1.25	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, SD, Med
Centaurea pseudosinaica Czerep.	SS	Campanulids	SB	F	1.25	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, IT, Med
Dicoma schimperi Baill. ex O.Hoffm.	M	Campanulids	DSh	F	0.70	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, SD, Med

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Family and species	**Habitats**	**AP G IV**	**Growth form**	**Diaspore unit**	**Diaspore size (cm)**	**Diaspore color**	**Diaspore appendage**	**Spatial dispersal**	**Dispersal mode**	**Dispersal phenology (month)**	**Phytogeograph.**
Asteraceae(Continued)											
Helichrysum glumaceum DC.	HM	Campanulids	DSh	F	0.50	Br	Absence	Rsd	Semachory	Dry	SA, Med
Ifloga spicata (Forssk.) Sch.Bip.	GP, SS	Campanulids	SB	F	0.55	Br	Pappus	Dav	Anemo-meteochory	Dry	SA
Iphiona aucheri (Boiss.) Anderb.	GP, M	Campanulids	DSh	F	0.70	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, SD
Iphiona scabra DC. ex Decne.	M	Campanulids	DSh	F	0.70	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, SD
Lactuca serriola L.	GP	Campanulids	SB	F	0.47	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, IT, Med
Launaea capitata (Spreng.) Dandy	SS	Campanulids	ShB	F	0.55	Br	Pappus	Dav	Anemo-meteochory	Rainy	SA, Med
Launaea massauensis (Fresen) Sch.Bip ex Kuntze	GP, HM, M	Campanulids	ShB	F	0.45	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, Med
Launaea mucronate Muschl.	SS	Campanulids	ShB	F	0.65	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, Med
Launaea nudicaulis Hook.f.	SS	Campanulids	ShB	F	0.85	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, Med
Launaea procumbens (Roxb.) Ramayya & Rajagopal	SS	Campanulids	ShB	F	0.65	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, Med
Launaea spinose Sch.Bip.	HM, M	Campanulids	DSh	F	0.70	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, Med
Matricaria aurea (Loefl.) Sch.Bip.	HM	Campanulids	SB	F	0.06	Br	Absence	Rsd	Semachory	Dry	SA, Med
Pentanema divaricatum Cass.	HM	Campanulids	SB	F	0.60	Bl	Pappus	Dav	Anemo-meteochory	Rainy	SA
Phagnalon arabicum Boiss.	GP, M	Campanulids	Sh	F	0.60	Br	Pappus	Dav	Anemo-meteochory	Dry	SA
Phagnalon viridifolium Decne. ex Boiss.	HM	Campanulids	DSh	F	0.60	Br	Pappus	Dav	Anemo-meteochory	Dry	SA

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Asteraceae (Continued)											
Pluchea arabica (Boiss.) Qaiser & Lack	GP	Campanulids	DSh	F	0.60	Br	Pappus	Dav	Anemo-meteochory	Rainy	SA
Pluchea dioscoridis (L.) DC.	SS	Campanulids	DSh	F	0.10	Br	Pappus	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Pulicaria arabica Cass.	M	Campanulids	SB	F	0.30	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, IT, Med
Pulicaria glutinosa Jaub. & Spach	GP, M	Campanulids	DSh	F	0.30	Br	Pappus	Dav	Anemo-meteochory	Dry	SA
Pulicaria undulata (L.) C.A.Mey.	GP, SS	Campanulids	DSh	F	0.30	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, IT, SD, Med
Reichardia tingitana (L.) Roth	GP, HM, M, SS	Campanulids	SB	F	0.90	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, Med
Scorzonera tortuosissima Boiss.	HM	Campanulids	DSh	F	0.90	Br	Pappus	Dav	Anemo-meteochory	Dry	SA
Senecio glaucus L. subsp. *coronopifolius* (Maire) C.Alexander	SS	Campanulids	SB	F	0.10	Br	Pappus	Dav	Anemo-meteochory	Rainy	SA, SD
Seriphidium herba-alba (Asso) Soják	HM	Campanulids	DSh	F	0.10	Br	Absence	Rsd	Semachory	Dry	SA, IT, Med
Sonchus asper (L.) Hill	HM	Campanulids	SB	F	0.70	Br	Pappus	Dav	Anemo-meteochory	Rainy	SA, IT, Med
Zoegea purpurea Fresen.	HM, M	Campanulids	SB	F	0.90	Br	Pappus	Dav	Anemo-meteochory	Dry	SA, IT, Med
Boraginaceae											
Anchusa hispida Forssk.	GP, M, SS	Lamiids	SB	F	0.35	Br	Absence	Rsd	Semachory	Dry	SA, IT, Med
*Arnebia hispidissima*n DC.	SS	Lamiids	SB	F	0.20	Bl	Absence	Rsd	Semachory	Rainy	SA, SD, Med
Echiochilon jugatum I.M.Johnst.	GP, M, SF, SS	Lamiids	DSh	F	0.19	Wh	Absence	Rsd	Barochory	Rainy	SA
Echiochilon persicum (Burm.f.) I.M.Johnst.	HM, M	Lamiids	DSh	F	0.20	Br	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Boraginaceae (Continued)											
Heliotropium bacciferum Forssk.	GP, SS	Lamiids	DSh	F	0.30	Br	Absence	Rsd	Barochory	All the year	SA, IT, Med
Heliotropium crispum Desf.	GP, SS	Lamiids	DSh	F	0.40	Wh	Absence	Rsd	Barochory	All the year	SA, IT, Med
Heliotropium curassavicum L.	GP	Lamiids	DSh	F	0.20	Br	Absence	Rsd	Barochory	Dry	SA, IT, Med
Heliotropium digynum Asch. ex C.Chr.	SS	Lamiids	DSh	F	0.50	Br	Absence	Rsd	Barochory	Dry	SA, IT, Med
Heliotropium kotschyi Gürke	GP, SF, SS	Lamiids	DSh	F	0.40	Wh	Absence	Rsd	Barochory	All the year	SA, IT, Med
Heliotropium rariflorum Stocks.	GP, SS	Lamiids	DSh	F	0.10	Br	Absence	Rsd	Barochory	Dry	SA, IT, Med
Moltkiopsis ciliata (Forssk.) I.M.Johnst.	SF, SS	Lamiids	DSh	F	0.30	Br	Absence	Rsd	Semachory	Dry	SA, IT, Med
Paracaryum intermedium Lipsky	GP, M	Lamiids	SB	F	0.40	Br	Wings	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Trichodesma ehrenbergii Schweinf. ex Boiss.	GP, M	Lamiids	SB	F	0.50	Gr	Wings	Dav	Anemo-meteochory	Dry	SA, SD
Brassicaceae											
Anastatica hierochuntica L.	SS	Malvids	ShB	S	0.18	Br	Absence	Rsd	Ombro hydrochory	Rainy	SA, SD, Med
Cardaria draba (L.) Desv.	HM	Malvids	DSh	S	0.20	Br	Absence	Rsd	Semachory	Dry	Cosm
Diplotaxis harra Boiss.	GP, HM, M	Malvids	SB	S	0.03	Br	Absence	Rsd	Semachory	Dry	SA, SD, Med
Eremobium aegyptiacum (Spreng.) Asch. ex Boiss.	SS	Malvids	SB	S	0.03	Br	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Erucaria hispanica Druce	HM, M, SS	Malvids	SB	F	0.10	Bl	Absence	Rsd	Barochory	Dry	SA, IT, SD, Med
Farsetia heliophila Bunge ex Coss.	SS	Malvids	DSh	S	0.25	Br	Wings	Dav	Anemo-meteochory	Dry	SA, SD, IT
Farsetia linearis Decne. ex Boiss.	GP, SS	Malvids	DSh	S	0.20	Br	Wings	Dav	Anemo-meteochory	Dry	SA

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<u>Brassicaceae (Continued)</u>											
Farsetia stylosa R.Br.	GP, SS	Malvids	SB	S	0.13	Br	Wings	Dav	Anemo-meteochory	Rainy	SA, SD, Med
**Morettia parviflora* Boiss.	GP, M, SS	Malvids	DSh	F	1.10	Br	Absence	Rsd	Barochory	Dry	SA, Med
Physorrhynchus chamaerapistrum (Boiss.) Boiss.	GP, M	Malvids	DSh	F	0.60	Br	Absence	Rsd	Barochory	Dry	SA, SD, IT
Savignya parviflora Webb	GP, SS	Malvids	SB	S	0.28	Ye	Wings	Dav	Anemo-meteochory	Rainy	SA, IT, SD, Med
Sisymbrium erysimoides Desf.	GP, M	Malvids	SB	S	0.10	Or	Absence	Rsd	Semachory	Dry	SA, Med
Sisymbrium irio L.	SS	Malvids	ShBr	S	0.20	Ye	Absence	Rsd	Semachory	Dry	SA, Med
**Zilla spinosa* Prantl	GP, M, SS	Malvids	DSh	F	1.50	Gr	Tip	Dav	Anemo-meteochory	Dry	SA, SD
<u>Campanulaceae</u>											
Campanula erinus L.	HM	Campanulids	SB	S	0.05	Bl	Absence	Rsd	Semachory	Rainy	SA, Med
<u>Capparaceae</u>											
Capparis spinosa L.	HM, M	Malvids	DSh	S	2.50	Br	Absence	Rsd	Semachory	Dry	SA, SD, Med
Cleome amblyocarpa Barratte & Murb.	SS	Malvids	SB	F	6.00	Br	Absence	Rsd	Barochory	Rainy	SA, IT, SD, Med
Cleome brachycarpa Vahl ex DC.	GP, SS	Malvids	DSh	S	0.65	Bl	Absence	Rsd	Semachory	Rainy	SA, SD
Cleome noeana Boiss.	GP, M	Malvids	SB	S	0.10	Bl	Absence	Rsd	Semachory	Rainy	SA, SD
Cleome rupicola Vicary	GP, M	Malvids	DSh	S	0.20	Br	Absence	Rsd	Semachory	Rainy	SA, SD
Dipterygium glaucum Decne.	SS	Malvids	DSh	F	0.45	Br	Wings	Dav	Anemo-meteochory	Dry	SA, SD, Med
Maerua crassifolia Forssk.	M	Malvids	Tr	F	4.50	Br	Absence	Rsd	Barochory	Dry	SA, SD
<u>Caryophyllaceae</u>											
Cometes surattensis L.	GP, HM, M	Basal Asterids	SB	S	0.20	Bl	Absence	Rsd	Semachory	Dry	SA, SD, IT
Dianthus crinitus Sm.	GP, HM, M	Basal Asterids	SB	S	0.25	Bl	Absence	Rsd	Semachory	Dry	SA, Med
Dianthus cyri Fisch. & C.A.Mey.	M	Basal Asterids	SB	S	0.30	Bl	Absence	Rsd	Semachory	Dry	SA, Med

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Caryophyllaceae (Continued)											
Gymnocarpos decandrus Forssk.	GP, HM, M	Basal Asterids	DSh	S	0.20	Br	Absence	Rsd	Semachory	Rainy	SA, IT, SD, Med
Gypsophila bellidifolia Boiss.	GP	Basal Asterids	SB	S	0.10	Br	Absence	Rsd	Semachory	Dry	SA, SD
Paronychia arabica DC.	SS	Basal Asterids	ShBp	S	0.08	Br	Absence	Rsd	Semachory	Rainy	SA, IT, Med
Polycarpaea repens Asch. & Schweinf. ex Asch.	GP, SS	Basal Asterids	SB	S	0.03	Bl	Absence	Rsd	Semachory	Dry	SA
Polycarpaea robbairea (Kuntze) Greuter & Burdet	M, SS	Basal Asterids	SB	S	0.03	Bl	Absence	Rsd	Semachory	Dry	SA
Polycarpon tetraphyllum (L.) L.	GP, M	Basal Asterids	ShBp	S	0.04	Br	Absence	Rsd	Semachory	Dry	Cosm
**Sclerocephalus arabicus* Boiss.	GP, HM, M, SS	Basal Asterids	SB	S	0.25	Bl	Absence	Rsd	Semachory	Dry	SA, IT, Med
Silene apetala Willd.	GP, M	Basal Asterids	SB	S	0.15	Bl	Wings	Dav	Anemo-meteochory	Dry	SA, IT, SD, Med
Silene arenosa K.Koch	SS	Basal Asterids	SB	S	0.09	Bl	Absence	Rsd	Semachory	Rainy	SA, SD, IT
Silene austroiranica Rech.f., Aellen & Esfand.	GP	Basal Asterids	SB	S	0.09	Bl	Absence	Rsd	Semachory	Rainy	SA
Silene villosa Forssk.	SS	Basal Asterids	SB	S	0.08	Br	Absence	Rsd	Semachory	Rainy	SA, SD, Med
Spergula fallax E.H.L.Krause	HM, M, SS	Basal Asterids	SB	S	0.13	Bl	Wings	Dav	Anemo-meteochory	Rainy	SA, SD, Med
Spergularia marina (L.) Griseb.	SS	Basal Asterids	SB	S	0.08	Br	Absence	Rsd	Semachory	Rainy	SA, IT, SD, Med
Sphaerocoma aucheri Boiss.	SF	Basal Asterids	DSh	F	0.20	Gr	Calyx	Dav	Anemo-meteochory	Rainy	SA, SD, IT
Cistaceae											
Helianthemum lippii Pers.	HM, SF, SS	Malvids	DSh	S	0.15	Br	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Helianthemum salicifolium (L.) Mill.	HM	Malvids	SB	S	0.15	Br	Absence	Rsd	Semachory	Dry	SA, SD, Med
Convolvulaceae											
Convolvulus cephalopodus Boiss.	SS	Lamiids	DSh	S	0.25	Bl	Absence	Rsd	Semachory	Dry	SA, SD, IT
Convolvulus glomeratus Choisy	M	Lamiids	DSh	S	0.20	Bl	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med

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Convolvulaceae (Continued)											
Convolvulus pilosellifolius Desr.	GP, SS	Lamiids	DSh	S	0.20	Bl	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Convolvulus prostratus Forssk.	SS	Lamiids	DSh	S	0.20	Bl	Absence	Rsd	Semachory	Dry	SA, SD, Med
Convolvulus ulicinus Boiss.	HM	Lamiids	DSh	S	0.20	Bl	Absence	Rsd	Semachory	Dry	SA
Convolvulus virgatus Boiss.	GP, M, SS	Lamiids	DSh	S	0.30	Br	Absence	Rsd	Semachory	Dry	SA, SD, IT
Cressa cretica L.	SS	Lamiids	DSh	S	2.50	Br	Absence	Rsd	Semachory	Rainy	Cosm
Crassulaceae											
Tillaea alata Viv.	HM	Basal Rosids	SB	S	0.03	Br	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Umbilicus horizontalis DC.	HM	Basal Rosids	SB	S	0.07	Br	Absence	Rsd	Semachory	Dry	SA, SD, Med
Cucurbitaceae											
**Citrullus colocynthis* (L.) Schrad.	GP, SS	Fabids	DSh	S	0.60	Br	Absence	Rsd	Ballistic	All the year	SA, SD
**Cucumis prophetarum* L.	GP, HM, M	Fabids	ShBp	S	0.40	Br	Absence	Rsd	Ballistic	All the year	SA, SD, Med
Cyperaceae											
Cyperus arenarius Retz.	SF, SS	Commelinids	Tu	F	0.16	Br	Absence	Rsd	Barochory	Rainy	SA, SD
Cyperus conglomeratus Rottb.	SF, SS	Commelinids	Tu	F	0.18	Br	Absence	Rsd	Barochory	Dry	SA, IT, SD, Med
Cyperus rotundus L.	SS	Commelinids	Tu	F	0.14	Br	Absence	Rsd	Barochory	Rainy	Cosm
Fimbristylis ferruginea (L.) Vahl	M	Commelinids	Tu	F	0.09	Br	Absence	Rsd	Barochory	Rainy	SA, IT, Med
Euphorbiaceae											
Chrozophora oblongifolia (Delile) A.Juss. ex Spreng.	GP, M	Fabids	DSh	F	0.80	Gr	Spine	Rsd	Barochory	Dry	SA, SD
Chrozophora plicata (Vahl) A.Juss. ex Spreng.	GP, SS	Fabids	SB	F	0.70	Gr	Absence	Rsd	Barochory	Dry	SA, SD
Euphorbia arabica Hochst. & Steud. ex T.Anderson	GP, M	Fabids	SB	F	0.15	Re	Absence	Rsd	Barochory	Dry	Cosm

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Euphorbiaceae (Continued)											
**Euphorbia larica* Boiss.	GP, HM, M	Fabids	DSh	F	1.00	Gr	Absence	Rsd	Barochory	Dry	Cosm
Euphorbia serpens Kunth	GP	Fabids	ShBp	F	0.15	Br	Absence	Rsd	Barochory	Dry	Cosm
**Ricinus communis* L.	SS	Fabids	Sh	F	1.25	Re	Absence	Rsd	Barochory	Rainy	SA, SD
Fabaceae											
Acacia ehrenbergiana Hayne	GP, SS	Fabids	Sh	F	8.50	Br	Absence	Rsd	Barochory	Dry	SA, SD
Acacia tortilis Hayne	GP, M, SS	Fabids	Tr	F	1.00	Br	Absence	Rsd	Barochory	Dry	SA, SD
Alhagi maurorum Medik.	SF, SS	Fabids	Sh	F	2.60	Br	Absence	Rsd	Barochory	Dry	SA, IT, SD, Med
Argyrolobium roseum (Cambess.) Jaub. & Spach	GP	Fabids	ShBp	S	0.30	Br	Absence	Rsd	Semachory	Dry	SA, SD
Astragalus eremophilus Boiss.	SF	Fabids	ShBp	S	0.1	Bl	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Astragalus hauarensis Boiss.	SF, SS	Fabids	ShBp	S	0.15	Bl	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Astragalus squarrosus Bunge	SS	Fabids	DSh	F	1.00	Wh	Wings	Rsd	Semachory	Dry	SA, SD, IT
Crotalaria aegyptiaca Benth.	GP, M, SS	Fabids	DSh	F	0.50	Gr	Absence	Rsd	Barochory	Dry	SA, SD
Crotalaria persica Merr.	SS	Fabids	DSh	F	0.50	Wh	Absence	Rsd	Barochory	Dry	SA, SD
Hippocrepis areolata Desv.	GP, M, SS	Fabids	ShBp	F	5.00	Br	Absence	Rsd	Barochory	Dry	SA, SD, Med
Hippocrepis constricta Kunze	GP, M, SS	Fabids	ShBp	F	2.25	Br	Absence	Rsd	Barochory	Dry	SA, IT, SD, Med
**Indigofera arabica* Jaub. & Spach	GP, SS	Fabids	ShBp	F	0.75	Wh	Absence	Rsd	Barochory	Dry	SA, SD
**Indigofera argentea* Burm.f.	GP, SS	Fabids	DSh	F	1.10	Wh	Absence	Rsd	Barochory	All the year	SA, SD
**Indigofera caerulea* Roxb.	GP, M	Fabids	DSh	F	0.80	Br	Absence	Rsd	Barochory	All the year	SA, SD
**Indigofera intricata* Boiss.	SS	Fabids	DSh	F	1.20	Br	Absence	Rsd	Barochory	All the year	SA, SD

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Fabaceae (Continued)											
*_Indigofera oblongifolia_ Forssk.	GP, SS	Fabids	DSh	F	1.60	Br	Absence	Rsd	Barochory	All the year	SA, SD
Indigofera spinosa Forssk.	HM	Fabids	DSh	F	1.50	Br	Absence	Rsd	Barochory	Dry	SA, SD
Lotononis platycarpa (Viv.) Pic.Serm.	GP, M, SS	Fabids	ShBp	S	0.13	Br	Absence	Rsd	Semachory	Dry	SA, SD
Lotus garcinii DC.	SF, SS	Fabids	DSh	F	1.10	Br	Calyx	Dav	Anemo-meteochory	Dry	SA, IT, SD, Med
Lotus halophilus Boiss. & Spruner	SF, SS	Fabids	ShBp	S	1.35	Br	Absence	Rsd	Semachory	Dry	SA, IT, Med
*_Medicago laciniata_ Mill.	GP, M	Fabids	ShBp	F	0.50	Gr	Spine	Dbv	Zoochory	Dry	SA, IT, SD, Med
Medicago polymorpha L.	GP, M	Fabids	ShBp	F	0.70	Gr	Spine	Dbv	Zoochory	Dry	Cosm
Melilotus albus Medik.	GP	Fabids	SB	F	0.40	Gr	Absence	Rsd	Barochory	Dry	SA, IT, Med
Ononis serrata Forssk.	SS	Fabids	EL	F	0.5	Br	Absence	Rsd	Barochory	Rainy	SA, Med
Prosopis cineraria Druce	SS	Fabids	Tr	F	18.75	Ye	Absence	Rsd	Barochory	Dry	SA, SD, IT
Prosopis farcta J.F.Macbr.	GP, SS	Fabids	DSh	F	1.50	Br	Absence	Rsd	Barochory	Dry	SA, SD, IT
Prosopis juliflora (Sw.) DC.	GP, SF, SS	Fabids	Tr	F	19.50	Ye	Absence	Rsd	Barochory	All the year	SA, SD
Rhynchosia minima (L.) DC. var. *minima*	GP, SS	Fabids	DSh	F	1.75	Gr	Absence	Rsd	Barochory	Dry	SA, SD
Rhynchosia schimperi Hochst. ex Boiss.	SS	Fabids	DSh	F	2.10	Gr	Absence	Rsd	Barochory	Dry	SA, IT, SD, Med
Senna italica Mill.	GP, SS	Fabids	DSh	F	3.09	Br	Absence	Rsd	Barochory	All the year	SA, IT, SD, Med
Taverniera glabra Boiss.	GP, M	Fabids	DSh	F	1.00	Gr	Absence	Rsd	Barochory	Dry	SA, SD, IT
Taverniera lappacea DC.	SS	Fabids	DSh	F	1.00	Gr	Absence	Rsd	Barochory	Dry	SA, SD, Med
Taverniera spartea DC.	SF	Fabids	DSh	F	1.10	Gr	Absence	Rsd	Barochory	Rainy	SA, SD
Tephrosia apollinea Link	GP, M, SS	Fabids	DSh	F	4.75	Br	Absence	Rsd	Barochory	Rainy	SA, SD
Tephrosia nubica Baker	GP	Fabids	DSh	F	1.10	Gr	Absence	Rsd	Semachory	Rainy	SA, SD
Tephrosia uniflora Pers. subsp. *petrosa* (Blatter & Hallberg) Gillett & Ali.	GP, SS	Fabids	DSh	F	4.00	Br	Tip	Rsd	Barochory	Dry	SA, SD

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Fabaceae (Continued)											
**Trigonella hamosa* L.	SS	Fabids	ShBp	F	2.00	Vi	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
**Trigonella stellata* Forssk.	GP, HM, M	Fabids	ShBp	S	0.15	Br	Absence	Rsd	Ballistic	Dry	SA, IT, Med
Frankeniaceae											
Frankenia pulverulenta L.	GP, SS	Basal Asterids	ShBp	S	0.10	Br	Absence	Rsd	Semachory	Dry	Cosm
Geraniaceae											
Monsonia nivea Webb	SS	Malvids	DSh	F	5.0	Wh	Hairs	Dav	Anemo-meteochory	Dry	SA, SD
Juncaceae											
**Juncus rigidus* Desf.	SF	Commelinids	Tu	S	0.10	Br	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
**Juncus socotranus* (Buchenau) Snogerup	SF	Commelinids	Tu	S	0.10	Br	Absence	Rsd	Semachory	Dry	SA
Lamiaceae											
Leucas inflata Benth.	M	Lamiids	SB	F	0.25	Br	Calyx	Dav	Anemo-meteochory	Dry	SA, SD, Med
**Salvia aegyptiaca* L.	GP, M	Lamiids	DSh	F	0.18	Bl	Absence	Rsd	Semachory	Dry	SA, Med
Salvia macilenta Boiss.	GP	Lamiids	DSh	F	0.15	Wh	Calyx	Dav	Anemo-meteochory	Dry	SA, Med
**Salvia spinosa* L.	M	Lamiids	ShBr	F	0.30	Bl	Absence	Rsd	Semachory	Dry	SA, Med
Satureja imbricata Briq.	HM	Lamiids	DSh	F	0.08	Bl	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Liliaceae											
Asparagus falcatus L.	M	Monocots	DSh	F	0.65	Re	Absence	Dbv	Barochory	Dry	SA, Med
Asphodelus tenuifolius Cav.	GP, HM, M, SS	Monocots	SB	S	0.30	Bl	Absence	Rsd	Semachory	Dry	SA, Med
Dipcadi biflorum Ghaz.	GP, M	Monocots	ShBr	S	0.05	Bl	Absence	Rsd	Semachory	Dry	SA
Dipcadi erythraeum Webb & Berthel.	SF, SS	Monocots	ShBr	S	0.05	Bl	Absence	Rsd	Semachory	Dry	SA

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Linaceae											
Linum corymbulosum Rchb.	HM, M	Monocots	SB	S	0.18	Bl	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Lythraceae											
**Lawsonia inermis* L.	M, SS	Malvids	Sh	F	0.60	Br	Absence	Rsd	Barochory	Rainy	SA, IT, SD, Med
Malpighiaceae											
Acridocarpus orientalis A.Juss.	M	Fabids	Sh	F	2.25	Br	Wings	Dav	Anemo-meteochory	Rainy	SA
Malvaceae											
**Abutilon fruticosum* Guill. & Perr.	M	Malvids	DSh	F	2.00	Br	Absence	Dav	Anemo-meteochory	Dry	SA, SD
**Abutilon pannosum* (G.Forst.) Schltdl.	GP, M	Malvids	DSh	F	0.80	Br	Absence	Dav	Anemo-meteochory	Dry	SA, SD
Hibiscus micranthus L.f.	M	Malvids	DSh	S	0.20	Br	Hairs	Dav	Anemo-meteochory	Rainy	SA, SD
**Malva parviflora* L.	SS	Malvids	ShBp	F	0.55	Br	Absence	Rsd	Semachory	Dry	SA, Med
Molluginaceae											
Gisekia pharnaceoides Linn.	SS	Basal Asterids	ShBp	S	0.10	Bl	Absence	Rsd	Semachory	Dry	Cosm
Limeum arabicum Friedrich	SS	Basal Asterids	DSh	F	0.30	Gr	Absence	Rsd	Semachory	Rainy	SA
Limeum indicum Stocks ex T.Anderson	GP, SS	Basal Asterids	ShBp	F	0.20	Br	Absence	Rsd	Semachory	Dry	SA, SD
Moraceae											
Ficus johannis Boiss.	HM, M	Fabids	Tr	F	1.10	Vi	Absence	Dbv	Barochory	Dry	SA, SD, IT
Moringaceae											
Moringa peregrina Fiori	HM, M	Malvids	Tr	S	1.45	Wh	Absence	Rsd	Semachory	Dry	SA, SD
Neuradaceae											
Neurada procumbens L.	GP, SS	Malvids	ShBp	F	1.15	Wh	Spine	Rsd	Semachory	Dry	SA, IT, SD, Med

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
<u>Nyctaginaceae</u>											
Boerhavia diffusa L.	M, SS	Malvids	DSh	F	0.30	Gr	Absence	Rsd	Semachory	Dry	SA, SD
Boerhavia rubicunda Steud. ex Heimerl	GP, M	Basal Asterids	DSh	F	0.40	Re	Absence	Rsd	Semachory	Dry	SA, SD
Commicarpus boissieri (Heimerl) Cufod.	HM	Basal Asterids	DSh	F	0.60	Gr	Absence	Rsd	Semachory	Dry	SA, SD
Commicarpus helenae (Romer & Schultes) Meikle	M	Basal Asterids	DSh	F	0.60	Gr	Absence	Rsd	Semachory	Dry	SA, SD
<u>Oleaceae</u>											
Olea europaea L. subsp. *cuspidat* (WAll. ex G. Don) Cif.	HM	Lamiids	Tr	F	1.25	Gr	Absence	Dbv	Barochory	Dry	SA, Med
<u>Plantaginaceae</u>											
Plantago afra L.	GP, HM, M	Lamiids	SB	S	0.25	Br	Absence	Rsd	Semachory	Dry	SA
Plantago albicans L.	M, SS	Lamiids	DSh	S	0.28	Br	Absence	Rsd	Semachory	Dry	SA
Plantago amplexicaulis Cav.	HM, M	Lamiids	ShB	S	0.43	Br	Absence	Rsd	Semachory	Dry	SA
Plantago boissieri Hausskn. & Bornm. ex Bornm.	SS	Lamiids	ShB	S	0.35	Br	Absence	Rsd	Semachory	Rainy	SA
Plantago ciliata Desf.	SS	Lamiids	ShB	S	0.26	Br	Absence	Rsd	Semachory	Dry	SA
**Plantago ovata* Forssk.	M, SS	Lamiids	ShB	S	0.25	Br	Absence	Rsd	Semachory	Rainy	SA
<u>Plumbaginaceae</u>											
Dyerophytum indicum Kuntze	M	Basal Asterids	Sh	S	1.00	Br	Wings	Dav	Anemo-meteochory	Dry	SA
Limonium carnosum Kuntze	GP, SF, SS	Basal Asterids	DSh	S	0.50	Br	Absence	Rsd	Semachory	Rainy	Cosm
<u>Poaceae</u>											
**Aeluropus lagopoides* (L.) Trin. ex Thwaites	SF	Commelinids	Tu	F	0.12	Wh	Absence	Rsd	Semachory	All the year	SA, IT, SD, Med
Aeluropus littoralis (Gouan) Parl.	SF	Commelinids	Tu	F	0.12	Wh	Absence	Rsd	Semachory	All the year	SA, IT, SD, Med
Aristida adscensionis L.	GP, SS	Commelinids	Tu	F	1.00	Gr	Long mucron	Rsd	Semachory	Dry	SA, SD

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Poaceae (Continued)											
**Cenchrus ciliaris* L.	GP, SS	Commelinids	Tu	F	0.03	Gr	Short mucron	Dav	Anemo-meteochory	All the year	SA, SD
Cenchrus pennisetiformis Hochst. & Steud.	SS	Commelinids	Tu	F	0.03	Gr	Short mucron	Dav	Anemo-meteochory	Dry	SA, SD
Centropodia forsskalii (Vahl) Cope	SS	Commelinids	Tu	F	0.10	Br	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Chloris barbata Sw.	SS	Commelinids	Tu	F	0.35	Br	Long mucron	Rsd	Semachory	Dry	SA, SD
Chloris virgata Sw.	SS	Commelinids	Tu	F	0.35	Br	Long mucron	Rsd	Semachory	Dry	SA, SD
Coelachyrum piercei (Benth.) Bor	SF, SS	Commelinids	Tu	F	0.12	Br	Absence	Rsd	Semachory	Dry	SA, SD
Cutandia memphitica K.Richt.	SS	Commelinids	Tu	F	0.45	Gr	Absence	Rsd	Semachory	Rainy	SA, IT, SD, Med
Cymbopogon commutatus Stapf	GP, M	Commelinids	Tu	F	0.15	Gr	Absence	Rsd	Semachory	Dry	SA, SD
Cynodon dactylon (L.) Pers.	SS	Commelinids	Tu	F	0.10	Gr	Absence	Rsd	Semachory	All the year	Cosm
Dichanthium annulatum (Forssk.) Stapf	SS	Commelinids	Tu	F	0.10	Gr	Short appendage	Rsd	Semachory	Dry	SA, SD
Dichanthium foveolatum (Delile) Roberty	SS	Commelinids	Tu	F	0.10	Gr	Long appendage	Rsd	Semachory	Dry	SA, SD, Med
Digitaria sanguinalis (L.) Scop.	SS	Commelinids	Tu	F	0.10	Gr	Absence	Rsd	Semachory	Dry	Cosm
Eragrostis barrelieri Daveau	SS	Commelinids	Tu	F	0.08	Br	Absence	Rsd	Semachory	Rainy	SA, Med
Halopyrum mucronatum Stapf	SF, SS	Commelinids	Tu	F	0.10	Br	Short appendage	Rsd	Semachory	Dry	SA, SD, Med
Lasiurus scindicus Henrard	SS	Commelinids	Tu	F	0.20	Br	Absence	Rsd	Semachory	Dry	SA, SD, Med
Lolium rigidum Gaudin	GP, SF	Commelinids	Tu	F	0.70	Br	Short appendage	Rsd	Semachory	Dry	SA, IT, SD, Med
Panicum antidotale Retz.	SF, SS	Commelinids	Tu	F	0.03	Br	Absence	Rsd	Semachory	Rainy	SA, SD
Panicum turgidum Forssk.	GP, SS	Commelinids	Tu	F	0.03	Br	Absence	Rsd	Semachory	Dry	SA, SD
Schismus barbatus (L.) Thell.	GP, SS	Commelinids	Tu	F	0.10	Br	Absence	Rsd	Semachory	Dry	SA, SD, Med
**Sporobolus ioclados* Nees	SF	Commelinids	Tu	F	0.08	Br	Absence	Rsd	Semachory	Rainy	SA

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Poaceae (Continued)											
**Sporobolus spicatus* Kunth	SF, SS	Commelinids	Tu	F	0.02	Br	Absence	Rsd	Semachory	All the year	SA
Stipa capensis Thunb.	GP, M, SS	Commelinids	Tu	F	1.20	Br	Short appendage	Rsd	Semachory	Rainy	SA, IT
Stipagrostis ciliata (Desf.) De Winter	GP, SS	Commelinids	Tu	F	1.80	Br	Absence	Rsd	Semachory	Dry	SA, SD
Stipagrostis plumosa Munro ex T.Anderson	GP, SS	Commelinids	Tu	F	1.80	Br	Absence	Rsd	Semachory	Dry	SA, SD
Tetrapogon villosus Desf.	M, SS	Commelinids	Tu	F	0.15	Br	Absence	Rsd	Semachory	Rainy	SA, SD
Tragus racemosus (L.) All.	SS	Commelinids	Tu	F	0.35	Br	Short appendage	Dav	Zoochory	Rainy	SA, SD, IT
Polygalaceae											
Polygala erioptera DC.	SS	Fabids	SB	F	0.38	Wh	Absence	Rsd	Semachory	Dry	SA, IT, Med
Polygala irregularis Boiss.	SS	Fabids	DSh	F	0.60	Wh	Wings	Dav	Anemo-meteochory	Dry	SA, IT, Med
Polygonaceae											
Calligonum comosum L'Her	SS	Basal Asterids	DSh	F	1.20	Re	Wings	Dav	Anemo-meteochory	Dry	SA, SD, Med
Calligonum crinitum Boiss	SS	Basal Asterids	DSh	F	2.35	Ye	Bristles	Dav	Anemo-meteochory	Dry	SA, SD, IT
Emex spinosa (L.) Campd.	SS	Basal Asterids	ShBp	F	0.45	Br	Spine	Rsd	Semachory	Dry	SA, Med
Pteropyrum scoparium Jaub. & Spach	GP, M	Basal Asterids	DSh	F	0.60	Br	Wings	Dav	Anemo-meteochory	Dry	SA
Rumex limoniastrum Jaub. & Spach	HM, M	Basal Asterids	Sh	F	0.70	Ye	Wings	Dav	Anemo-meteochory	Dry	SA, Med
Rumex pictus Forssk.	SS	Basal Asterids	SB	F	0.80	Ye	Absence	Rsd	Semachory	Dry	SA, Med
Rumex vesicarius L.	GP, HM, M	Basal Asterids	SB	F	2.00	Gr	Wings	Dav	Anemo-meteochory	Dry	SA, Med

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Resedaceae											
Ochradenus arabicus Chaudhary, Hillc. & A.G.Mill.	HM, M, SS	Malvids	DSh	S	0.20	Bl	Absence	Rsd	Semachory	Rainy	SA
Ochradenus aucheri Boiss.	GP	Malvids	DSh	S	0.11	Bl	Absence	Rsd	Semachory	Rainy	SA, SD, IT
Oligomeris linifolia J.F.Macbr.	GP, M, SS	Malvids	SB	S	0.07	Bl	Absence	Rsd	Semachory	Rainy	SA
Reseda aucheri Boiss.	GP, M	Malvids	DSh	S	0.08	Bl	Absence	Rsd	Semachory	Dry	SA, Med
Reseda muricata C.Presl	GP, M, SS	Malvids	DSh	S	0.08	Bl	Absence	Rsd	Semachory	Rainy	SA, Med
Rhamnaceae											
Ziziphus lotus Lam.	GP, M	Fabids	Sh	F	0.40	Br	Absence	Dbv	Barochory	Rainy	SA, SD
Rhamnaceae (Continued)											
Ziziphus nummularia (Burm.f.) Wight & Arn.	SS	Fabids	Sh	F	0.75	Br	Absence	Dbv	Barochory	Rainy	SA, SD, IT
Ziziphus spina-christi (L.) Willd.	GP, HM, M	Fabids	Tr	F	3.50	Br	Absence	Rsd	Barochory	Rainy	SA, SD
Rubiaceae											
Jaubertia aucheri Guill.	GP, M	Lamiids	Sh	F	0.30	Bl	Absence	Dbv	Barochory	Dry	SA, SD, IT
Kohautia retrorsa (Boiss.) Bremek.	GP, SS	Lamiids	SB	S	0.20	Br	Absence	Rsd	Semachory	Dry	SA, SD
Pseudogaillonia hymenostephana (Jaub. & Spach) Lincz.	GP, M	Lamiids	DSh	F	0.13	Wh	Calyx	Dav	Anemo-meteochory	Dry	SA, SD, IT
Pterogaillonia calycoptera (Decne.) Lincz.	HM	Lamiids	DSh	F	0.80	Wh	Wings	Dav	Anemo-meteochory	Dry	SA, IT, SD, Med
Salvadoraceae											
Salvadora persica L.	M, SS	Malvids	Tr	F	0.50	Re	Absence	Dbv	Barochory	Dry	SA, SD
Scrophulariaceae											
Anticharis arabica Endl.	GP, M	Lamiids	EL	S	0.10	Ye	Absence	Rsd	Semachory	Dry	SA, SD
Kickxia hastata (R.Br. ex Benth.) Dandy	GP	Lamiids	SB	S	0.50	Bl	Absence	Rsd	Semachory	Dry	SA, SD
Lindenbergia arabica (S.Moore) Hartl	M	Lamiids	DSh	S	0.50	Bl	Absence	Rsd	Semachory	Rainy	SA
Lindenbergia indica (L.) Vatke	M	Lamiids	DSh	S	0.50	Bl	Absence	Rsd	Semachory	Rainy	SA, SD, Med
Misopates orontium (L.) Raf.	GP, HM, M	Lamiids	SB	S	0.10	Bl	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Scrophulariaceae (Continued)											
Schweinfurthia papilionacea Boiss.	GP, M, SS	Lamiids	SB	S	0.20	Bl	Absence	Rsd	Semachory	Dry	SA
**Scrophularia deserti* Delile	GP, HM, M	Lamiids	SB	F	0.30	Br	Tip	Rsd	Barochory	Dry	SA, IT, Med
Solanaceae											
Lycium shawii Roem. & Schult.	GP, SS, M, HM	Lamiids	Sh	F	0.50	Re	Absence	Dbv	Barochory	Rainy	SA, SD, IT
**Solanum incanum* L.	GP, HM	Lamiids	Sh	F	3.00	Ye	Absence	Dbv	Barochory	Dry	SA, SD, Med
Solanum nigrum L.	GP	Lamiids	SB	F	0.65	Bl	Absence	Dbv	Barochory	Rainy	SA, SD, Med
Sterculiaceae											
Melhania muricata Balf.f.	HM, M	Malvids	Sh	F	0.55	Ye	Wings	Dav	Anemo-meteochory	Dry	SA, SD
Melhania phillipsiae Baker f.	HM	Malvids	Sh	F	0.90	Or	Absence	Rsd	Barochory	Dry	SA, SD
Tamaricaceae											
Tamarix aphylla (L.) H.Karst.	GP, M, SS	Basal Asterids	Tr	S	0.05	Bl	Pappus	Dav	Anemo-meteochory	Rainy	SA
Tamarix aucheriana (Decne. ex Walp.) B.R.Baum	SF	Basal Asterids	Tr	S	0.05	Bl	Pappus	Dav	Anemo-meteochory	Rainy	SA
Tamarix nilotica (Ehrenb.) Bunge	SF	Basal Asterids	Tr	S	0.05	Bl	Pappus	Dav	Anemo-meteochory	Rainy	SA
Tiliaceae											
Corchorus trilocularis L.	SS	Malvids	SB	S	0.10	Bl	Absence	Rsd	Semachory	Dry	Cosm
Grewia erythraea Schweinf.	HM, M	Malvids	DSh	F	1.50	Re	Absence	Dbv	Barochory	Rainy	SA, SD
Grewia tenax (Forssk.) Fiori	HM	Malvids	Tr	F	1.20	Or	Absence	Dbv	Barochory	Rainy	SA, SD
Grewia villosa Willd.	M	Malvids	Tr	F	1.00	Ye	Absence	Dbv	Barochory	Rainy	SA, SD
Umbelliferae											
Ammi majus L.	GP, M	Campanulids	SB	F	0.20	Gr	Absence	Rsd	Semachory	Dry	SA, IT, SD, Med
Ducrosia anethifolia Boiss.	GP, M, SS	Campanulids	SB	F	0.60	Gr	Absence	Rsd	Semachory	Dry	SA, SD, IT

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Family and species	Habitats	AP G IV	Growth form	Diaspore unit	Diaspore size (cm)	Diaspore color	Diaspore appendage	Spatial dispersal	Dispersal mode	Dispersal phenology (month)	Phytogeograph.
Umbelliferae (Continued)											
Scandix pecten-veneris L.	HM	Campanulids	SB	F	0.60	Gr	Long mucron	Rsd	Semachory	Dry	SA, IT, SD, Med
Urticaceae											
Forsskaolea tenacissima L.	GP, M	Fabids	DSh	S	0.30	Bl	Pappus	Dav	Anemo-meteochory	Dry	SA, SD
Violaceae											
Viola cinerea Boiss.	GP, HM, M	Fabids	SB	S	1.20	Bl	Absence	Rsd	Semachory	Rainy	SA, SD, IT
Zygophyllaceae											
Fagonia bruguieri DC.	GP, M, SS	Fabids	DSh	F	0.40	Br	Spine	Rsd	Semachory	Dry	SA
Fagonia indica Burm.f.	GP, M	Fabids	DSh	F	0.40	Gr	Spine	Rsd	Semachory	Dry	SA
Fagonia ovalifolia Hadidi	GP, SS	Fabids	ShBp	F	0.40	Br	Spine	Rsd	Semachory	Dry	SA
Tribulus arabicus Hosni	SS	Fabids	DSh	F	1.00	Br	Hair wings	Dav	Anemo-meteochory	Dry	SA, SD
Tribulus macropterus Boiss.	SS	Fabids	ShBp	F	1.75	Br	Wings	Dav	Anemo-meteochory	Dry	SA, SD
Tribulus omanense Hosni	SS	Fabids	DSh	F	1.00	Br	Wings	Dav	Anemo-meteochory	Dry	SA, SD
Tribulus pentandrus Forssk.	SS	Fabids	DSh	F	1.00	Br	Wings	Dav	Anemo-meteochory	Rainy	SA, SD
Zygophyllaceae											
Tribulus terrestris L.	GP, M, SS	Fabids	ShBp	F	1.50	Br	Spine and Hairs	Rsd	Semachory	Rainy	SA, SD
Zygophyllum boulosii Hosny	SF, SS	Fabids	DSh	F	0.50	Br	Absence	Rsd	Barochory	Rainy	SA, SD
Zygophyllum mandavillei Hadidi	SF, SS	Fabids	DSh	F	0.50	Br	Absence	Rsd	Barochory	Dry	SA, SD
Zygophyllum qatarense Hadidi	GP, SF, SS	Fabids	DSh	F	1.49	Br	Absence	Rsd	Barochory	Dry	SA, SD
Zygophyllum simplex L.	GP, SF, SS	Fabids	ShBp	F	0.20	Br	Wings	Dav	Anemo-meteochory	Dry	SA, SD

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CHAPTER 2

Seed mass and germination traits relationships among different plant growth forms with aerial seed bank in the hyper-arid hot desert of the United Arab Emirates (UAE)

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CHAPTER 2

Seed mass and germination traits relationships among different plant growth forms with aerial seed bank in the hyper-arid hot desert of the United Arab Emirates (UAE)

2.1. Introduction

Dormancy is defined as the inability of an intact viable seed to complete germination under favourable conditions under which non-dormant seeds can germinate (Bewley 1997). It is controlled by several environmental factors, such as light, temperature and seed storage period and condition (Koornneef et al. 2002). Seed dormancy is an adaptation adopted by many desert plants, especially those that grow in heterogeneous soils that receive scarce amounts of spatially and temporally unpredictable rainfalls (Böer 1997, El-Keblawy 2003, El-Keblawy 2017a). Dormancy delay seed germination until the arrival of favourable conditions that allow seedling establishment and minimise seedling mortality. Such 'bet-hedging strategy' spreads the risk over time (Rees 1996, Gremer et al. 2012). It has been reported that plants that are subjected to high risks of mortality during their early life stages develop dormancy and dispersal strategies that offset fluctuations in habitat suitability (Fenner & Thompson 2005). Bet-hedging strategy is usually linked to seed size (Larson et al. 2016).

Seeds are either stored in the soil (i.e., soil seed bank), or retained above-ground on maternal plants until they are released (i.e., aerial seed bank) (Gunster 1992). Aerial seed bank (bradychory) is a phenomenon described in many species of the arid deserts where it protects seeds from unfavourable conditions in the soil and releases them when conditions are favourable for germination and seedling recruitment (Lamont et al. 1991, El-Keblawy & Bhatt 2015). The environmental factors associated with seeds in the soil seed bank differ from those in the aerial seed bank. Seeds at first are exposed to light and face diurnal fluctuations in temperature and those buried in the soil are stored in darkness and face less temperature fluctuations (El-Keblawy et al. 2015). Some studies have reported that aerial seed bank would play the same role as the soil seed bank; both protect seeds during unfavourable conditions for germination and release them when optimal field conditions for seed germination and seedling emergence are met (e.g., El-Keblawy & Bhatt, 2015, El-Keblawy et al. 2015). Few studies have assessed the role of aerial seed bank in regulating germination in desert plants (Lamont et al. 1991, El-Keblawy & Bhatt 2015, El-Keblawy et al. 2015).

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Seed size (mass) is an important trait influencing early phases in the life cycle of a plant, including germination, emergence, seed dispersal, persistence in soil, seedling establishment, growth and fitness in plants (Seiwa 2000, Long et al. 2015, Metzner et al. 2017). Several studies have indicated that large seeds have advantages over smaller seeds in the early stages of seedling establishment (Gross 1984, Leishman & Westoby 1994, Long et al. 2015, Larson et al. 2016). Seed size affects seedlings through embryo size and available reserve that could support seedlings during the most sensitive earlier stages of the life cycle (Jurado & Westoby 1992). Generally, large seeds produce bigger seedlings with better competitive ability than smaller seeds, especially under resource-limited (e.g., deserts) or competitive conditions (under the canopy of shrubs and trees) (Seiwa & Kikuzawa 1996). Moreover, seed size might affect light requirements during germination. Whereas large seeds of many species germinate in both light and darkness, small seeds require light for germination (Leishman & Westoby 1994, Milberg et al. 2000, Venier et al. 2016, El-Keblawy 2017a). The light requirement for small seeds prevents them from germination when buried in the soil (Leishman & Westoby 1994, Milberg et al. 2000, El-Keblawy 2014, Venier et al. 2016). Photosynthetic traits of seedling from small-seeded species, such as photosynthetic type cotyledons and a high specific leaf area and leaf area ratio, enable them to grow better in sites exposed to light. However, large-seeded seedlings tend to be more shade tolerant (Quero et al. 2007).

Germination is most likely to occur at time and place that enhance the survival of seedlings. Light, temperature and moisture are among the most important factors that determine germination time and place in desert environments (Milberg et al. 2000, El-Keblawy & Al-Rawai 2006, El-Keblawy 2014, Venier et al. 2016). For example, light can be a key factor in determining safe sites that enhance seedling establishment in environments where seeds are likely to be buried, covered with litter or present under the shade of nurse plants (Molofsky & Augspurger 1992). In addition, the germination response of seeds to light is temperature dependent (Pons 2000). The superficial soil layer serves as the major germination bed and experiences wide daily and seasonal fluctuations in light and temperature conditions, especially in arid deserts (El-Keblawy & Gairola 2017). In hot arid deserts of the United Arab Emirates (UAE), germination of many plants occurs only when particular combinations of light, temperature and soil moisture are optimal for seedling survival (El-Keblawy 2017a, b).

Few studies have assessed the relationship between seed size and germination among different growth forms. For example, growth form can affect dispersal mode and determine the place where diaspores are stored and consequently affect place of seedling establishment, growth and survival, which, in turn, could shape community structure (Saatkamp et al. 2014, Jiménez-Alfaro et al. 2016, Shabana et al. 2018). In addition, Baker (1972) examined the possible relationships between seed mass of different growth forms with different environmental conditions in the flora of California, including deserts, and concluded that seed size was proportionally correlated with both plant size and the length of generation time; smallest seeds belonging to herbs and the largest to trees. The relationship between place of seed storage and growth forms would be especially important for species that have aerial seed banks (i.e., store their seeds either within maternal tissues on the plant or on the soil surface) (El-Keblawy & Bhatt 2015, El-Keblawy et al. 2015). However, few studies have assessed the impact of growth forms and seed size and mass on germination traits of desert plants, where germination requirements could affect the time and place of seedling emergence and establishment (e.g., Wang et al. 2017, El-Keblawy 2017a).

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Theoretical models have proposed that germination rate is positively correlated with seed mass (e.g., Rees 1996, de Casas et al. 2017). However, there has been no clear trend observed in empirical studies. Some studies have reported lower dormancy (i.e., higher germination) in large-seeded species and high dormancy in small-seeded species (e.g., Pake & Venable 1996, Galíndez et al. 2009). However, Wang et al. (2017) investigated the relationship of seed mass and dormancy in 124 plant species from different families and found a trend in which heavier seeds (> 1 mg) had significantly greater dormancy than smaller seeds (< 0.1 mg). In addition, there has been no clear relationship observed between seed size and dormancy in eight common perennial grasses of the Arabian desert (El-Keblawy 2017a, b). These contradictory trends might be attributed to the place of seed storage and/or developmental constraints that affect seed development in plants with different growth forms and habitat types (de Casas et al. 2015). The objective of present study, therefore, was to assess the relationship between plant growth forms, place of seed storage (storage conditions), and seed mass and light and temperature requirements during germination of 23 desert plants with an aerial seed bank. Correlations between seed mass and final germination, relative light germination, and germination speed of the studied species under different temperatures and light conditions could help in determination of factors controlling emergence and establishment under and away from plant canopies of different growth forms. We tested the hypothesis that germination is positively correlated with seed mass (e.g., Rees 1996, de Casas et al. 2017) in plants with aerial seed bank and belonging to different growth forms. Testing this hypothesis is especially important as there has been no clear trend observed in empirical studies that have assessed this relationship. We expected that the dispersal and the place where seeds are stored after their release from the aerial seed bank differed between the different growth forms; small seeds of annuals would be dispersed away and heavier seeds of shrubs and trees would more likely to be trapped or would fall under closed canopies.

2.2. Material and Methods

2.2.1. *Study species*

Seeds of 23 species with aerial seed bank were used in this study. The species studied had an aerial seed bank with seeds stored within maternal tissues after maturation either on maternal plants (14 species) or on the soil surface (9 species) (Table 2.1). Seeds retained within maternal tissues either on maternal plants or soil surface were considered as aerial seed bank. At least within the first year after their production, seeds of these species are not released from the maternal tissues to form soil seed banks. The species represented three growth forms (six herbaceous, 11 small shrubs and six trees). Among the six-herbaceous species, three species were perennial graminoids. The different growth forms were classified according to Cornelissen et al. (2003). None of the perennial species were deciduous.

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The plant height of herbaceous plants varied between 15 to 60 cm, except for *Juncus rigidus* that could reach up to 150 cm height with open canopies; the height of small shrubs ranged between 20 cm to 125 cm, with a denser canopy; trees were 3-10 m tall.

For each species, the average seed mass was determined by weighing three replicates, each of 100 seeds. In addition, average seed size of each species was assessed by measuring the length of 50 seeds. Seed length was measured as it mainly determines the degree of seed burial in soil. In addition, seed shape was described for each species as ovoid (12 species), reniform (5 species), rounded (3 species), spatulate (2 species) and elongate-truncate (one species). Most of species flower from January - February until May - June; most species fruit between May and June. However, some species can flower and fruit throughout the year (Table 2.1).

2.2.2. *Study area*

The northern part of the United Arab Emirates (UAE) is generally hot and dry with a hyper-arid hot (subtropical arid) climate. The region is characterised by two distinctive seasons: a long season (April to October) with very high temperatures and almost no rainfalls but with high air humidity and a short season (November to March) with mild to warm temperatures and light rainfalls. The mean daily temperature ranges between 12.1 °C in January and about 42 °C in June - August. Temperatures can reach up to 47 °C in summer. The average annual rainfall in the coastal region is 120 mm (Böer 1997).

The 23 species studied were among the most common species in four geographical regions in the northern Emirates (coastal salt flats, mountains, sand sheets, and gravel plains) (Fig. 2.1). The coastal salt flats were dominated by *Avicenna marina* (mangrove tree) with several small shrubby halophytes, such as *Arthrocnemum macrostachyum*, *Halopeplis perfoliata*, *Suaeda vermiculata* and *Zygophyllum qatarense*. The mountainous were dominated by trees of *Acacia tortilis*, *Prosopis cineraria* and *Ziziphus* species with several small shrubs and herbs, such as *Abutilon pannosum*, *Asphodelus tenuifolius*, *Blepharis ciliaris*, *Euphorbia larica*, *Fagonia indica*, *Ochradenus aucheri* and *Pulicaria glutinosa*. The sandy habitats were dominated by the sedge *Cyperus conglomeratus*, several grasses, mostly *Stipagrostis plumosa* and several annuals and small shrubs dominated by *Citrullus colocynthis*, *Haloxylon salicornicum* and *Tribulus omanense*. The gravel plains were characterised by coarse sand and small rocky fragments dominated by *Acacia tortilis*, *Prosopis cineraria*, *Calotropis procera* and *Leptadenia pyrotechnica* (Jongbloed 2003, Karim & Fawzi 2007a, b).

2.2.3. *Seed collection*

Mature seeds of the 23 species were collected during May - June 2015 from four habitat types of the northern Emirates (Fig. 2.1). Seeds of each species were randomly collected from 20 - 30 individuals to diminish the effect of genetic variation within the population. The individuals of each species were distributed along transects of 300 - 500 m in length and 10 m wide. In order to assess the effect of field storage, seeds of the same species were collected again in February 2016 from either maternal plants or soil surface. In order to ensure that seed age was only around 9 months (i.e., not from earlier seasons), old fruits were removed in May - June 2015 from above the maternal plants or from soil surface of 15 tagged plants of each species. At that time, all seeds were still enclosed within the maternal tissues on or under the maternal plants (hereafter referred as field storage). Seeds of all collections were separated from debris with a hand-made rubber thresher and cleaned with a series of sieves.

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Table 2.1. Seed traits (mass, size "length" and shape), storage condition, canopy shape, height, and flowering and fruiting time of species belonging to different growth forms, northern United Arab Emirates.

Growth form	Family	Species	Seed shape	Average mass (100 seeds/g)	Seed length (cm)	Mean plant height (cm)	Storage condition	Canopy shape	Flowering time	Fruiting time
Herbaceous	Aizoaceae	*Aizoon canariense* L.	Reniform	0.016	0.085	35	On plant	-	Jan.-Jun.	Feb.-Jul.
	Brassicaceae	*Anastatica hierochuntica* L.	Rounded	0.113	0.179	10	On plant	-	Feb.-May	Mar.-Jun.
	Capparaceae	*Cleome noeana* Boiss. & Popov	Reniform	0.011	0.100	60	On plant	-	May-Aug.	Jun.-Sep.
	Juncaceae	*Juncus rigidus* Desf.	Ovoid	0.003	0.100	150	On plant	-	Mar.-Jun.	Apr.-Jul.
	Juncaceae	*Juncus socotranus* (Buchenau) Snogerup	Ovoid	0.017	0.100	60	On plant	-	Mar.-Jun.	Apr.-Jul.
	Poaceae	*Aeluropus lagopoides* (L.) Thw.	Ovoid	0.019	0.050	15	On plant	-	year-round	year-round
Shrubs	Acanthaceae	*Blepharis ciliaris* (L.) B.L.Burtt	Ovoid	3.352	0.700	20	On plant	-	Oct.-Apr.	Mar.-Jul.
	Amaranthaceae	*Arthrocnemum macrostachyum* (Moric.) K.Koch	Ovoid	0.032	0.120	125	On plant	Open-shrub	Sep.-Feb.	Dec.-May
	Asteraceae	*Pulicaria undulata* (L.) C.A.Mey.	Elongate-truncate	0.006	0.170	52	On soil	Dense-cushion	Apr.-July	May-Aug.
	Convolvulaceae	*Convolvulus prostratus* Forssk.	Rounded	0.313	0.200	60	On soil	Open-shrub	year-round	year-round
	Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.	Ovoid	1.800	0.600	25	On plant	-	year-round	year-round
	Fabaceae	*Indigofera oblongifolia* Forssk.	Ovoid	0.166	0.170	100	On plant	Dense-shrubby	Feb.-Apr.	Mar.-Jun.
	Fabaceae	*Lotus garcinii* DC.	Rounded	0.176	0.120	30	On soil	Dense-shrubby	Dec.-Jun.	Mar.-Aug.
	Fabaceae	*Senna italica* Mill.	Spatulate	2.144	0.550	60	On soil	Open-shrubby	year-round	year-round
	Fabaceae	*Tephrosia nubica* (Boiss.) Baker	Reniform	1.940	0.520	125	On soil	Dense-shrubby	Jan.-May	Mar.-Jun.
	Malvaceae	*Abutilon pannosum* (G.Forst.) Schltdl.	Reniform	0.251	0.200	100	On plant	Open-shrubby	Jan.-Jun.	Mar.-Jul.
	Rutaceae	*Haplophyllum tuberculatum* (Forssk.) A.Juss.	Reniform	0.022	0.132	60	On plant	Open	Feb.-May	Mar.-Jun.
Trees	Euphorbiaceae	*Ricinus communis* L.	Ovoid	37.967	1.400	200	On plant	Open-shrubby	Jan.-May	Feb.-Jun.
	Fabaceae	*Acacia farnesiana* (L.) Willd.	Ovoid	6.962	0.600	300	On soil	Dense-umbrella	Feb.-Apr.	May-Aug.
	Fabaceae	*Acacia tortilis* (Forssk.) Hayne	Ovoid	1.815	0.450	500	On soil	Dense-umbrella	Apr.-Jun.	May-Aug.
	Fabaceae	*Prosopis cineraria* (L.) Druce	Ovoid	1.954	0.570	1000	On soil	Dense-rounded	Apr.-Jun.	May-Aug.
	Fabaceae	*Prosopis juliflora* (Sw.) DC.	Ovoid	3.045	0.560	900	On soil	Dense-umbrella	year-round	year-round
	Lythraceae	*Lawsonia inermis* L.	Spatulate	0.099	0.160	400	On plant	Dense-subrounded	Sept.-Apr.	Nov.-May

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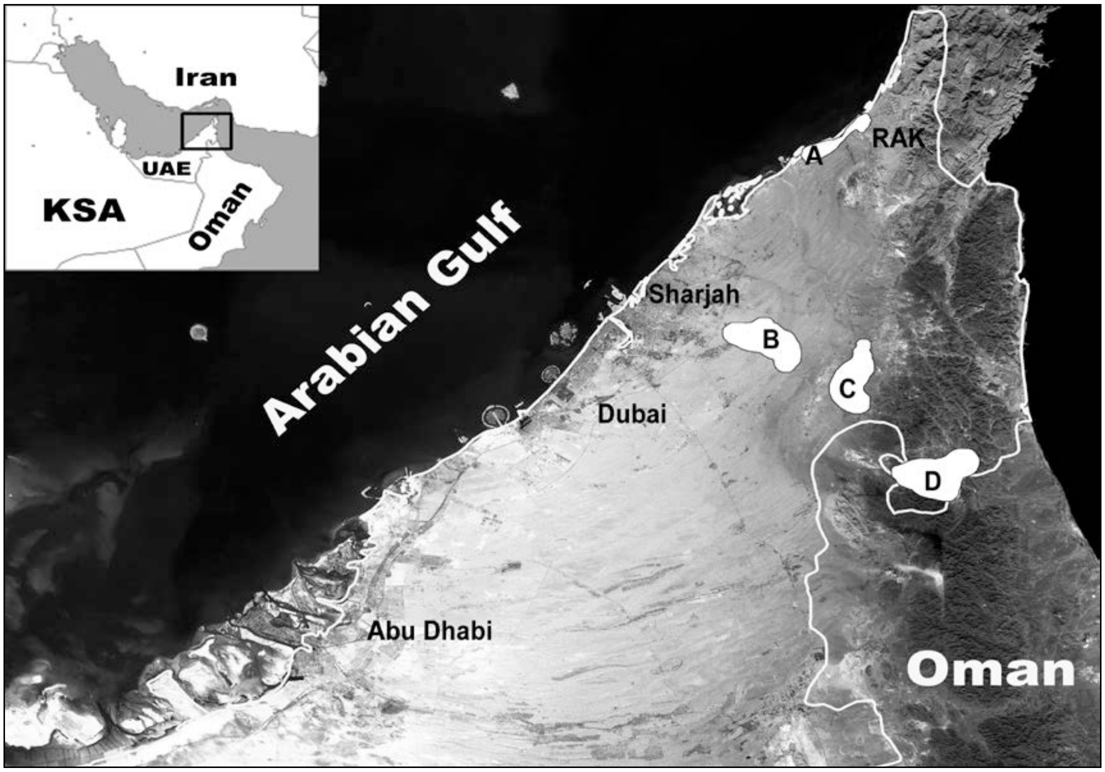
Figure 2.1. Four different sampling sites in the United Arab Emirates. A, coastal salt flats; B, sand sheets; C, gravel plains; D, mountains.



Freshly collected seeds of the collection of 2015 were divided into two parts; one part was germinated immediately after collection (hereafter referred as fresh seeds) and the second part was stored in brown paper bags at room temperature (20 ± 2 ºC) until their germination in February 2016 (hereafter referred as room temperature storage). On February 2016, seeds of the field storage were immediately germinated after collection. Germination was conducted in May - June for freshly harvested seeds and in February for room temperature- and field-stored seeds. The germination was conducted in February, when most species germinate in the Arabian deserts.

2.2.4. *Germination experiment*

The germination was conducted in 9 cm petri dishes containing one disk of Whatman No. 1 filter paper, with 10 ml distilled water. Fresh and stored seeds of the different collections were germinated in three programmed incubators set 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. For each species, a total of 72 petri

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dishes were used: three seed collections (fresh, room temperature storage and field storage), three temperatures and two light regimes with four dish replicates in each treatment, each with 25 seeds. A seed was considered to be germinated when the radicle had emerged. Germinated seedlings were counted and removed every alternate day for 24 days. Seeds incubated in the dark were checked only once after 24 days; therefore, they were not exposed to any light during the incubation period.

2.2.5. *Data analyses*

Relative light germination (RLG) that expresses the light requirement for seed germination was calculated for every species according to Milberg et al. (2000) by dividing the germination percentage recorded in the light by the sum of the germination percentages observed in light and in darkness. The values vary from 0 (germination only in dark condition) to 1 (germination only in light).

For seeds germinated only in the light, germination speed was assessed by calculating germination rate index (GRI). GRI was estimated using a modified Timson index of germination velocity = $\Sigma G/t$, where G is the percentage of seed germination at 2 days intervals and t is the total germination period. The maximum possible value for GRI in our study was 50 (1200/24). The greater the value, the more rapid is the germination.

Four-way ANOVA was carried out to assess the effects of the four factors (growth form, seed storage, and light and temperature of incubation) and their interactions on final germination as a dependent variable. Three-way ANOVAs were used to assess the effect of three factors (growth form, seed storage and temperature of incubation) on both RLG and GRI as dependent variables. Tukey HSD test was carried out for multiple comparisons to determine significant differences among the treatments at $P = 0.05$. Pearson correlation coefficients (r) were used to assess the significance of the relationship between seed mass and final germination, RLG and GRI for each growth form at each temperature and each light regime. Both RLG and GRI were log-transformed and germination percentage was arcsine-transformed to meet the assumptions of ANOVA. These transformations improved normality of the distribution of the data. All statistical methods were performed using SYSTAT 13.

2.3. Results

2.3.1. *Seed size and mass variations*

Growth form was significantly related to average seed size ($F = 489.5$, $P < 0.001$) and mass ($F = 207.1$, $P < 0.001$). Trees had significantly larger and heavier seeds, compared to both shrubs and herbs; the average seed length and mass of trees was greater than that of shrubs by 36.2% and 870.6%, respectively, and greater than that of herbs by 54.9% and 948.7%, respectively. Similarly, average seed size and mass of shrubs was greater than that of herbs by 18.7% and 78.1%, respectively (Table 2.2).

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Table 2.2. Diaspore size "length" and mass (range and average ± SE) of different growth forms in four habitats, northern Emirates, United Arab Emirates. Numbers in parentheses are the number of species in each growth form.

Seed trait	Herbaceous (6)	Small Shrubs (11)	Trees (6)
Seed size (cm)			
Range	0.05 - 0.179	0.12 - 0.70	0.16 - 1.40
Average	0.107 ± 0.002	0.294 ± 0.008	0.656 ± 0.019
Seed mass (100 seeds/g)			
Range	0.003 - 0.113	0.006 - 3.35	0.01 - 37.97
Average	0.033 ± 0.002	0.814 ± 0.042	9.52 ± 0.706

2.3.2. *Effect of storage condition and growth form on germination traits*

There were significant effects for storage condition, growth form, and light and temperature of incubation on final germination (Table 2.3). Generally, room temperature storage, but not field storage, significantly improved final germination, compared to fresh seeds. Overall, germination of herbaceous and tree species was significantly greater than that of shrubs. In addition, overall germination in light was significantly greater than in darkness (Fig. 2.2). Moreover, germination was significantly greater at moderate temperatures (20/30 °C, 36.0%) than at higher temperatures (25/35 °C, 33.2%). As the interactive effect of temperature with growth form and storage condition was not significant, result of temperatures are not shown.

The interaction between storage condition, growth form and light of incubation was significant ($P < 0.001$) (Table 2.3). The germination of fresh and room temperature- stored seeds of herbaceous plants was significantly greater in light, but not in dark, compared to that of shrubs and trees seeds. However, germination of field-stored seeds of trees was significantly greater in both light and dark than that of the other two growth forms. Germination was significantly greater in light than in dark in seeds of herbaceous plants stored in different conditions. In both shrub and tree species, germination was significantly greater in light than in dark for field-stored seeds, but not for fresh or room temperature-stored seeds (Fig. 2.2).

The effects of both light and growth form on RLG were significant ($P < 0.001$) (Table 2.3). Germination needed more light in herbaceous plants (RLG = 0.73 ± 0.02), than either shrubs (RLG = 0.58 ± 0.01) or trees (RLG = 0.56 ± 0.0). In addition, RLG was significantly greater at 25/35 ºC (RLG = 0.66 ± 0.01) than at 15/25 ºC (RLG = 0.57 ± 0.01).

The interactive effect of storage type and growth form on GRI was significant ($P < 0.01$, Table 2.3). Field-stored seeds of trees germinated faster than both fresh and room temperature-stored seeds. In both herbs and shrubs, however, room temperature seeds attained significantly faster germination than fresh seeds and field-stored seeds (Fig. 2.2).

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Table 2.3. Results of ANOVAs showing the effects of seed storage, growth form, and light and temperature of incubation on final germination percentage, relative light germination and germination rate index in 23 desert plants, northern Emirates, United Arab Emirates. Ns, not significant at *P* = 0.05

Source	**Df**	**Mean Squares**	**F-Ratio**	***P*-Value**
Final germination				
Growth form (GF)	2	10.103	75.887	<0.001
Storage (S)	2	2.444	18.357	<0.001
Temperature (T)	2	0.422	3.166	<0.05
Light (L)	1	9.507	71.409	<0.001
GF * S	4	1.803	13.545	<0.001
GF * T	4	0.245	1.840	Ns
GF * L	2	3.060	22.986	<0.001
S * T	4	0.029	0.217	Ns
S * L	2	0.080	0.598	Ns
T * L	2	0.482	3.622	<0.05
GF * S * T	8	0.075	0.561	Ns
GF * S * L	4	0.655	4.921	<0.001
S * T * L	4	0.015	0.110	Ns
GF * T * L	4	0.163	1.224	Ns
GF *S * T * L	8	0.073	0.548	Ns
Error	1.314	0.133		
Relative light germination				
Growth form (GF)	2	1.347	48.640	<0.001
Storage (S)	2	0.038	1.378	Ns
Temperature (T)	2	0.300	10.838	<0.001
GF * S	4	0.048	1.724	Ns
GF * T	4	0.024	0.850	Ns
S * T	4	0.020	0.717	Ns
GF * S * T	8	0.021	0.746	Ns
Error	462	0.028		
Germination rate index				
Growth form (GF)	2	0.698	4.036	<0.05
Storage (S)	2	1.133	6.557	<0.01
Temperature (T)	2	0.385	2.230	Ns
GF * S	4	0.744	4.303	<0.01
GF * T	4	0.021	0.124	Ns
S * T	4	0.161	0.932	Ns
GF * S * T	8	0.081	0.466	Ns
Error	565	0.173		

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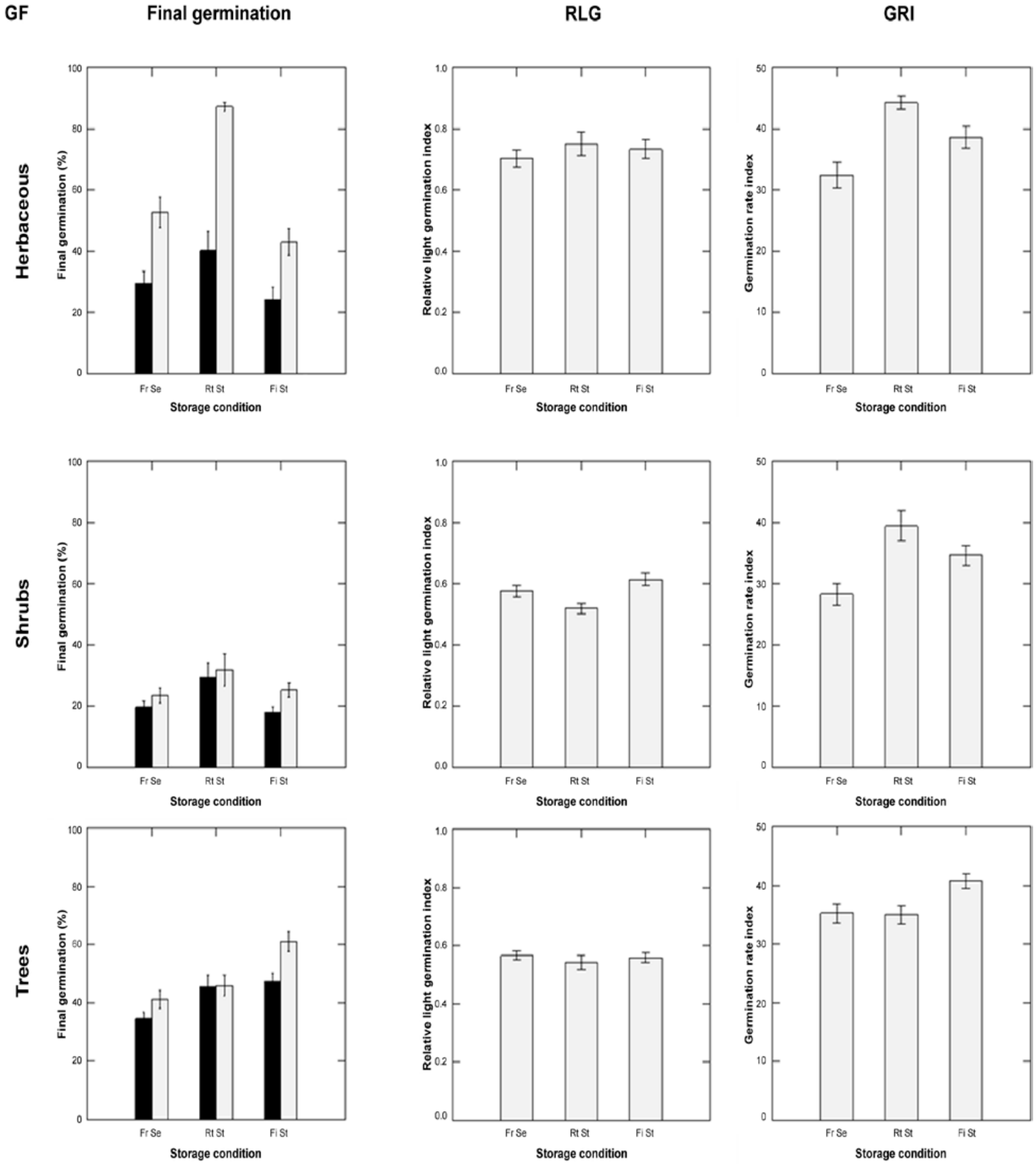
Figure 2.2. Effects of growth form, seed storage condition and light of incubation on final germination percentage, relative light germination and germination rate index (mean ± SE) of desert plants. Dark bar, dark; light bar, light; GF, Growth form; Fr Se, Fresh seeds; Rt St, Room temperature storage; Fi St, Field storage.



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2.3.3. *Correlations between seed and germination traits*

2.3.3.1. *All species*

The overall results for the 23 species studied indicated that there was no significant relationship between seed mass and final germination rate and germination speed, expressed as GRI (Table 2.4). However, the direction and strength of the relationship depended on light conditions; whereas the relationship was significantly positive in dark, it was significantly negative in light. This indicates that large-seeded species germinated better in dark, but small-seeded species germinated better in light. This trend was confirmed by the significant positive relationship between seed mass and RLG. The relationship between seed mass and GRI was not significant. However, these relationships varied greatly based on growth forms (Table 2.4).

Table 2.4. Pearson correlation coefficient (*r*) showing the relationship between seed mass and different germination traits of seeds of different growth forms germinated in light and dark conditions, northern Emirates, United Arab Emirates. ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$.

Growth form	Light condition	Final germination	RLG	GRI
Herbaceous	Light	0.460***	-0.626***	0.410***
	Dark	0.818***		
	Overall	0.594***		
Shrubs	Light	-0.183*	0.257**	-0.069
	Dark	-0.243***		
	Overall	-0.208***		
Trees	Light	-0.501***	- 0.536***	-0.277**
	Dark	0.148		
	Overall	-0.203**		
Overall	Light	-0.129**		
	Dark	0.181***		
Overall		0.012	-0.311***	-0.064

2.3.3.2. *Among growth forms*

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There were positive significant relationships between final germination in light and in darkness with seed mass of herbaceous plants. However, this relationship was significantly negative for shrubs. In trees, the relationship between final germination rate and seed mass was significantly negative in light, but not significant in dark. In trees, small-seeded species had lower germination in dark and higher germination in light (Table 2.4).

The relationship between seed mass and RLG was significantly negative for seeds of both herbaceous and tree species and was significantly positive for seeds of shrubs, indicating that small seeds of the first two groups require light for germination, while small-seeded shrubs do not require light to germinate (Table 2.4). In addition, there were significant positive relationships between GRI and seed mass of seeds of herbaceous and small shrubs. However, this relationship was significantly negative for seeds of trees. This indicates that germination was more rapid for larger seeds of herbs and shrubs and the reverse was true for the seeds of trees (Table 2.4).

2.4. Discussion

The results of this study showed that seed size and mass differed among plants of the different growth forms; the order of seed size and mass were: trees > shrubs> herbs. However, within each growth form, different trends of the relationships between seed mass and both final germination and germination speed were observed. This would explain the contradictions among studies that have assessed the relationship between seed size and germination rate (e.g., Pake & Venable 1996, Galíndez et al. 2009, Wang et al. 2017, El-Keblawy 2017a), despite that theoretical models had suggested that dormancy would be negatively correlated with seed mass (e.g., Rees 1996, de Casas et al. 2017).

Several studies have reported a significant effect of dry storage on seed dormancy of desert plants (Gutterman 2000, Allen & Meyer 2002, El-Keblawy & Al-Rawai 2006). In non-desert species, however, germinability has remained unaffected or reduced after dry storage (Baskin & Baskin 1998). Such inconsistency in the results could be attributed to storage conditions and periods. Our results indicate that field storage did not affect the germination of seeds of herbs and shrubs, while the seed germination of trees was greater after field storage. All the studied trees belong to Fabaceae, which have seeds with physical dormancy. Under field condition, physical dormancy of many species is broken down by scarification by drifting sand (Baskin & Baskin 2000). In addition, thick seed coat of seeds with physical dormancy might become permeable to water by mechanical abrasion and microbial attack (Mayer & Poljakoff-Mayber 1989). Further, diurnal fluctuations in day and night moisture and temperatures could result in breaking down physical dormancy (Moreno-Casasola et al. 1994). Storage of large seeds, such as those of the Fabaceae, on soil surface might expose them to an increase in the fluctuation and magnitude of temperature, which help in breaking their physical dormancy (Vázquez-Yanes & Orozco-Segovia 1982, Baskin & Baskin 2000).

Room temperature storage resulted in greater germination rate of herbaceous seeds in light, compared to dark. However, there was no significant difference between light and dark germination for room-stored seeds of trees and shrubs. Seed size difference could explain the differential responses of seeds stored at different conditions to light during germination. Generally, room temperature storage could mimic the natural conditions under litter; by reducing diurnal temperatures fluctuations (El-Keblawy & Al-Rawai 2006). Despite seeds of the three growth forms have the chance to be stored under accumulated litter, light was a requirement for

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smaller seeds of herbaceous plants, but not for the larger seeds of shrubs and trees. Greater light requirement of smaller seeds of herbs (average seed mass was 0.33 g) (Table 2.2) would ensure their germination after their dispersal, before becoming buried by litter. The little resources available in small seeds could not be enough to secure seedling emergence from under the litter. Conversely, large resources available in larger seeds could help seedling establishment under such conditions (Herrera 2002, Wright et al. 2007).

In herbaceous plants, positive relationships were observed between seed mass and both final germination and GRI (Tables 2.4). This indicates that large-seeded herbs can germinate to a higher level and faster in both light and dark, compared to small-seeded herbs. This further indicates that small-seeded herbs contribute more of their seeds to soil seed bank, but large-seeded herbs invest more in the regeneration. It seems that large-seeded herbs are more opportunistic and germinate whenever conditions are favourable for recruitment (Chambers & MacMahon 1994). The relatively greater food reservoirs of larger seeds would encourage granivores to consume them if they were stored in a soil seed bank (Herrera 2002, Wright et al. 2007). However, herbs with small seeds distribute the risk over time. Such bet hedging strategy could be understood as an insurance against reproduction failure, which could increase long-term fitness (Venable & Brown 1988). It could also be explained as a form of risk spreading in temporally variable, unpredictable environments (El-Keblawy 2017a). In addition, in response to spatial uncertainty of seed landing in highly heterogeneous patchy desert environments, small-seeded herbaceous plants retain a fraction of un-germinated seeds for possible future germination opportunities in potentially more favourable years (Saatkamp et al. 2014).

Our results indicated that the germination response to light was related to seed mass in herbaceous plants; small-seeded herbs required more light for germination, but large-seeded ones germinated better in darkness. Schütz et al. (2002) reported similar result in their study of the germination of four annual Asteraceae; herbaceous annual *Ursinia anthemoides* and *Podotheca chrysantha* that have larger seeds germinated better in darkness than in light, whereas germination in *Millotia myosotidifolia* that has the smallest seeds was almost exclusively confined to light. A similar result was also reported in ten Asteraceae species from south-western Australia; a light requirement for germination was recorded for seeds weighing less than 0.5 mg, whereas the response varied among species with heavier seeds (Plummer & Bell 1995). These findings indicate that small seeds might detect their position in the soil through light requirement; thereby small seeds buried too deep in the soil avoid possible fatal germination (Grime 1979, Milberg et al. 2000). Consequently, small buried seeds of herbs could delay their germination until any possible disturbance that brings them to soil surface (El-Keblawy & Gairola 2017, El-Keblawy 2017a). Small seeds have little resources, which limits seedling emergence from a depth deeper than superficial soils (Bewley & Black 1994). However, the more food reserves allocated to seeds the more able they are to emerge from deeper soil (El-Keblawy 2017a, b).

In shrubs, a negative relationship was observed between seed size and final germination rate. This relationship was true in both light and dark (Table 2.4). In addition, the positive

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relationship between seed mass and RLG indicates that the fewer large seeds that could germinate do so mainly in light. As larger seeds of shrubs need light to germinate, they should be dispersed away from their canopies, a mechanism similar to gap detection in forests (Leishman & Westoby 1994, Venier et al. 2016). Grazing could help in seed dispersal away from the maternal plants (Erfanzadeh et al. 2016). However, the positive relationship between seed mass and RLG indicates that small seeds germinate better in the dark. The better dispersal capacity of small seeds increases their opportunity to find safe sites such as moist crevices that would increase the chances of successful seedling establishment (Rodriguez et al. 2017). If not germinated, such small seeds would enter the soil seed bank.

The relationship between seed size and final germination of trees was significantly negative in light, but was positive in dark, indicating that the studied trees adopted a strategy intermediate between shrubs and herbs; tree species with large seeds germinated better in the dark and those with small seeds germinated better in light. This was confirmed by the significant negative relationship between RLG and seed mass and could be explained in the light of the mode of dispersal of the tree species (Grime 1979, Milberg et al. 2000). All these species have evergreen leaves and form dense closed canopies. Five of the six trees have large seeds that are enclosed within fruit structures. Four of them belong to the Fabaceae family (*Acacia farnasiana*, *A. tortilis*, *Prosopis cineraria* and *P. juliflora*) and have secondary seed dispersal once fallen under the mother plant canopy. Their seeds have long-distance endozoochorous dispersal through grazing animals; the fifth (*Ricinus communis*) has long-distance exozoochorous dispersal on animal fur. The four endozoochorous species would disperse within the feces of grazing animals and consequently germinate in darkness; either within the feces or when feces buried in soil. When large seeds germinate under tree canopies they will produce larger seedlings that could compete with the mother trees in the long term. However, this might not be the case in relation to small shrubs; larger seedlings produced from large seeds would result in short term exclusion of their maternal plants.

2.4.1. *Conclusions*

The study showed that different growth forms produced seeds with different masses and with different germination responses. As predicted, trees and shrubs produced larger seeds with lower germination, but herbs produced smaller seeds with higher germination. Both small seeded herbs and trees germinated better in light than in dark. Small seeds of the two growth forms have the chance to disperse and bury and consequently required light for germination. The presence of different relationships between seed mass and germination rate among different growth forms does not support the theoretical models, which propose that germination is positively correlated with seed mass. However, such results would explain the contradictions among studies assessed the relation between seed size and germination rate (e.g., Pake & Venable 1996, Galíndez et al. 2009, Wang et al. 2017, El-Keblawy 2017a).

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2.5. References

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CHAPTER 3

Delayed seed dispersal in the hyper-arid hot desert of the United Arab Emirates (UAE)

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3.1. Introduction

Some plants gradually release their seeds. Such bet-hedging' strategy retains the mature seeds within the maternal canopy and delay their dispersal for varying periods of time (Cohen 1966, Brown & Venable 1986, Lamont & Enright 2000, Venable 2007, Peters et al. 2011); in a phenomenon called bradychory or delayed dispersal (Doussi & Thanos 1999, Thanos 2000, 2004). This known also as serotiny (Vogl et al. 1977, Lamont et al. 1991, Martínez-Berdeja et al. 2015) or bradyspory (Ellner & Schmida 1981, Stock et al. 1990, Meney et al. 1994, van Rheede van Oudtshoorn & van Rooyen 1999, Price & Morgan 2003). According to Thanos (2004), bradychory is wider as a term than serotiny and bradyspory where it can explain all cases of delayed dispersal (closed fruits as well as delay of seed dissemination). Therefore, bradychory is suggested to replace serotiny and bradyspory terms in the field of dispersal.

It has been documented that delaying seed dispersal in bradychoric species has many advantages (Lamont et al. 1991, Lamont & Enright 2000). Bradychory provides seeds with protection from predators (granivores) and/or abiotic stresses, such as heat, drought, fire, lack of nutrients (Enright et al. 1998a, b, Martínez-Berdeja et al. 2015). In addition, in desert environments, it has been reported that bradychory delays seed release until arrival of favourable conditions (e.g., rainfall) for seed germination and seedling establishment (Lamont 1991, Gutterman & Ginott 1994, Aguado et al. 2012, Gao et al. 2014, Martínez-Berdeja et al. 2015).

About 1200 bradychoric species belong to 40 different genera are distributed in different regions in the world such as Mediterranean, south-western Australia, South Africa, and North America regions and, semi-arid and arid regions (Groom & Lamont 1998, Lamont & Enright 2000, Navarro et al. 2009a, b, Gao et al. 2014, Martínez-Berdeja et al. 2015). For the arid regions, Gutterman & Ginott (1994) recorded about 40 bradychoric species in Negev and Sinai deserts. Navarro et al. (2009a, b) recorded 27 bradychoric species in arid high mountains from the Moroccan Atlas and 40 species from SE Spain arid shrublands. Martínez-Berdeja et al. (2015) recorded 30 bradychoric species in the Mojave and Sonoran deserts in California and Gunster (1992) recorded 11 species in the central Namib Desert.

In desert environments with unpredictable climate, in many species, seeds stored on mother plants are exposed to diurnal and seasonal fluctuations rains, atmospheric moistures, wind, hydration-dehydration cycles, temperature and light (Santini & Martorell 2013, Gao et al. 2014, El-Keblawy & Bhatt 2015). These conditions could help breaking the dormancy of these

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seeds thus reduce germination requirements and result in faster germination immediately after dispersal (Gao et al. 2014, El-Keblawy et al 2018).

It has been suggested that bradychory is associated with specific plant traits, such as seed dispersal (e.g., spatial dispersal), plant life traits (e.g., life cycle, growth forms and plant height) (Gunster 1994, Navarro et al. 2009a, b) and the mechanisms that prevent the dispersion of diaspore away from the mother plant (antitelechoric mechanisms) (Gutterman 1994). Navarro et al. (2009a) reported an association between bradychory and trees and large shrubs that are dispersed by biotic vectors. Ellner & Shmida (1981) and Kamenetsky & Gutterman (1994) reported evidences for the association of growth forms and bradychory in the Negev Desert. Gunster (1994) demonstrated the predominance of bradychory in annual species, compared to perennials. Gutterman (1993, 2001) and Kamenetsky & Gutterman (1994) show the relationships between bradychory and two antitelechoric mechanisms, myxospermy and synaptospermy in Negev Desert.

The United Arab Emirates (UAE) is hyper-arid hot desert (Abdelfattah 2013, El-Keblawy et al. 2015, Shabana et al. 2018). The ecophysiological properties of the seasonal hyper-arid hot desert ecosystems are largely determined by the duration and seasonality of the dry period, which selects ecological adaption strategies related to avoidance, resistance, or tolerance of the water stress or survival strategies. One of these adaption strategies is the retention of mature seeds on mother plants and the delay in their dispersal for varying periods of time (Gutterman 1994, 2002, Singh & Kushwaha 2005).

In the desert of the Arabian Peninsula, which is characterized by extreme seasonality in rainfalls and temperatures, there is no studies assessed the prevalence of the bradychory and its relationships with other plant traits, such as growth forms, dispersal traits, and antitelechoric mechanisms (e.g., myxospermy, synaptospermy and trypanocarpy). The aims of this study are: (1) to identify the bradychoric species in the UAE flora and (2) to assess the relationships between bradychory and growth forms, plant habits, dispersal traits, antitelechoric mechanisms and seed release time in a hyper-arid hot desert. The results of this study would be important in understanding bradychory as a plant survival adaption in arid hot desert with erratic seasonal rainfalls.

3.2. Material and Methods

3.2.1. *Study area*

The United Arab Emirates is located in the south-eastern part of the Arabian Peninsula between latitudes 22° 40' and 26° 00' north and longitudes 51° 00' and 56° 00' east. The total area covers about 83.600 Km^2. The climate is a hyper-arid hot and it can be distinguished into two main seasons. The rainy season (November to March) is short with mild temperatures (mean temperature is about 20 °C). The dry season is longer and hot; average temperature ranges between 35 - 40 °C and can reach 47 °C (Merabtene et al. 2016). The rainfall is very scarce and

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erratic and concentrated in only four months from November to February (Böer 1997, Sherif et al. 2009, UAE Ministry of Energy 2012).

3.2.2. *Bradychoric species identification*

The incidence of bradychory was examined in 307 species in several field trips (May 2014 - October 2016) in four inland habitats (gravel plains, mountains, salt flats and sand sheets) in the UAE. The selected species cover the most common and some rare perennial species that characterize the vegetation of the UAE (Jongbloed 2003, Karim & Fawzi 2007a, b). Voucher specimens of studied species were kept in the Sharjah Seed Bank and Herbarium, Sharjah Research Academy. Botanical nomenclature follows The International Plant Names Index (IPNI 2016).

Bradychoric species were identified according to the duration of seed retention in mother plants. A species was defined as bradychoric when seeds are retained on the mother plants for more than six months (Thanos 2004). We classify the bradychoric species into five species groups following Martinez-Berdeja et al. (2015), these groups are based on the morphological structures that retain the seeds on the plants, dispersal characteristics, diaspore traits and growth season. The first group (hereafter referred as "basicarpic species") has the species that produce flowers immediately above ground level and release their seeds in response to rainfall or sand storms events which correspond to the basycarpy described by Ellner & Shmida (1981). The second group (gradually open capsules species) comprise species with woody branches hold lignified capsules or calyx that open and gradually release seeds along more than one season. In these species, exposure to rainwater accelerates fruits opening (Walck & Hidayati 2007). The third group (species with schizocarpic fruits) includes species produce schizocarpic dry fruits that are developed from multiple carpels split up into mericarps when matured. Sometimes, the mericarp itself is the dispersal unit and the diaspores could be retained for relatively long time (Shreve & Wiggins 1964). The fourth group (species with persistent fruits) is characterized by the presence of the persistent dried or fleshy fruits that retain indehiscent fruits for long time. Finally, the fifth group (species with persistent lignified fruits) has species retain seeds in dry or persistent lignified fruits for long periods in the dried plant.

3.2.3. *Studied plant traits*

The classification of plant growth forms and plant habits follow Weiher et al. (1999), Cornelissen et al. (2003) and Pérez-Harguindeguy et al. (2013). Growth forms were categorized to: 1- herbaceous form; which has plants with stems and roots with soft tissues and divided into "short basal, semi-basal, erect leafy, tussocks", 2- dwarf shrubs; with a woody base and multiple woody stems (< 0.8 m tall), 3- shrubs; with main canopy close to the soil surface on one or more short woody trunks (> 0.8 m tall) and 4- trees; which is woody plants with main canopy elevated on a substantial trunk (> 0.8 m tall).

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The main growth forms recognized to perennial, annual and graminoids (six perennial and one annual species).

Plant habits were erect (with ascending stems), prostrate (with branches spreading or lying on the ground) and short basal (erect with leaves concentrated very close to the soil surface).

The antitelechoric mechanisms (van Rheede van Oudtshoorn & van Rooyen 1999) include synaptospermy “two or more seeds or one-seeded fruits are joined together to form a compound diaspore” (Ellner & Shmida 1981, van Rooyen et al. 1990), myxospermy “ability of a seed to produce mucilage upon hydration” (van Rooyen et al. 1990, Garcia-Fayos et al. 2010, 2013), trypanocarpy “dispersed fruit turning around, creeping or drilling by hygroscopic movement” (van Rooyen et al. 1990). We scored whether species had diaspores equipped with structures that facilitate spatial dispersal (developed spatial dispersal), such as pappi, barbs or wings for dispersal by abiotic vectors (e.g., wind) (developed dispersal by abiotic vectors) or fleshy fruits to disperse by biotic vectors (e.g., vertebrate) (developed dispersal by biotic vectors) (Ellner & Shmida 1981, Venable & Levin 1985, Cain et al. 2000, Navarro et. al 2009a). Species were considered as having restricted dispersal if diaspores lacked such dispersal-enhancing characters (restricted spatial dispersal) (Willson 1993). In order to describe the release time and seasonality, the species were observed 10 - 12 times every; with approximately 30 - 45-day intervals during 2 years and 6 months during the study time (Appendix 3.1).

3.2.4. *Data analyses*

A nonlinear principal components analysis (NLPCA) (De Leeuw 1982) was used for comparison and representation of the results to identify the main attributes that recognize dispersal strategies. NLPCA is similar to principal components analysis. It can handle variables of different types simultaneously and deal with nonlinear relationships between variables. Relationships between traits were assessed with Pearson Chi-square tests. All statistical analyses were performed by using SPSS 14 and SYSTAT 13.

3.3. Results

A total of 46 bradychoric species were identified in our study, which represent around 15.0% of 307 studied species. These species belong to 22 families and 37 genera (Appendix 3.1). Fabaceae was the predominant family in bradychoric species (8 species, 17.4% of total species). Dwarf shrubs and annual herbs (41.3% and 23.9%, respectively) were the growth forms with greater presence of bradychoric species. The most dominant bradychoric species group was species with persistent fruits (13 species, 28.3%), followed by basicarpic species, gradually open capsules species and species with persistent lignified fruits (each represented by 10 species, 21.7%) and species with schizocarpic fruits (3 species, 6.5%).

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3.3.1. *Bradychoric species groups and related studied traits*

NLPCA analysis results distinguished the five major bradychoric species groups, basicarpic species (B), species with persistent fruits (PF), gradually open capsules species (GO), species with schizocarpic fruits (S) and species with persistent lignified fruits (PLF) (Fig. 3.1). The first principal component accounted for 39.1% of variance and had high loadings from synaptospermy and spatial dispersal (Table 3.1). It separated species with developed spatial dispersal and synaptospermy (species with persistent fruits (PF)) (e.g., *Zilla spinosa*, *Aerva javanica* and *Indigofera oblongifolia*) from species with restricted spatial dispersal (basicarpic species (B)) (e.g., *Mesembryanthemum nodiflorum*) (Appendix 3.1).

The second principal component accounted for 26.2% of the variance and had a high positive loading with main growth forms (annual, perennial and graminoids), plant habit and myxospermy (Table 3.1). It separated species with persistent lignified fruits (PLF) which have mainly graminoids with erect habit and non myxospermic (e.g., *Juncus* sp.) from the basicarpic species (B) which includes prostrate annual and myxospermic species (e.g., *Aizoon canariense*) (Appendix 3.1).

The correlations among traits used in the NLPCA analysis are shown in table 3.2.

Figure 3.1. Ordination plot of the 46 studied species using Nonlinear Principal Components Analysis (NLPCA). Diamond full, basicarpic species (B); circles empty, gradually open capsules species (GO); circles full, species with persistent fruits (PF); square empty, species with persistent lignified fruits (PLF); star full, species with schizocarpic fruits (S).

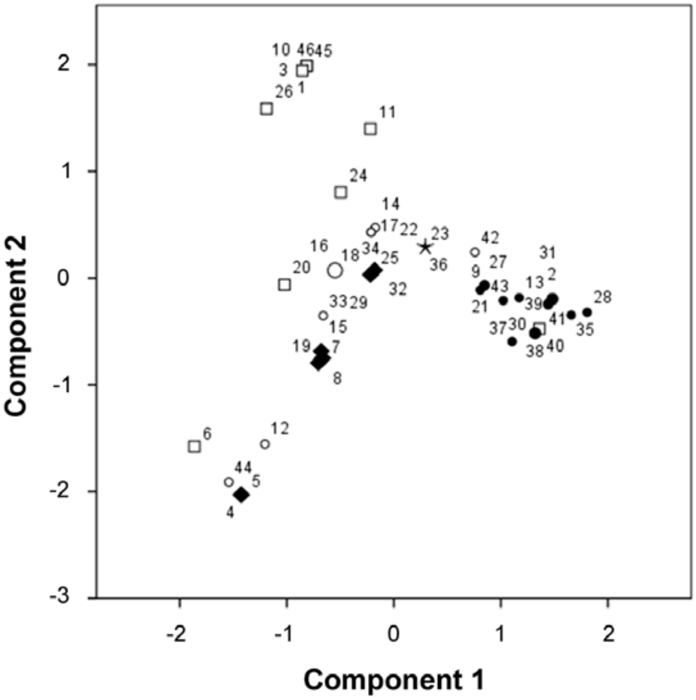

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Table 3.1. Loading of seven studied traits on the first two components of Nonlinear Principal Components Analysis (NLPCA).

Traits	**Components**	
	1	**2**
Main growth form	0.177	0.616
Plant habit	0.277	0.509
Seed release time	0.178	0.078
Spatial dispersal	0.541	0.035
Myxospermy	0.347	0.387
Synaptospermy	0.742	0.010
Trypanocarpy	0.187	0.007
Active Total	3.125	2.095
% of Variance	39.058	26.183

Table 3.2. Pearson correlations between the studied traits. ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; P. Habit, Plant habit; S.R.T, Seed release time; G.Forms, Main growth forms; S.Dispersal, Spatial dispersal; Myx, Myxospermy; Syn, Synaptospermy; Try, Trypanocarpy.

Traits	**P.Habit**	**S.R.T**	**G.Forms**	**S.Dispersal**	**Myx**	**Syn**	**Try**
Plant habit	1.000						
Seed release time	-0.393*	1.000					
Main growth form	-0.233*	-0.093	1.000				
Spatial dispersal	-0.206	0.097	-0.192	1.000			
Myxospermy	-0.620***	0.275	0.223	0.349*	1.000		
Synaptospermy	-0.292	0.143	-0.199	0.668***	0.404**	1.000	
Trypanocarpy	-0.082	0.161	-0.112	0.176	0.139	0.345*	1.000
Eigenvalue	1.829	1.013	0.888	0.500	0.356	0.342	0.134

3.3.2. *Relationships between bradychory and dispersal traits (spatial dispersal)*

Bradychoric species were mainly restricted spatial dispersal (31 species, 67.4%) (Appendix 3.1).

Bradychoric species groups were significantly related to spatial dispersal ($\chi^2 = 31.663$, df = 8, $P < 0.001$). Basicarpic species (8 species), gradually open capsules species and species with lignified persistent fruits (9 species each one) were restricted dispersal species. However, within species with persistent fruits (13 species), only 5 species were restricted spatial dispersal and 8 were developed spatial dispersal species. All schizocarpic species were spatial dispersal by abiotic vectors (Fig. 3.2).

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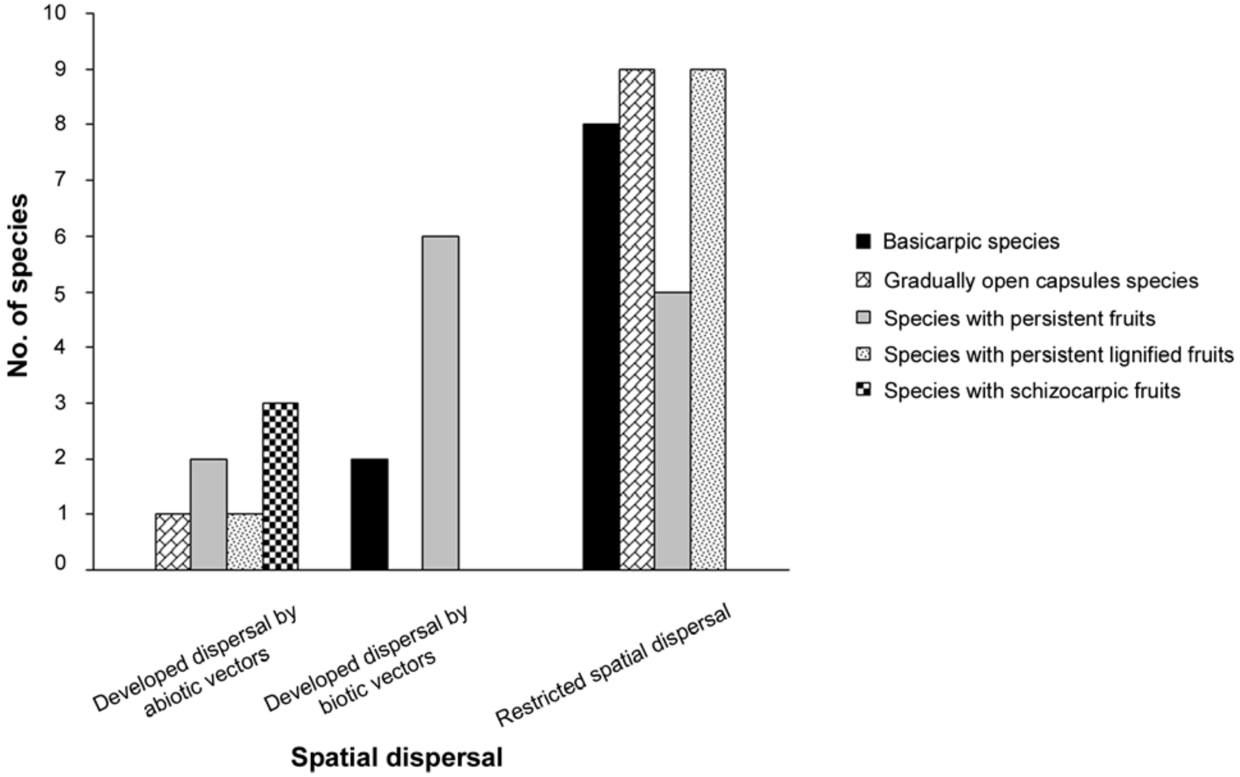
Figure 3.2. Relationships between bradychoric species groups and spatial dispersal.



3.3.3. *Relationships between bradychory, and main growth forms and plant habits*

The perennial bradychoric species were predominant (28 species, 60.9%), followed by annuals (11 species, 23.9%) and graminoids (7 species, 15.2%) (Appendix 3.1).

Bradychoric species groups were significantly related with the main growth forms (χ^2 = 46.373, df = 8, $P < 0.001$). All graminoids species were species with persistent lignified fruits. Among perennials (28 species), 13 were species with persistent fruits and 8 gradually open capsules species. Most part of annuals species were basicarpics (63.0%) (Fig. 3.3).

The bradychoric species were mainly species with erect habit (30 species, 65.2%) and only 21.7% were prostrate (10 species) and 13.0% short basal plants (6 species) (Appendix 3.1).

Bradychoric species groups were significantly related with plant habits (χ^2 = 34.394, df = 8, $P < 0.001$). Most basicarpic species were prostrate (80.0%). Erect habit was overrepresented in species with persistent fruits (11 species), followed by species with persistent lignified fruits (9 species) and gradually open capsules species (7 species). All schizocarpic species were erects (Fig. 3.4).

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Figure 3.3. Relationships between bradychoric species groups and main growth forms.

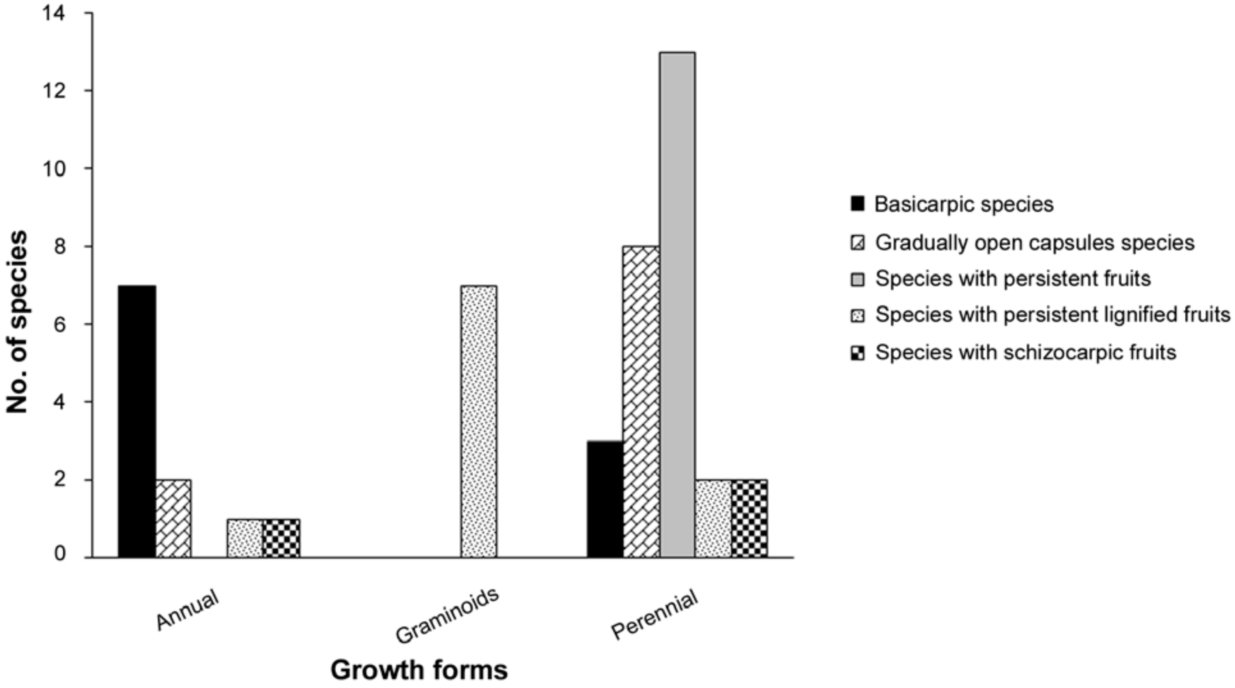
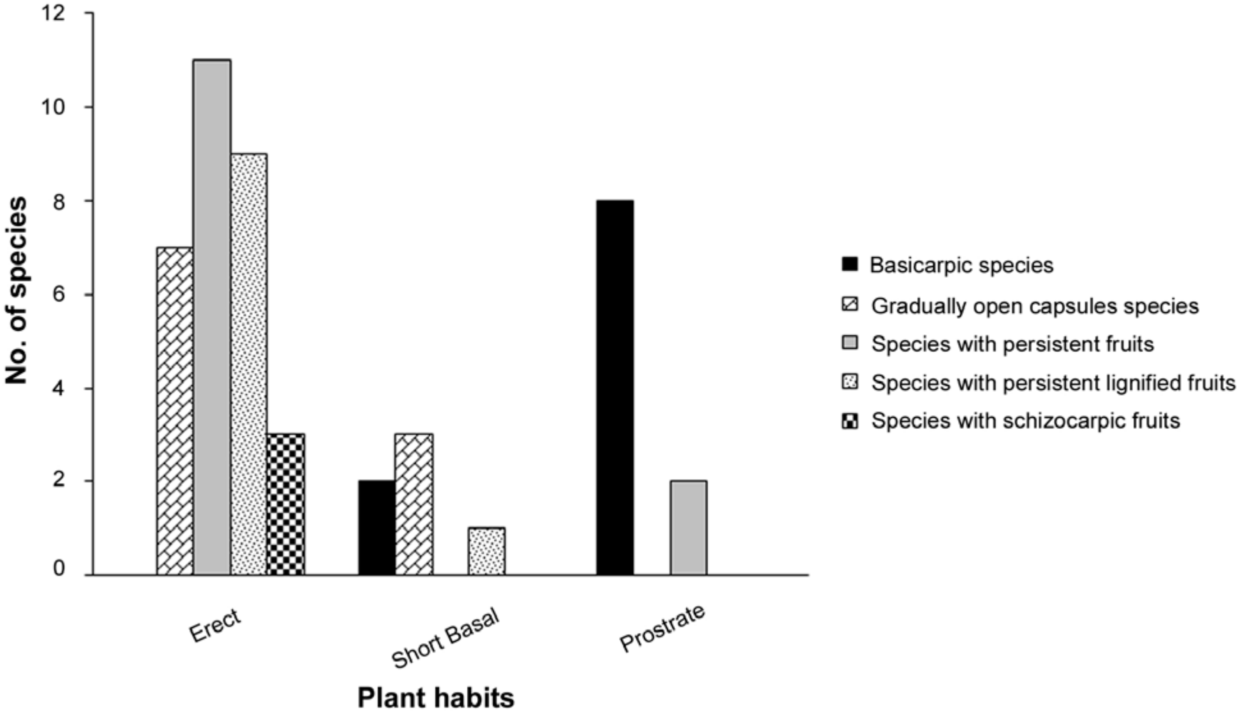


Figure 3.4. Relationships between bradychoric species groups and plant habits



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3.3.4. *Relationships between bradychory and the antitelechoric mechanisms*

Among the three analyzed antitelochoric mechanisms (myxospermy, synaptospermy and trypanocarpy), synaptospermic bradychoric species (37.0%) and myxospermy (21.7%) were the most dominant (Table 3.3 and Appendix 3.1).

There were significant relationships between bradychoric species groups and each of myxospermy and synaptospermy ($P < 0.05$) (Table 3.3). Synaptospermy was predominant in species of persistent fruits (13 species) (e.g., *Ricinus communis* and *Zilla spinosa*) and absent in species with schizocarpic fruits (Table 3.3).

Table 3.3. The relationships between bradychoric species groups and antitelochoric mechanisms.

	Myxospermy	**Synaptospermy**	**Trypanocarpy**	**Overall bradychory**
Basicarpic species	5	2	1	10
Gradually open capsules species	3	1	0	10
Species with persistent fruits	0	13	2	13
Species with persistent lignified fruits	2	1	0	10
Species with schizocarpic fruits	0	0	0	3
χ^2	9.558	31.407		
P	< 0.05	< 0.001		
Total	10	17	3	46

3.3.5. *Bradychory and seed release time*

Bradychory was not related with the time of seed release ($\chi^2 = 4.740$, $P > 0.05$); yet, species that release their seeds in the dry season were more frequent (21 species), compared to those released their seeds in rainy (9 species) and in both rainy and dry seasons (16 species) (Appendix 3.1).

There was no significant difference in the average number of months required for seeds to be released in the different bradychoric species groups (seed storage time); it ranged between eight months for most bradychoric species groups (basicarpic species, species with persistent fruits, species with persistent lignified fruits and species with schizocarpic fruits) and seven months for gradually open capsules species. The dry season was the main release time for species with persistent fruits and species with schizocarpic fruits (Appendix 3.1).

3.3.6. *Relantionships between bradychory and studied habitats*

The number of bradychoric species didn't differ between the different habitats; 25, 23, 22 and 11 species in sand sheets, gravel plains, mountains and salt flats, respectively (Appendix 3.1).

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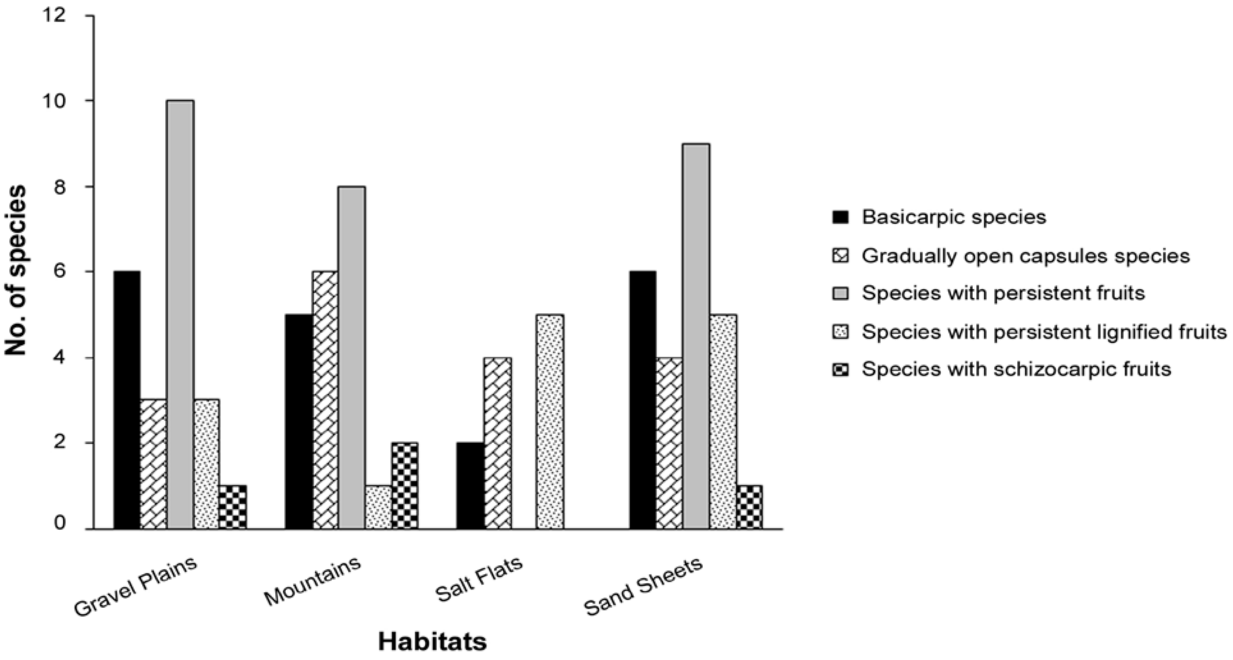
There was no significant relationship within bradychoric species groups and habitats ($\chi^2 = 16.173$, df = 12, $P > 0.05$). All bradichoric species groups were represented in all habitats, except for species with persistent fruits and species with schizocarpic fruits which were not present in salt flats. Interestingly, species with persistent fruits were the most common in sand sheets, mountains and gravel plains. In salt flats, the predominant groups were species with persistent lignified fruits and gradually open capsules species (Fig. 3.5).

Figure 3.5. Relationships between bradychoric species groups and the four inland studied habitats.



3.4. Discussion

The significant adaptation of seed retention (bradychory) in desert plants has been discussed in many studies, such as Ellner & Shmida (1981), Lamont et al. (1991), Gunster (1992, 1994), van Rheede van Oudtshoorn & van Rooyen (1999) and Lamont & Enright (2000). Delayed seed dispersal (bradychory) is widespread in regions with strongly seasonal climates, poor soils and recurrent fires (Bastida & Talavera 2002, Simon & Pennington 2012). It has also been described in arid and semi-arid regions, where it has been shown to play an important role in protecting seeds against soil-living granivores (Gunster 1994) or desiccation (Pritchard et al. 2004). In our study, 46 species, out of examined 307 species (15% of total) were bradychoric

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species. A similar proportion has been reported in the central Namib Desert (13% from the total species, Gunster 1992). However, Navarro et al. (2009a, b) and Rodriguez et al. (2017) reported that the bradychory represented 52.9% of the Moroccan High Atlas arid mountain, 33.5% of the south-east semi-arid shrublands vegetation and 48% in southern part of coastal dunes of Spain. This indicates that the representation of bradychory is less in hyper-arid hot deserts than in high mountains and semi-arid Mediterranean shrubland vegetation (Navarro et al. 2009a, b) and Mediterranean coastal dunes (Rodriguez et al. 2017).

In the unpredictable arid deserts, for some species, rainfalls stimulate dehiscence of diaspores through controlling the opening of specific structures such as scales and bracts. Under these conditions, plants regulate the timing of germination to coincide with time rainfalls (Gunster 1992, van Rheede van Oudtshoorn & van Rooyen 1999). In the UAE, the rainfall is temporally unpredictable and usually restricted to the short season (November-March). However, we recoded 21 species (46%) of the bradychoric species that disperse their seeds in the dry period of the year; i.e., before the arrival of the next rainy season. Similar results have been reported in the Moroccan High Atlas arid mountain (Navarro et al. 2009a) and the Mediterranean coastal dunes of Spain (Rodriguez et al. 2017). The high frequency of species that disperse their seeds in the dry period in our study could be explained in the light of the activity of granivores; species that release their seeds immediately after maturation would be exposed to granivores that are usually active by the end of the fruiting season. It has been reported that the activity of granivores are usually much less in the dry hot seasons than in moist cooler seasons of the year (Molokwu et al. 2010, Gremer & Venable 2014).

In the Negev and Sinai deserts, all the recorded bradychoric species (40 species) disperse their seeds in response to rainfalls (Gutterman 1994, Gutterman & Ginott 1994). In our study, however, only nine species released their seeds in response to rainfall. The lower incidence of rainy season dispersal in the UAE bradychoric species, compared to it in Negev and Sinai could be attributed to the regularity and frequency of effective rainfalls in the two regions. In the Mediterranean climate of Negev and Sinai, dispersal in response to rainfalls is more advantageous; rainfalls are more predictable and hence germination is predicted to happen in response to rainfalls (Gutterman & Ginott 1994, Gutterman 2002). In the arid deserts of the UAE, however, effective rainfall is unpredictable and therefore germination is not predictable (Feulner 2006). If seeds dispersed and germinated in response to ineffective rainfall they might die before reaching the next seasons (El-Keblawy et al. 1997). In addition, the dry season dispersal might be advantageous in the UAE as most of the species have innate dormancy (El-Keblawy & Gairola 2017, El-Keblawy et al. 2018). Seed dispersal in the dry seasons would help in breaking dormancy as the exposure to the diurnal fluctuation in moisture and temperatures is greater on soil surface than on mother plants (El-Keblawy & Bhatt 2015). Breaking seed dormancy would ensure germination after the arrival of effective rainfalls (El-Keblawy 2014).

Few studies have assessed the presence and advantages of bradychory in sand sheets of arid ecosystem (Zhang & Maun 1994, Wang & Liang 1995, Liu et al. 2005). In our study, we recorded 25 bradychoric species in sandy sheets (54.0% of the total bradychoric species examined in that habitat). Such high frequency of bradychory reflects the importance of bradychory in sandy habitats. In the loose sands, sand drifts by winds, which usually happen early in the growing season, is a major problem that would bury seeds deep in the soil (Glennie & Evamy 1968). In addition, early germination would expose seedling to burial (Peng et al. 2012). Furthermore, the fast water infiltration from the surface soils of sandy habitats leaves the top layer dry shortly after precipitation (El-Keblawy & Bhatt 2015, El-Keblawy et al. 2015). Consequently, delaying seed dispersal (bradychory) in species of sand sheets would postpones seed dispersal and germination till the end of windy seasons (Li 1980, Venable & Lawlor 1980, Liu et al. 2006, Ma & Liu 2008, Ma et al. 2010). Interestingly, we noticed that many of the bradychoric species on sand dunes have erect habit (14 out of 25 species). Those species can adapt the sand burial on active sand dunes (Gunster 1992).

In our study, bradychory was less represented in salt flats (23.9%). Similar results were reported in Namib Desert (Gunster 1992). In general, seed germination in salt flats is limited to the period after effective rainfalls that dilute soil salinity. Therefore, the time of rainfalls is the limiting factor that control successful seedling emergence and establishments in salt flats. The lower occurrence of bradychory in salt flats in the present cannot reflect the importance of delayed seed dispersal in this habitat. Interestingly, all the recorded bradychoric species in salt flats have restricted spatially dispersal. This reflects the special adaptation of the halophytes to survive only in very specific habitat type, which are the salt flats.

The present study showed overrepresentation of restricted dispersal (67.3%), compared to developed spatial dispersal (28.7%). The high incidence of restricted dispersal could be attributed to the heterogeneity of the UAE deserts. The distribution of vegetation in the UAE deserts is patchy with little gaps suitable for seedling establishment (El-Keblawy et al. 2015). However, restricted dispersal ensures that seeds dispersed in safe sites around mother plants (Rodriguez et al. 2017).

Biotic dispersal in arid desert is not a common phenomenon (Shabana et al. 2018). The environmental conditions of such deserts are not supporting the activities of the biotic vectors (Ellner & Shmida 1981). Our results indicated that only eight species (17.4%) of the 46 bradychoric species adopt the biotic dispersal. However, six of these eight species were species with persistent fruits (five species of *Indigofera* and *Solanum incanum*) are distributed by grazing animals. Seeds of these species are released with animal dungs and in many cases are able to germinate after their release. Seed passage through animal gut partially breakdown physical dormancy imposed by hard impermeable seed coats and should facilitate subsequent environmental scarification by soil abrasion or extreme temperature cycles (Ortega Baes et al. 2002, Campos et al 2008).

Interestingly, the species with persistent fruits were predominantly synaptospermics. The combination of synaptospermy and bradychory (e.g., *Zilla macroptera*) would improve seedling establishment and reduce diaspore losses through ant predation (Gutterman 2000 & 2001).

Species with basicarpy were overspread in all habitats of the hyper-arid hot deserts of the UAE (Fig. 3.5). Similarly, Martínez-Berdeja et al. (2015) reported that the basicarpic group was

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over represented in Mojave and Sonoran deserts in California. The basicarpy provide anchorage against surface run-off and protect diaspore from predation (Ellner & Shmida 1981, van Rheede van Oudtshoorn & van Rooyen 1999). Even in years when seed production is low, seed-predation on the basicarpic species is minimal (Ellner & Shmida 1981). In our results, basicarpic species were mainly annual and prostrate species and coinciding with Ellner & Shmida (1981), Navarro et al. (2009a) and Martínez-Berdeja et al. (2015).

Graminoid is typified by almost all grasses and sedges (Billings 1974, Zhang et al. 2004). In our study, seven graminoids species were recorded (five grasses and two sedges). All of these graminoids belonged to species with persistent lignified fruits. It was reported that the vegetative shoots of many graminoids, especially perennials, could die in response to weather conditions and with aging (Weaver & Zink 1946). For example, diaspore of *Setaria verticillata* (Ernst et al. 1992, Cheplick 1998, van Rheede van Oudtshoorn & van Rooyen 1999) *Stipa tenacissima* (Haase et al. 1995) are remained protected in inflorescence of their parent plant until suitable conditions are available for successful seed germination and seedling emergence.

3.4.1. *Conclusions*

Delayed seed dispersal (bradychory) is an important adaption that allow plants to cope with environmental variability and unpredictability of spatially and temporally unpredicted arid deserts. The presence of different groups of bradychory represents different types of survival adaptation in the hyper-arid hot desert of the UAE. Unlike predictable semi-arid deserts, bradychory did not depend mainly on the presence of the rainfall in the hyper-arid hot desert. This study is among the leading studies in Arabian deserts. More studies on the complete Arabian flora should be conducted to enhance our knowledge about bradychory in in the arid climate.

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3.6. Appendices

Appendix 3.1. The species, family, habitats, bradychoric species group, growth form, plant habit, main growth form, seed storage time, seed release time, dispersal traits (spatial dispersal), antitelechoric mechanisms (synaptospermy, trypanocarpy and myxospermy) of 46 bradichoric species found in the hyper-arid hot desert of the United Arab Emirates. Habitats: GP, gravel plains; M, mountains; SF, salt flats; SS, sand sheets. Growth forms: AH, annual herbs; DS, dwarf shrubs; GR, graminoids; LS, large shrubs; PH, perennial herbs; TR, trees. Habits: ER, erect; PO, prostrate; SB, short basal. Main growth forms: AN, annual; GR, graminoids; PE, perennial. Spatial dispersal: DAV, Dispersal by abiotic vectors; DBV, Dispersal by biotic vectors; RSD, restricted spatial dispersal.

Family and species	Habitats	Bradychoric species groups	Growth form	Plant habit	Main growth forms	Seed storage time (month)	Seed release time	Spatial dispersal	Synaptospermy	Trypanocarpy	Myxospermy
Acanthaceae											
Blepharis ciliaris (L.) B.L.Burtt	GP, M, SS	Species with persistent lignified fruits	PH	SB	PE	7	Rainy	RSD	A	A	P
Aizoaceae											
Aizoon canariense L.	GP, M, SS	Basicarpic species	AH	SB	AN	9	Rainy	RSD	A	A	P
Mesembryanthemum nodiflorum L.	SF	Basicarpic species	AH	PO	AN	9	Rainy & Dry	RSD	A	A	P
Amaranthaceae											
Aerva javanica Juss.	GP, M, SS	Species with persistent fruits	DS	ER	PE	10	Rainy & Dry	DAV	P	A	A
Arthrocnemum macrostachyum (Moric.) K.Koch	SF	Gradually open capsules species	DS	ER	PE	7	Dry	RSD	A	A	A
Halocnemum strobilaceum M.Bieb.	SF	Gradually open capsules species	DS	ER	PE	7	Rainy	RSD	A	A	A

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Family and species	Habitats	Bradychoric species groups	Growth form	Plant habit	Main growth forms	Seed storage time (month)	Seed release time	Spatial dispersal	Synaptospermy	Trypanocarpy	Myxospermy
Amaranthaceae (Continued)											
Halopeplis perfoliata Bunge ex Schweinf. & Asch.	SF	Gradually open capsules species	DS	ER	PE	10	Rainy & Dry	RSD	A	A	A
Suaeda aegyptiaca (Hasselq.) Zohary	SF, SS	Gradually open capsules species	AH	ER	AN	7	Rainy	RSD	A	A	A
Asclepiadaceae											
Glossonema varians Benth. ex Hook.f.	GP, M	Gradually open capsules species	PH	ER	PE	6	Rainy & Dry	DAV	P	A	A
Asteraceae											
Anvillea garcinii DC.	SS	Species with persistent lignified fruits	DS	ER	PE	8	Rainy & Dry	RSD	A	A	P
Brassicaceae											
Anastatica hierochuntica L.	SS	Basicarpic species	AH	SB	AN	9	Rainy	RSD	A	A	P
Morettia parviflora Boiss.	GP, M, SS	Species with persistent fruits	DS	ER	PE	7	Dry	RSD	P	A	A
Zilla spinose Prantl	GP, M, SS	Species with persistent fruits	DS	ER	PE	7	Dry	DAV	P	P	A
Caryophyllaceae											
Sclerocephalus arabicus Boiss.	M, SF, SS	Basicarpic species	AH	PO	AN	9	Rainy & Dry	RSD	A	A	A
Cucurbitaceae											
Citrullus colocynthis (L.) Schrad.	GP, SS	Basicarpic species	DS	PO	PE	7	Dry	RSD	A	A	P
Cucumis prophetarum L.	GP, M	Basicarpic species	PH	PO	PE	7	Dry	RSD	A	A	P
Euphorbiaceae											
Euphorbia larica Boiss.	GP, M	Species with persistent fruits	DS	ER	PE	7	Dry	RSD	P	A	A
Ricinus communis L.	SS	Species with persistent fruits	LS	ER	PE	8	Rainy & Dry	RSD	P	A	A

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Family and species	Habitats	Bradychoric species group	Growth form	Plant habit	Main growth form	Seed storage time (month)	Seed release time	Spatial dispersal	Synaptospermy	Trypanocarpy	Myxospermy
Fabaceae											
Indigofera arabica Jaub. & Spach	GP, SS	Species with persistent fruits	DS	PO	PE	6	Dry	DBV	P	A	A
Indigofera argentea Burm.f.	GP, SS	Species with persistent fruits	DS	ER	PE	11	Rainy & Dry	DBV	P	A	A
Indigofera caerulea Roxb.	GP, M	Species with persistent fruits	DS	ER	PE	6	Rainy	DBV	P	A	A
Indigofera intricata Boiss.	SS	Species with persistent fruits	DS	PO	PE	11	Rainy & Dry	DBV	P	A	A
Indigofera oblongifolia Forssk.	GP, SS	Species with persistent fruits	DS	ER	PE	6	Rainy & Dry	DBV	P	A	A
Medicago laciniata Mill.	GP, M	Basicarpic species	AH	PO	AN	8	Dry	DBV	P	P	A
Trigonella hamosa L.	SS	Basicarpic species	AH	PO	AN	10	Rainy & Dry	DBV	P	A	A
Trigonella stellata Forssk.	GP, M	Basicarpic species	AH	PO	AN	8	Dry	RSD	A	A	A
Juncaceae											
Juncus rigidus Desf.	SF	Species with persistent lignified fruits	GR	ER	GR	9	Dry	RSD	A	A	A
Juncus socotranus (Buchenau) Snogerup	SF	Species with persistent lignified fruits	GR	ER	GR	7	Dry	RSD	A	A	A
Lamiaceae											
Salvia aegyptiaca L.	GP, M	Gradually open capsules species	DS	ER	PE	8	Dry	RSD	A	A	P
Salvia spinosa L.	M	Gradually open capsules species	PH	SB	PE	6	Rainy	RSD	A	A	P

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Family and species	Habitats	Bradychoric species group	Growth form	Plant habit	Main growth form	Seed storage time (month)	Seed release time	Spatial dispersal	Synaptospermy	Trypanocarpy	Myxospermy
Liliaceae											
Asphodelus tenuifolius Cav.	GP, M, SS	Gradually open capsules species	PH	SB	PE	7	Dry	RSD	A	A	A
Lythraceae											
Lawsonia inermis L.	M, SS	Species with persistent fruits	TR	ER	PE	7	Dry	RSD	P	A	A
Malvaceae											
Abutilon fruticosum Guill. & Perr.	M	Species with schizocarpic fruits	DS	ER	PE	8	Dry	DAV	A	A	A
Abutilon pannosum (G.Forst.) Schltdl.	GP, M	Species with schizocarpic fruits	DS	ER	PE	8	Dry	DAV	A	A	A
Malva parviflora L.	SS	Species with schizocarpic fruits	AH	ER	AN	7	Dry	DAV	A	A	A
Plantaginaceae											
Plantago ovata Forssk.	M, SS	Gradually open capsules species	AH	SB	AN	7	Rainy & Dry	RSD	A	A	P
Poaceae											
Aeluropus lagopoides (L.) Trin. ex Thwaites	SF	Retain fruits in dried plants	GR	ER	GR	9	Rainy & Dry	RSD	A	A	A
Cenchrus ciliaris L.	GP, SS	Species with persistent lignified fruits	GR	ER	GR	8	Rainy	DAV	P	A	A
Setaria verticillata (L.) P.Beauv.	GP	Species with persistent lignified fruits	GR	ER	GR	7	Rainy	RSD	A	A	A
Sporobolus ioclados Nees	SF	Species with persistent lignified fruits	GR	ER	GR	8	Dry	RSD	A	A	A
Sporobolus spicatus Kunth	SF, SS	Species with persistent lignified fruits	GR	ER	GR	9	Rainy & Dry	RSD	A	A	A
Polygonaceae											
Rumex dentatus L.	SS	Species with persistent lignified fruits	AH	ER	AN	6	Dry	RSD	A	A	A

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Family and species	Habitats	Bradychoric species group	Growth form	Plant habit	Main growth form	Seed storage time (month)	Seed release time	Spatial dispersal	Synaptospermy	Trypanocarpy	Myxospermy
Resedaceae											
Ochradenus arabicus Chaudhary, Hillc. & A.G.Mill.	M, SS	Gradually open capsules species	DS	ER	PE	6	Rainy & Dry	RSD	A	A	A
Scrophulariaceae											
Scrophularia deserti Delile	GP, M	Species with persistent fruits	PH	ER	PE	6	Dry	RSD	P	P	A
Solanaceae											
Solanum incanum L.	GP, M	Species with persistent fruits	LS	ER	PE	7	Dry	DBV	P	A	A
Tiliaceae											
Corchorus depressus (L.) Stocks	GP, SS	Basicarpic species	DS	PO	PE	6	Rainy & Dry	RSD	A	A	A

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CHAPTER 4

Effect of maturation time on dormancy and germination of *Citrullus colocynthis* (Cucurbitaceae) seeds from the hyper-arid hot desert of United Arab Emirates (UAE)

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CHAPTER 4

Effect of maturation time on dormancy and germination of *Citrullus colocynthis* (Cucurbitaceae) seeds from the hyper-arid hot desert of United Arab Emirates (UAE)

4.1. Introduction

Seed dormancy is a temporary failure of a viable seed to complete germination under normally favorable physical environmental conditions (Baskin & Baskin 2004). It enables seeds to delay germination until the environment is favorable to subsequent seedling survival. Seed germination in the unpredictable desert environments is usually controlled by adverse climatic conditions, such as drought and/or high temperatures (El-Keblawy 2017). Many desert plants produce seeds with different types and levels of dormancy that could only be broken once they are exposed to proper environmental signals. In many cases, such signals could be coincided with the proper time of seedling establishment (Finch-Savage & Leubner-Metzger 2006, Yoong et al. 2016).

It has been reported that environmentally induced parental effects can influence the phenotypic expression of morphological, physiological, and several life cycle traits in plants (Roach & Wulff 1987, Fenner 1991, El-Keblawy & Lovett-Doust 1996a, b, Lacey et al. 1997, El-Keblawy & Lovett-Doust 1998, Gutterman 2000). For example, seeds matured at different seasons have different temperature and light requirements during germination (Fenner 1991, Gutterman 1991, El-Keblawy & Al-Ansari 2000, El-Keblawy & Al-Rawai 2006). Several studies have reported that autumn or winter-matured seeds germinated significantly greater at higher temperatures and in continuous light, compared to spring- or summer-matured seeds (Meyer et al. 1989, Gutterman 1991, El-Keblawy & Al-Rawai 2006, El-Keblawy et al. 2009). In addition, Cone & Spruit (1983) found that seeds of *Arabidopsis thaliana* harvested in winter were more sensitive to light than those harvested in summer. The seasonal timing of seed maturation and dispersal can in turn determine the season of seed germination and germination rate and consequently the overall life cycle (El-Keblawy & Al-Rawai 2006).

The photoperiod during seed maturation is particularly a reliable indicator of a growth season. Photoperiod and light quality prevailing during seed maturation can affect seed dormancy and subsequent germination in several species. In general, germinability is promoted with short day regimes in many species such as *Chenopodium polyspermum* (Jacques 1968), *C. album* (Karssen 1970), *Portulaca oleracea* (Gutterman 1974, El-Keblawy & Al-Ansari 2000), *Beta vulgaris* (Heide et al. 1976), *Amaranthus retroflexus* (Kigel et al. 1979) and *Aegilops kotschyi* (Wurzburger & Koller 1976). However, short days resulted in greater dormancy in fewer other species, such as *Avena fatua* and *A. sterilis*, *Polygonum monspeliensis* and *Carrichtera annua* (Fenner 1991).

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Temperature is another very important factor experienced during seed maturation that affects seed dormancy (Fenner 1991). Generally, seeds produced at higher temperatures have lower dormancy (i.e., higher germinability) in many species (Harrington & Thompson 1952, Wurzburger & Koller 1976, Dorne 1981, Alexander & Wulff 1985, Probert et al. 1985, El-Keblawy & Al-Ansari 2000, Qaderi et al. 2003, El-Keblawy et al. 2009). It has been proposed that light, temperatures and other environmental factors prevailing during seed development can affect seed dormancy by affecting seed chemical composition and provisioning (e.g., mineral, photosynthetic and phytohormone resources) and through affecting structure and thickness of the seed coat (Lacey et al. 1997, Galloway 2002, Qaderi et al. 2003). In addition, environmental cues like light and temperature can change the tissue-specific localization of GA biosynthesis (Yamauchi et al. 2004), which is well known to play a crucial role in regulating seed germination (Kucera et al. 2005, El-Keblawy & Gairola 2017).

Several studies have documented the importance of light and temperatures during germination process in triggering germination of several Cucurbitaceae species. For example, darkness is a requirement for seed germination of many species, such as *Citrullus lanatus*, *Cucurbita maxima*, *Lagenaria siceraria*, *Benincasa hispida* and *Momordica harantia* (Nakamura et al. 1955), *Citrullus lanatus* cv. Sugar Baby (Thanos & Mitrakos 1992), and *C. lanatus* var. *citroides* (Ramirez et al. 2014). In addition, seed germination of other species of Cucurbitaceae is sensitive to the germination temperature. For example, melon germination sharply declined from almost 100.0% to zero when the temperatures were below the optimum (Edelstein & Kigel 1990). In addition, germination of the Sugar Baby watermelon in darkness was nearly 100% at 20 - 40 °C, but decreased sharply at 15.0 °C and 42.5 °C (Thanos & Mitrakos 1992). Further, there was no germination in *Citrullus lanatus* var. *citroides* at day/night temperatures between 10/5 °C and 15/10 °C regardless of light regimes (Ramirez et al. 2014).

Citrullus colocynthis (bitter apple) is a desert plant of Cucurbitaceae. It is a perennial small shrub (with a woody base) with prostrate or climbing annual stem (mostly) and perennial rootstocks. The plant could propagate by both seeds and vegetative buds on the rootstocks. This species has many medicinal benefits against different ailments including diabetes type II (Huseini et al. 2009) and breast cancer (Tannin-Spitz et al. 2007). It possesses antiinflammatory and anti-bacterial compounds that may help to fight the related diseases (Shahid & Rao 2014). In addition, *C. colocynthis* produces big amount of oily seeds that could be converted to low cost biodiesel (Giwa et al. 2010), which is similar to that of Jatropha seeds (Govindan et al. 2014). In the UAE, several researchers reported the flowering time of *C. colocynthis* in the period from November to July (Jongbloed 2003, Karim & Fawzi 2007). However, the extensive surveys in the UAE showed that the plants of this species are evergreen and can flower and produce fruits all over the year in few sandy places.

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Mature seeds of *C. colocynthis* collected from Negev Desert (Koller et al. 1963), UAE desert (Menon et al. 2014) and Iranian desert (Saberi et al. 2011, Gharehmatrossian et al. 2014) did not germinate without treatments. Dormancy of this species was attributed to the mechanical barrier of testa (i.e., physical dormancy), but not to the presence of allelochemicals in the seed testa that might inhibit the germination. None of these studies mentioned the time of seed maturation and collection. As *C. colocynthis* is fruiting all over the year in some habitats of the UAE, the present study aimed to assess the impacts of time of fruit collection on dormancy level, and factors that might trigger germination, such as light and temperature. We hypothesized that environmental factors prevailing during seed development and maturation, such as day length and temperatures, could affect dormancy level, and light and temperature requirements during seed germination. As seeds of one collection (March) did not germinate, another aim of the study was to assess the impact of different treatments, such as dry storage, soaking in water and physical scarification on dormancy breakage and germination requirements of this seed lot.

4.2. Material and Methods

4.2.1. *Study area*

The northern Emirates of the United Arab Emirates (UAE) is generally hot and dry with hyper-arid hot (subtropical arid) climate, which is warm in winter and hot humid in summer. The region is characterized by two distinctive seasons: a long humid season (April to October) with very high temperatures and a short season (November to March) with mild to warm temperatures and light rainfall. The mean daily temperature ranges between 12.1 °C in January and about 42 °C in June-August. Temperatures can reach up to 47 °C in summer. The average annual rainfall in the coastal area is 120 mm (Böer 1997).

The climatic data of the study area during the study year shows that the coolest temperatures were in January (minimum and maximum are 16.4 °C and 24.8 °C, respectively), while the hottest were in July and August (minimum and maximum are 32.2 °C and 41 °C, respectively). The average relative humidity ranged from 30.7% in May to 58.2% in January. The study year was very dry; total amount of rainfall received during the whole growing season (October 2014 - June 2015) was only 26.9 mm (72.0% of them in January). December has the shortest day length (10.4 h), while the longest was in June (13.5 h) (Table 4.1).

4.2.2. *Seed collection*

Fully ripened yellow fruits of large uniform sizes were collected five times throughout the 2014 / 2015 growing season (mid of October and December 2014, early March, and mid of April and June 2015) from a wild population of *C. colocynthis* growing around Dubai city, north of the UAE. Generally, yellowish color of fruits was used as an indicator for fruit ripening. To diminish the effect of genetic variation, we used 20 - 30 individuals permanently tagged to collect fruits of the different collections. Immediately after collection, seeds were extracted manually from the fruits and then washed with water, dried, and stored in brown paper bags at room temperatures. Fresh seeds were germinated within 10 - 15 days after their collection.

For each collection, the average seed mass was determined by weighing three replicates, each of 50 seeds. In addition, average seed length, width and height and seed coat thickness was assessed in 50 seeds of each collection.

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Table 4.1. Meteorological data of the study site. Monthly variation in temperatures, relative humidity, precipitation and day length in nearest (Nadd ash Shiba) meteorological station, Dubai, to the studied population. *Data are extracted from time and date website (2015).

Month	**Temp. (°C)**			**Humidity (%)**			**rainfall (mm)**		**Photoperiod (day length in hours) ***
	Max.	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Avg.**	**Sum**	
July-2014	41.13	32.16	36.58	72.52	23.84	50.00	0.00	0.0	13.3
August	40.97	32.23	36.71	71.68	24.32	49.77	0.00	0.0	12.8
September	39.47	30.07	34.70	78.00	22.70	55.03	0.00	0.0	12.0
October	36.52	27.58	31.84	69.81	22.39	48.58	0.02	0.5	11.3
November	29.67	22.07	25.90	66.73	27.83	49.47	0.00	0.0	10.6
December	26.52	17.94	22.06	74.68	29.81	55.32	0.02	0.5	10.4
January-2015	24.81	16.39	20.58	80.13	26.97	58.52	0.61	19.5	10.47
February	27.96	19.43	23.79	73.32	22.86	50.36	0.01	0.3	11.2
March	29.19	20.55	24.84	74.10	22.61	51.10	0.06	1.8	12.0
April	33.47	23.57	28.40	71.80	21.97	48.37	0.14	4.3	12.4
May	39.00	28.39	33.55	50.65	11.32	30.68	0.00	0.0	13.2
June	40.00	30.83	35.40	64.40	21.83	44.23	0.00	0.0	13.4

4.2.3. *Germination experiment*

In order to assess light and temperature requirements during germination of *C. colocynthis*, seeds were germinated (incubated) in three programmed incubators adjusted to a daily night/day temperature regime of 15/25 °C, 20/30 °C and 25/35 °C in both continuous darkness and alternating 12h darkness / 12h light (hereafter referred as dark and light, respectively). A dark condition was achieved by wrapping the Petri dishes with two layers of aluminum foil. Seeds were germinated in 9-cm tight-fitting Petri dishes containing one disk of Whatman No. 1 filter paper with 10 ml of distilled water. Four replicate dishes, each with 25 seeds, were used for each treatment. A seed was considered to be germinated when the radicle had emerged. Germinated seedlings were counted and removed every alternate day for 30 days following seed soaking. Seeds incubated in the dark were checked only once after 30 days. Therefore, they were not exposed to any light during the incubation period.

To assess possible reasons for high dormancy (no germination) recorded for March collection, several dormancy breakage treatments were assessed. These include dry storage, soaking in water and physical scarification. Physical scarification was performed on one-month stored seeds by cutting a part of the coat at the seed side with a nail clipper, without harming the underlying endosperm. Both scarified and non-scarified seeds were soaked for 48 hours and incubated in light and temperature regimes as mentioned above.

To assess the effect of long term storage on germination, seeds of March and December were stored in brown paper bags at room temperatures for one year and then

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incubated in light and temperature regimes as mentioned above. The room temperature storage condition mimics the natural conditions of after-ripening of buried seeds.

4.2.4. *Data analyses*

The rate of germination was estimated using a modified Timson index of germination velocity = ΣG/t, where G is the percentage of seed germination at 2-day intervals and t is the total germination period (El-Keblawy et al. 2009). 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.

Three-way ANOVA was used to assess the significance of the main factors (collection time, and temperature and light of incubation) and their interactions on final germination. The same test was used to assess the effect of seed storage, light condition and incubation temperature and their interactions on final germination of March seeds that were after-ripened (stored) for one year. Two-way ANOVA was used to assess the impact of maternal habitat and incubation temperature and their interaction on the germination rate index (GRI). The same test was used to assess the effect of seed storage and incubation temperature and their interaction on germination rate index of March collection. Pearson correlation coefficient (*r*) was used to assess the significance of the relationship between germination in light and in dark and different seed traits (e.g., seed length, width, height and mass and seed coat thickness. 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 13.

4.3. Results

4.3.1. *Germination of fresh seeds*

There were significant effects ($P < 0.001$) of time of seed collection, incubation temperature and light condition and their interactions on final germination of *C. colocynthis* seeds (Table 4.2). Seeds collected in March didn't germinate at all. The overall germination of April collected seeds (52.0%) was significantly greater than that of both June and October collected seeds (27.8% and 36.7%, respectively), but was significantly lower than that of December collection (74.0%). In addition, germination had significantly increased with the increase in incubation temperature and was significantly greater in dark than in light.

The effect of the interaction between time of fruit collection, light condition and incubation temperature on seed germination was significant ($P < 0.001$) (Table 4.2). Insignificant number of seeds of March collection germinated in both light and dark at the three tested temperatures. However, germination of seeds from the other collections responded differently to both incubation temperature and light condition. At 15/25 °C, seeds of all the collections did not germinate in light and seeds of April collection did not germinate

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in dark. At the same temperature, seeds of June, October and December collections germinated to 22.0%, 34.0% and 100.0% in dark, respectively (Fig. 4.1).

In light, germination at 25/35 °C was significantly greater than at 20/30 °C in October, December and April seeds, but not in June seeds. In dark, however, there was no significant difference in final germination of seeds of all the collections at 20/30 °C with that at 25/35 °C, except for June collected seeds. Interestingly, for December collection, germination reached almost 100.0% at the highest temperature in light, but at lowest temperature in dark. These results indicate that germination in light requires higher temperatures, but germination in darkness seems to be independent on temperature regime; it depends more on the time of seed collection (Fig. 4.1).

The effects of seed collection time and incubation temperature and their interaction on germination rate index were significant ($P < 0.001$) (Table 4.2). Germination of all seed collections was significantly faster at 25/35 °C than at 20/30 °C. At 15/25 °C, no germination occurred in light and germination rate index was not calculated for germination in dark (Fig. 4.2).

Seeds of March and June are bigger, heavier and with thicker seed coat, but attained significantly lower germination, compared to seeds of the other collections. For seeds of all collections, there were negative correlations between final germination in light and in dark and different seed traits, including seed length, width, mass and coat thickness. However, this relationship was significant in case of light germination ($P < 0.05$), but not for dark germination, $P > 0.05$ (Table 4.3).

Table 4.2. Results of three-way ANOVA showing the effects of time of seed collection, and temperature and light of incubation on final germination of *Citrullus colocynthis* seeds from fresh fruits.

Source	**Df**	**Mean Squares**	**F-Ratio**	***P*-Value**
Final germination percentage (arcsine transformed)				
Collection time (CT)	4	4.597	548.952	<0.001
Temperature (T)	2	2.503	298.902	<0.001
Light (L)	1	0.816	97.477	<0.001
CT x T	8	0.689	82.238	<0.001
CT x L	4	0.356	42.532	<0.001
T x L	2	1.502	179.344	<0.001
CT x T x L	8	0.524	62.534	<0.001
Error	90	0.008		
Germination rate index (log transformed)				
Collection time (CT)	4	23.709	22,256.983	<0.001
Temperature (T)	2	63.248	59,373.865	<0.001
CT x T	8	5.947	5,582.507	<0.001
Error	45	0.001		

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Figure 4.1. Effect of time of seed maturation, and incubation temperature on final germination of *Citrullus colocynthis* fresh seeds in (A) light and (B) dark photoperiods. Black bar, 15/25 °C; hatched bar, 20/30 °C; light bar, 25/35 °C.

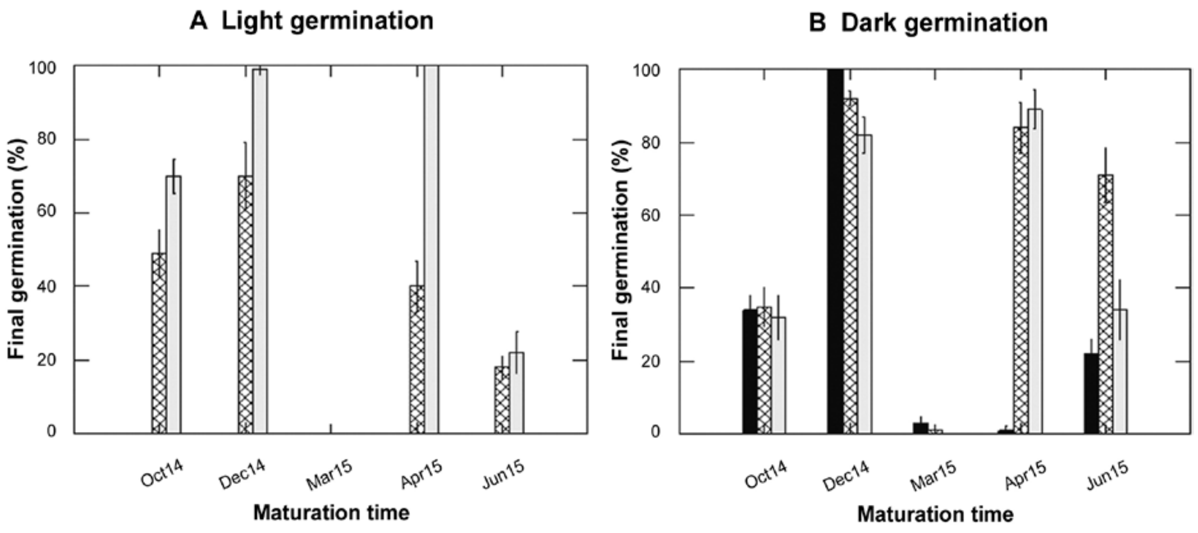

Figure 4.2. Effect of time of seed maturation, and temperature of incubation on germination rate index (mean ± SE) of *Citrullus colocynthis* fresh seeds. Hatched bar, 20/30 °C; light bar, 25/35 °C. No germination happened at 15/25 °C.

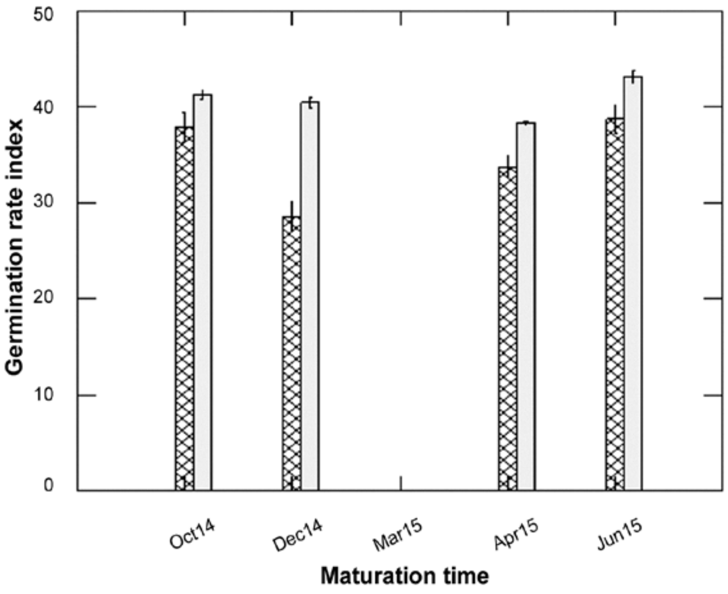

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Table 4.3. Final germination percentage of fresh and one-year stored seeds in light (LG) and dark (DG) and some seed traits of the different collections of *Citrullus colocynthis*. *r* = correlation coefficients of the relationships between germination in light and in dark with different seed traits. *, *r* is significant at *P* = 0.05.

Seed collection	Storage	LG	DG	Length (cm)	Width (cm)	Height (mm)	Mass of 50 seeds (g)	Coat thickness (mm)
Oct 2014	Fresh	39.7	33.7	0.53	0.34	1.50	0.90	0.17
Dec 2014	Fresh	56.3	91.3	0.57	0.31	1.55	0.93	0.20
March 2015	Fresh	0.0	1.3	0.80	0.42	2.05	2.21	0.31
April 2015	Fresh	46.7	58.0	0.55	0.32	1.62	0.98	0.22
June 2015	Fresh	13.3	42.3	0.78	0.48	2.02	2.38	0.30
Dec 2014	Stored	4.5	1.0	0.80	0.42	2.05	2.21	0.31
March 2015	Stored	42.3	53.3	0.57	0.31	1.55	0.93	0.20
r for DG of fresh seeds				-0.60	-0.58	-0.63	-0.61	-0.55
r for LG of fresh seeds				-0.92*	-0.88*	-0.93*	-0.93*	-0.88*

4.3.2. *Effects of dry storage*

4.3.2.1. *March seeds*

Storage for one year did not affect the dormancy level of seeds matured in March; no germination occurred in fresh seeds and in those stored for one year (data are not shown).

4.3.2.2. *December seeds*

Three-way ANOVA showed significant effects for the main factors (seed storage, incubation temperature and light condition) and their interactions on final germination of *C. colocynthis* seeds matured in December (*P* < 0.001) (Table 4.4). Storage resulted in the reduction of the germination, but the reduction depended on incubation temperature and light condition. Germination in dark of the stored seeds was significantly lower at both lower (15/25 °C) and higher (25/35 °C) temperatures, compared to that of fresh seeds. At intermediate temperature (20/30 °C), there was no significant difference in dark germination between fresh and stored seeds. In addition, germination in light did not differ significantly between fresh and stored seeds at 25/35 °C, but was significantly greater in fresh, compared to stored seeds, at 20/30 °C (Fig. 4.3).

4.3.3. *Effects of scarification and water soaking on March seeds*

Neither physical scarification (scars in seed coat) nor water soaking resulted in any improvement in germination of March seeds. Almost no germination occurred at the different temperatures in both light and dark after seed scarification and water soaking (data are not represented).

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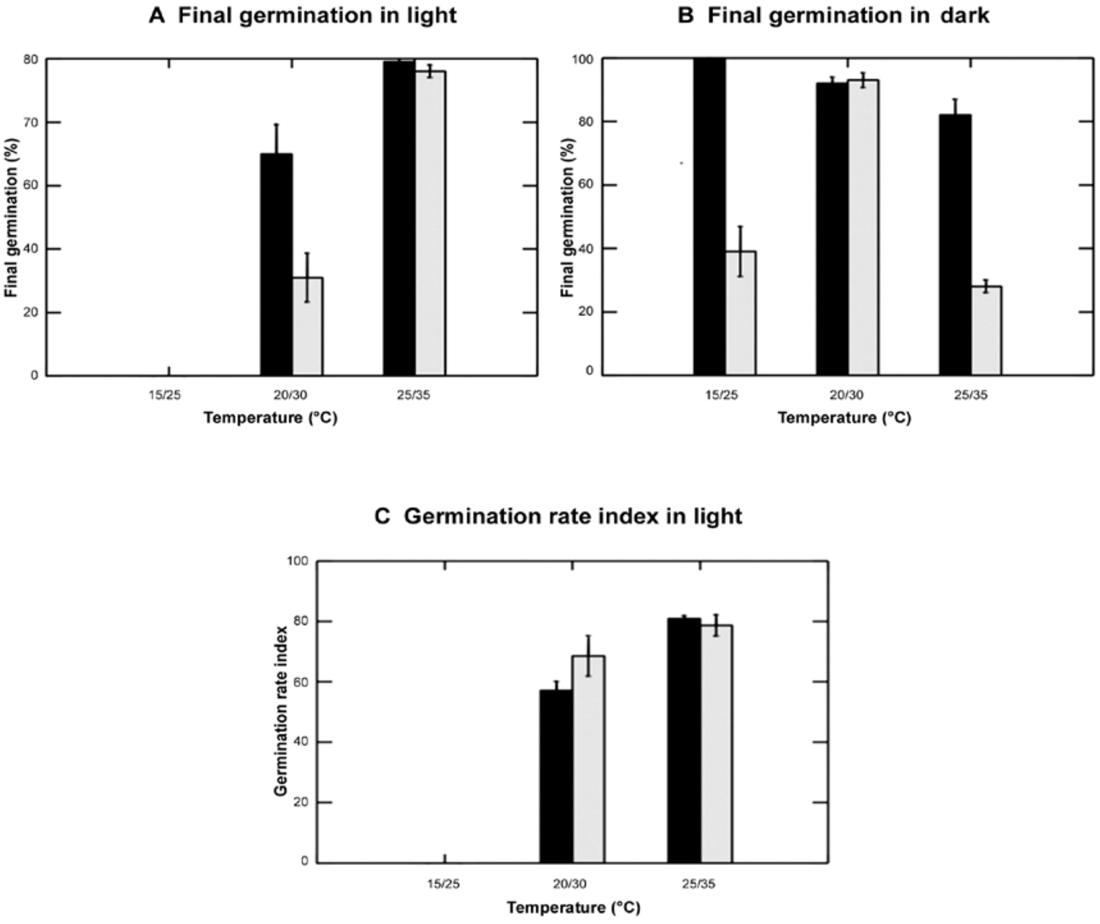
Table 4.4. Results of three-way ANOVA showing the effects of storage, and temperature and light of incubation on final germination of *Citrullus colocynthis* seeds matured in December.

Source	Df	Mean Squares	F-Ratio	*P*-Value
Final germination percentage (arcsine transformed)				
Storage (S)	1	2.039	140.604	0.000
Temperature (T)	2	1.185	81.703	0.000
Light (L)	1	0.935	64.482	0.000
S * T	2	0.132	9.089	0.001
S * L	1	0.466	32.132	0.000
T * L	2	3.521	242.828	0.000
S * T * L	2	0.710	48.930	0.000
Error	36	0.015		
Germination rate index (log transformed)				
Storage (S)	1	0.013	1.825	0.193
Temperature (T)	2	34.467	4,931.527	0.000
S x T	2	0.023	3.231	0.063
Error	18	0.007		

Figure 4.3. Effect of two years storage, and temperature on (A) final germination in light (mean ± SE), (B) final germination in dark and (C) germination rate index of *Citrullus colocynthis* seeds matured in December. Dark bar, fresh seeds; light bar, stored seeds.



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4.4. Discussion

The present study showed that *C. colocynthis* seeds germinated very well in both light and dark at moderate and higher temperatures (20/30 and 25/35 °C). At lower temperature (15/25 °C), germination of all collections was completely inhibited in light, but reached to ~ 100.0% in dark for December collection. This result is consistent with a trend observed in many species of the family Cucurbitaceae; seeds require warm temperatures for successful germination, but fail to germinate at low temperatures (Edelstein & Kigel 1990, Edelstein et al. 2001). For example, whereas melon seeds germinated to very high level at high temperatures, their germination fallen to zero when the temperatures were below 15 °C (Edelstein & Kigel 1990). Similarly, germination of the Sugar Baby watermelon in dark was nearly 100.0% at optimal temperatures (20 - 40 °C), but decreased sharply at lower temperatures (15 °C) (Thanos & Mitrakos 1992). The failure of melon seeds to germinate at low temperatures has been attributed to low levels of endogenous gibberellin, impermeability of the testa to gases, and deficiency of the growth potential of the embryo (Edelstein & Nerson 2005). In addition, it has been proposed that the seed coat-imposed dormancy at low temperature in melon seeds is the combined effect of lower amount of oxygen diffusion through the seed coat and greater embryo sensitivity to oxygen deficiency, rather than to physical constraints of radicle break-through or impairment of imbibition (Edelstein et al. 1995). In *C. colocynthis*, the ability of June, October and December seeds, but not those of March and April, to germinate in dark at the low temperature regime indicate that temperature requirement has a phylogenetic basis as well as maternally induced effect (Edelstein & Kigel 1990, Thanos & Mitrakos 1992, Edelstein et al. 2001).

Seeds of many species of the family Cucurbitaceae are negatively photoblastic; i.e., their germination is inhibited in light (Thanos & Mitrakos 1992). For example, Nakamura et al. (1955) reported that germination of *C. lanatus*, *Cucurbita maxima*, *Lagenaria siceraria*, *Benincasa hispida* and *Momordica harantia* was hindered by continuous white light at 20 - 30 °C (Nakamura et al. 1955). However, germination of *Cucumis sativus* and *C. melo* was inhibited in light only at 20 °C. Our results indicated that *C. colocynthis* germination was completely inhibited in light at 15/25 °C, but ranged between as low as 1.0% for April collection to 100.0% for December collection in dark. At higher temperatures, however, seeds germinated equally well in light and dark. This result further supports a significant role for maternal environment in regulating germination in light.

Time of seed development and maturation affects seed dormancy and germinability of several species (Roach & Wulff 1987, Lacey et al. 1997, Gutterman 2000). Several studies have reported that even little variation in temperatures during seed maturation can influence seed germination and dormancy. For example, caryopses of *Aegilops ovata* maturated at higher temperatures (28/22 °C) germinated significantly greater than those matured on plants grown at relatively lower temperatures (15/10 °C) (Datta et al. 1972). Similarly, seeds of *Amaranthus retroflexus* matured on plants grown at 27/22 °C attained greater germination than those matured at 22/17 °C (Kigel et al. 1977). In *C. colocynthis*, seeds collected in March didn't germinate at all in both light and dark at all the tested temperatures. Seeds of December and April attained the highest germination among the different seed collections. Despite the great variation in the germination of the three collections, they were all developed

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at different times during winter. It was noticed that fruits of both December and April collections developed and matured within less than a month, but those of March required more than two months for full maturation (A. El-Keblawy, unpublished data). The average temperatures during fruit development and maturation was cooler for fruits collected at early March (average minimum and maximum temperatures of January and February was 17.9 °C and 26.4 °C, respectively), compared to average temperatures of fruits matured at mid of December (average minimum and maximum temperatures of November and December was 22.1 and 29.7 °C, respectively) and those matured at mid of April (average minimum and maximum temperatures of March and April was 22.1 and 31.3 °C, respectively) (Table 4.1). This indicates that the lower temperatures might be responsible of the great dormancy observed in March seeds. El-Keblawy et al. (2018) reached to a similar conclusion when they allowed seeds of *C. colocynthis* to mature under different light and temperature treatments. Their results indicated that seeds matured at lower temperatures had lower germinations, as compared with those matured at warmer temperatures.

In Cucurbitaceae, it is known that physiological dormancy is attributed to the presence of inhibitors or variable concentrations of growth factors within the seed coat, while physical dormancy is associated with the presence of physical factors regulated by the intact seed coat (Baskin & Baskin 2014, Ramirez et al. 2014). In *C. colocynthis*, seeds from deserts of south-east of Iran showed less than 5.0% germination, but physical and chemical scarifications significantly increased the germination (Saberi et al. 2011). Similarly, Menon et al. (2014) found that physical scarification followed by soaking for 48 hours of *C. colocynthis* seeds from a UAE population resulted in a higher germination, compared to non-treated seeds. However, Koller et al. (1963) reported that matured seeds from southern Negev Desert did not germinate under a wide range of experimental conditions. Those authors didn’t attribute such lower germination to the mechanical barrier of seed coat or the presence of allelochemicals, but to the presence of an inner seed membrane. Similarly, our study indicated that neither physical scarification nor water soaking and their combination succeeded to stimulate the germination of dormant seeds of *C. colocynthis* that were collected in March. However, non-treated seeds of other collections reached to very high level of germination without any treatments. This result further supports the hypothesis that maternal effect plays a significant role in controlling dormancy and germinability of *C. colocynthis*.

Day length during seed development can also affect seed coat structure, thickness and composition (Luzuriaga et al. 2006, Giwa et al. 2010). For example, long days promote thicker, harder coats that reduced seed germinability of several species (Gutterman & Heydecker 1973, Gutterman 1978, El-Keblawy et al. 2009). Conversely, seeds matured during the short days have water permeable seed coats and germinated to higher level (Gutterman 2000). In *C. colocynthis*, however, seeds matured during shortest days (December) and those matured at longer days (April, June and October; have day lengths more than 12 h) (Table 4.1) attained higher germination, at least at 20/30 and 25/35 °C, whereas seeds of March that matured at day lengths intermediate between the other collections didn't germinate at all at the different temperatures in both light and dark. This indicates that seed coat attributes mediated through day length cannot explain the germination variation in *C. colocynthis*. However, in their experimental manipulation to the maturation

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day lengths, El-Keblawy et al. (2018) indicated that seeds matured in dark conditions germinated significantly greater than those germinated under day/night light regimes.

Storage of *C. colocynthis* fresh seed from an Indian population resulted in reduction of the germination from 72.9% for fresh seeds to only 16.4% after one year. This was attributed to the increase of seed coat hardening that limited the gas exchange between the embryo and surrounding atmosphere (Mahajan & Kumawat 2013). In the present study, one-year storage of dormant seeds collected in March didn't result in any alleviation in the dormancy level. However, storage of December seeds resulted in a significant reduction in the dark germination at both low and high temperatures, but not at the moderate temperatures. In addition, stored seeds germinated also to almost 100.0% in light at the high temperatures. Such result indicates that storage didn't affect seed viability, but might have changed phytochrome sensitivity in dark (Cresswell & Grime 1981, Casal & Sánchez 1998).

4.4.1. *Conclusions*

The overall results indicated that germination behavior in *C. colocynthis* is very sensitive to light and temperature during seed soaking as well as to the environmental conditions associated with the time of seed maturation. However, the exact mechanisms controlling such sensitivity are not clear. Since day length, temperature and other climatic factors vary simultaneously through the year, it is very important to investigate the effect of these factors individually and in combinations under controlled experimental conditions on seed dormancy of *C. colocynthis*. Such experiments could help to understand the differential sensitivity of the seeds to light condition and incubation temperatures. In addition, assessing different assimilates, such as phytohormones and enzymes as well as anatomical investigation for different parts of seed coat and under laid membrane might help to understand mechanisms underlying maternal effects on germination behavior in *C. colocynthis*.

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V. CONCLUSIONS

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V. CONCLUSIONS

1. We studied the dispersal spectra (seeds or fruits) of 302 most common species from the five inland communities of the hyper-arid hot desert of the United Arab Emirates (UAE). The predominant dispersal modes in are semachory (dispersal of seeds by the swaying motion of the infructescence) (43.7%), anemo-meteochory (28.8%) and barochory (23.8%). Diaspores (seeds or fruits) of the studied species are small (between 10^{-4} to 10^{2} order of magnitude) with mean size (length) 0.8 cm. Restricted spatial dispersal is predominant over developed (58.6% and 41.4%, respectively) and help the diaspores stay near the “safe site” (mother plant) for seedling establishment. The synchronization in plant dispersal time (63.9% of total species) is in the dry season, only 25.0% of species disperse in rainy season which are Afro-Arabian species from Savanna vegetation.

2. The seed germination characteristics of 23 studied species with aerial seed bank (seed stored in plant canopy or under plant for more than 9 months) from four inland communities of the UAE are strongly related with seed mass (size), plant growth form, seed storage condition, and light and temperature of incubation. The fresh seeds (not stored) from small shrubs and trees show lower germination percentage (21.6% and 37.9%, respectively) than the seeds of herbaceous plant (41.0%). The field storage condition improved germination of the seeds of trees (field storage seeds 54.2% vs. 37.9% for non-stored seed “fresh seed"). The large seeds of the herbaceous species germinate better than the small ones. The small seeds of the shrubs germinate better than the largest and these germinate mainly in light. The large seeds of the trees germinate better in dark and the smaller in light.

3. We identify 46 bradychoric species in a total of 307 species from four inland communities of the hyper-arid hot desert from UAE, being predominant in perennial plants (73.9%), in the Fabaceae family (17.4% of total species) and in the sandy sheets habitats (54.3% of total species). We classify bradychoric species into five groups; species with persistent fruits (predominates; 28.3%), basicarpic species which include most prostrate annuals, gradually open capsules species, species with schizocarpic fruits and species with persistent lignified fruits which include all graminoids. Bradychory is more associated with restricted spatial dispersal species (67.4%) than developed spatial dispersal ones (32.6%). The bradychoric species dispersal mainly occurs in the dry season (21 species, 46%). Synaptospermy was associated mwith species with persistent fruits, while as myxospermy was dominant in basicarpic species.

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4. *Citrullus colocynthis* (L.) Schrad., produce seeds throughout the year. The germination behavior of these seeds is sensitive to light and temperature of incubation and to the time of seed maturation, which is characteristic to Cucurbitaceae family.

The seeds of *C. colocynthis* collected in October, December, March, April and June do not germinate at lower temperature (15/25 °C) in light. All seeds, except those collected in March and April, germinate in dark and at all temperatures (15/25 °C, 20/30 °C and 25/35 °C). The seeds of *C. colocynthis* collected in March didn't germinate; lower temperature might be responsible for greater dormancy. The seeds collected in December under storage treatments reduce significantly their germination in dark at all temperatures. The thickness of seed coat of *C. colocynthis* is not related with the germination rate.

CONCLUSIONES

1. Se ha estudiado el espectro de dispersión de las diásporas (semillas o frutos) de las 302 especies más comunes de las comunidades de interior estudiadas en el desierto híper-árido de los Emiratos Árabes Unidos (EAU). Los modos de dispersión predominantes en los EAU son semacoría (43.7%), anemo-meteocoría (28.8%) y barocoría (23.8%). Las diásporas (semillas o frutos) de las especies estudiadas son pequeñas (entre 10-4 a 102 orden de magnitud) con un tamaño promedio (longitud) de 0.8 cm. La dispersión espacial restringida es predominante sobre la dispersión espacial desarrollada (58.6% y 41.4%, respectivamente) y ayuda a las diásporas a permanecer cerca del "sitio seguro" (planta madre) para el establecimiento de plántulas. La sincronización en la dispersión (63.9% del total de las especies) es en la estación seca, solo el 25.0% de las que dispersan en la estación de lluvias, son afro-árabian especies de la Sabana de los EAU.

2. Las características de germinación de las semillas de las 23 especies estudiadas con banco aéreo de semillas (semilla almacenada en el dosel planta o bajo ella durante más de 9 meses) de cuatro comunidades de interior de los EAU están fuertemente relacionadas con el de masa la semilla (tamaño), la forma de crecimiento de la planta, las condiciones de almacenamiento de la semilla y la incubación de luz y temperatura. Las semillas frescas (no almacenadas) de arbustos pequeños y árboles muestran un menor porcentaje de germinación (21.6% y 37.9%, respectivamente) que las semillas de plantas herbáceas (41.0%). El almacenamiento en el campo mejoró la germinación de las semillas de los árboles (semillas de almacenamiento en el campo 54.2% para vs. 37.9% para semillas no almacenadas). Las semillas grandes de las especies herbáceas germinan mejor que las pequeñas. Las semillas pequeñas de los arbustos germinan mejor que las más grandes (principalmente en luz. Las semillas grandes de los árboles germinan mejor en la oscuridad y las más pequeñas en la luz.

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3. Se han identificados 46 especies bradicoras en un total de 307 especies de cuatro comunidades de interior del desierto híper-árido de los EAU, predominando en las plantas perennes (73.9%), en la familia Fabaceae (17.4% del total) y en laos hábitats

arenosos (54.3% del total). Se clasificcan en cinco grupos; especies con frutos persistentes (predominantes, 28.3%); especies basicarpicas que incluyen las plantas anuales postradas; especies que abren gradualmente sus cápsulas; especies con frutos esquizocárpicos y especies con frutos lignificados persistente que incluyen todas las graminoides. La bradicoria está más asociada con especies de dispersión espacial restringida (67.4%) que a las de dispersión espacial desarrollada (32.6%). La dispersión de las especies bradicoras es principalmente en la estación seca (21 especies, 46.0%). La sinaptospermia esta asociada principalmente con las especies con frutos persistentes, mientras que la mixospermia es dominante en especies basicárpicas.

4. *Citrullus colocynthis* (L.) Schrad., es una especie que produce semillas durante todo el año. El comportamiento de germinación de estas semillas es sensible a la luz y la temperatura de incubación y al momento de la maduración de la semilla. Las semillas de *C. colocynthis* recolectadas en octubre, diciembre, marzo, abril y junio no germinan a temperaturas bajas (15/25 °C) en la luz. Todas las semillas, excepto las recolectadas en marzo y abril, germinan en la oscuridad y a todas las temperaturas (15/25 °C, 20/30 °C y 25/35 °C). Las semillas de *C. colocynthis* recolectadas en marzo, que maduran a temperaturas más frías, no germinaron. Las semillas recolectadas en diciembre bajo tratamientos de almacenamiento reducen significativamente su germinación en la oscuridad a todas las temperaturas. El espesor de la cubierta de la semilla de *C. colocynthis* no está relacionado con la tasa de germinación.

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