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Germination and seedling performance of five native legumes of the Arabian Desert

Arvind Bhatt[a,*], María Mercedes Carón[b], Kris Verheyen[c], Esam Elsarrag[a], Yousef Alhorr[a]

[a] Gulf Organization for Research & Development, P.O. Box: 210162 Doha, Qatar
[b] Laboratorio de Investigaciones Botánicas (LABIBO), Facultad de Ciencias Naturales, Universidad Nacional de Salta-CONICET, Av. Bolivia 5150, 4400 Salta, Argentina
[c] Forest & Nature Lab, Ghent University, Geraardsbergsesteenweg 267, Melle-Gontrode B-9090, Belgium

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ABSTRACT

Introducing nitrogen-fixing legumes in desert land could enhance rangeland productivity and help in soil reclamation. However, detailed information about germination and seedling performance of many desert legumes species is still lacking. We investigated these plant characteristics for five native legumes of the Arabian Desert in Qatar: *Crotalaria aegyptiaca*, *Crotalaria persica*, *Rhynchosia minima*, *Senna alexandrina* and *Senna italica*. Germination of the species was tested under laboratory conditions using different temperature and light treatments: 15/25, 20/30 and 25/35 °C, in either continuous darkness or cycles of 12 h light/12 h darkness. The germination percentage recorded under the different temperature and light conditions was very low. Therefore, four scarification treatments, water soaking (12 and 24 h) and concentrated sulfuric acid application (5 and 10 min), were applied. The scarification treatments improved the germination of all the species. However, the different species did not equally respond to the scarification treatments tested. In general, the treatments with sulfuric acid were the most effective. Subsequent seedling survival and growth were evaluated under greenhouse and field (nursery) conditions. All the studied species exhibited higher seedling survival inside (69–96%) than outside the greenhouse (53–89%). Regarding growth, these species did not show much difference in terms of shoot and root length when placed in the greenhouse or the nursery. However, the species showed differences in biomass allocation (aboveground vs. belowground biomass) between greenhouse and nursery but with species-specific responses. The information provided here on scarification requirements and seedling survival and biomass allocation as dependent on the growth environment is helpful for conservation and landscape agencies interested in using these species for conservation, restoration and landscaping projects.

1. Introduction

The arid desert climate of the Arabian Peninsula is characterized by exceptionally high temperatures, low unpredictable rainfall and high evaporation rates (Abu Sukar et al., 2007). These environmental factors together with other factors such as drought, high irradiance and salinity allow the survival of only few plant species. Fabaceae is one of the most diverse and widespread plant families present in desert environments with the capacity of hosting N-fixing bacteria (e.g. *Rhizobium*) (Crews, 1999). The symbiotic relationship between legumes and rhizobium is the most important nitrogen-fixing system and has potential to increase N input in the soil (Wolde-Meskel et al., 2004). Moreover, the use of fertilizers to increase soil fertility is not a common practice in many areas around the world due to the high costs of this practice. Hence, the use of legumes can facilitate the conservation and restoration of soil functioning and biodiversity. Introducing the nitrogen-fixing legumes in desert land can be a viable technique to enhance rangeland productivity and help in soil reclamation (Skujins, 1991). Besides their relation with soil fertility, legumes are used for various purposes such as food, fodder, fiber, fuel wood, timber and medicine (Athar, 2005; Singh et al., 2013).

The production of good quality seedlings is essential for the successful establishment of any species that could be used for the rehabilitation of desert land. However, the presence of a hard seed coat is a characteristic feature of most of the legumes that often limits rapid and uniform germination in legume species. Dormancy imposed by a hard seed coat is part of the seed survival strategy in many species (Werker, 1981; Kelly et al., 1992). Seed coats play an important role in protecting the embryo against mechanical

* Corresponding author.
E-mail address: drbhatt79@gmail.com (A. Bhatt).

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injuries, attacks of pests and pathogens, and in the regulation of gas exchange between the embryo and the external environment (Weber et al., 1996; Morris et al., 2000). Furthermore, presence of phytotoxic compounds in the seed coat of some legume species also causes germination inhibition (Simões et al., 2008).

Previous studies reported that dormancy in the genera *Crotalaria*, *Senna* and *Rhynchosia* is mainly caused by a hard seed coat which makes the seeds impermeable to water and/or oxygen or causes mechanical resistance to radical protrusion (Baskin et al., 1998; Kak et al., 2006; Jurado and Flores, 2005; Tauro et al., 2009; Ali et al., 2011, 2012; De Paula et al., 2012). Until now, most of the studies on seed dormancy and germination were conducted under laboratory conditions. However, under nursery conditions seed germination can be affected by an altered ability of inhibitors (due to leaching) and by altered dynamics of micro-organisms available for decomposition (Burrows, 1997; Morpeth and Hall, 2000). Physical dormancy can result in erratic and low germination under field conditions. Therefore, various pretreatments, including mechanical (nicking or sandpaper), chemical (acid scarification) and heat (hot water soaking) treatments, have been widely used to improve seed germination of hard seed coat Fabaceae species to obtain uniform and fast germination (Hu et al., 2009; Büyükkartal et al., 2013).

The species *Crotalaria aegyptiaca* Benth., *C. persica* (Burm. f.) Merr., *Rhynchosia minima* (L.) DC., *Senna alexandrina* Mill. and *Senna italica* Mill. are important legumes of the Arabian Desert. They are widely used for fodder, fuel wood and medicine (Franz, 1993; Jongbloed, 2003; Norton et al., 2009; Molares and Ladio, 2011; Phondani et al., 2015). Furthermore, the species have several features (e.g. attractive foliage and flowers, evergreen character) that make them good candidates for use in landscaping in arid regions according to the criteria measures of global sustainability assessment system (GSAS, 2014). They also have the potential to establish successfully in a water deficient desert environment due to their drought tolerance and to perform well in nitrogen deficient soils due to the ability to fix atmospheric nitrogen. All these species commonly occur in different desert habitats such as wadis and sand and gravel plains (Jongbloed, 2003). Furthermore, these species can facilitate creating suitable habitats for other species by improving soil conditions. However, there is a lack of knowledge about their germination and establishment behavior, limiting their use in e.g. restoration and landscaping projects. Thus, detailed information on methods to improve seed germination, seedling survival and growth is needed. The present study was carried out to (a) determine the effect of temperature and light on the germination of these five species under laboratory conditions; (b) test dormancy breaking treatments using acid scarification and water soaking under greenhouse conditions; and (c) evaluate seedling survival and growth under greenhouse and nursery conditions.

2. Materials and methods

2.1. Study species

Crotalaria persica is a perennial small branched herb (up to 40 cm), mostly occurring on low sand dunes areas. *S. alexandrina* and *S. italica* are perennial medium sized herbs (50–90 cm) with a woody stem that produces yellow flowers. The species grow in compact sand, sandy gravel plains and wadis. Finally, *C. aegyptiaca* and *R. minima* are perennial and relatively big branched herbs that reach up to 100 cm. Both species produce yellow flowers and mostly occur in sandy and gravel plain habitats.

2.2. Seed collection and storage

Seeds of *C. aegyptiaca, C. persica, R. minima, S. alexandrina* and *S. italica* were collected in July 2014 from plants growing on Shahniya Nursery (25°27′39″N, 51°11′22″E), Doha, Qatar. Seeds were randomly collected from approximately 50 plants of each species to represent genetic diversity. Immediately after collection, the seeds were cleaned and stored in brown paper envelopes at room temperature (20 ± 2 °C).

2.3. Germination under laboratory conditions

The effects of temperature and light and their interaction on seed germination was assessed in incubators set at daily 15/25, 20/30 and 25/35 °C temperature regimes in either continuous darkness or 12 h light/12 h darkness. These temperature regimes are close to those that occur between December and March when the conditions for germination and seedling establishment are better due to higher chances of rainfall in the study area (Böer, 1997). The incubators were set with light coinciding with the higher temperatures. For the dark treatment, the dishes were wrapped in aluminum foil to prevent any exposure to light. Four replicates of 25 seeds were used for each treatment. Radicle emergence was the criterion for germination. Germinated seeds were counted every alternate day for 22 days following seed soaking. Germination of seeds incubated in the dark was evaluated only after 22 days. The experiment was stopped after 22 days because no new germination occurred for a consecutive five days period.

2.4. Germination after scarification

Because the germination percentages of all the species were very low under laboratory conditions, subsamples of seeds (four replicates of 25 seeds of each species) were treated with one of the following treatments: water soaking for 12 and 24 h and sulfuric acid (100%) application for 5 and 10 min. Seeds treated with sulfuric acid were rinsed five times using distilled water. After scarification, four replicates of 25 seeds of each species were sown in 8.0 cm plastic pots at 0.5 cm depth (one replicate per pot) using a mixture of farm soil, beach sand and potting soil (160–280 mg/l N, 190–320 mg/l P and 200–340 mg/l K), organic matter 85–90% and salt level (KCl) of 1.6 g/L (SAB potting soil, Germany). The proportion between farm soil, sand and potting soil was 1:1:1. After sowing the pots were placed in a greenhouse. The control for this experiment consisted of seeds without any treatment. The number of germinated seeds was counted every alternate day for 28 days. After 28 days, no new germinated seed occurred for a consecutive five days period; therefore germination was considered to be completed. The criterion used to define germination in this case was first leaf emergence. Pots were watered every alternate day with 50 ml water. To keep track of the environmental conditions in the greenhouse, the minimum/maximum air temperature and relative humidity were recorded using a Thermo-Hygrometer (Electronic Temperature Instrument Ltd, UK).

2.5. Survival and growth performance under nursery and greenhouse conditions

The average temperature was higher inside the greenhouse (39.6 °C maximum and 35.7 °C minimum) compared to the nursery (36.3 °C maximum and 28.6 °C minimum). The relative humidity varied from 81.8 to 63.5% inside the greenhouse and from 84.5 to 26.9% in the nursery. To test the effect of these climatological differences on seedling survival and performance, after 28 days of the beginning of the experiment the germinated seedlings were pooled separately for each species (irrespective of the scarification treatment) and half of them were kept inside the greenhouse and half were transplanted to the nursery. Seedling survival percentage and growth parameters (shoot height, root length, above and belowground dry weight) under greenhouse and nursery (open) conditions were measured after 90 days. Twelve randomly selected

Table 1
Effects of different light (complete darkness or cycles of 12 h light/12 h darkness) and temperature regimes (15/25, 20/30 and 25/35 °C) on the germination of the five studied legumes.

Species	Predictor	Par. Est.	z-value
Crotalaria aegyptiaca			n.s.
Crotalaria persica			n.s.
Rhynchosia minima	Temp20/30	2.5044	↑3.358***
	Temp25/35	2.7377	↑3.699***
Senna alexandrina	Temp20/30	1.1190	1.360 n.s.
	Temp25/35	2.0828	↑2.742**
Senna italica			n.s.

Signif. codes: n.s. P > 0.05; *P < 0.05.
** P < 0.01.
*** P < 0.001.

individuals from each condition (greenhouse or nursery) for each species were harvested and washed carefully and shoot height and root length was recorded. Thereafter, the entire sample (shoot and root) was oven dried at 80 °C to constant weight and the above and belowground dry biomass were recorded (Bhatt et al., 2007).

2.6. Data analysis

For each species, the binomial germination data were analyzed with generalized least squares (*gls*) with binomial error structure, using the nlme-library in R version 3.1.2 (R Core Team, 2014). The effects of different temperature and light regimes were analyzed using temperature, light and their interaction as explanatory variables. First the full model was fitted (all the factors and the interaction included), next a model simplification was achieved by dropping one non-significant interaction and explanatory variable at a time. Chi square tests were performed each time a variable was dropped to make sure that the model fit did not significantly decrease. The germination recorded after the different scarification treatments was also analyzed with *gls* using the scarification treatment as explanatory variable. The growth variables (i.e. shoot and root length and above and belowground biomass) were analyzed with a Wilcoxon test for comparison of means with non-normally distributed errors.

3. Results

3.1. Germination under laboratory conditions

Most of the species exhibited the lowest germination under the 15/25 °C × dark treatment. The germination under this treatment was 8, 0, 1 and 0% for *C. aegyptiaca, R. minima, S. alexandrina, S. italica*, respectively, while the minimum germination for *C. persica* was 13%, recorded under the 15/25 °C × light treatment. The maximum germination of most of the species was recorded under the 25/35 °C × dark treatment and was of 13, 25, 17 and 10% for *C. aegyptiaca, C. persica, R. minima* and *S. alexandrina*, respectively, while the maximum germination of *S. italica* was 2%, recorded under the 25/35 °C × light treatment (Fig. 1).

The germination of all the species was irresponsive to the light treatments: no significant differences in germination amount were detected when the seeds were placed under continuous darkness or cycles of 12 h of light and 12 h of darkness. Conversely, the germination of two species, *S. alexandrina* and *R. minima* varied according to the temperature regime experienced during germination (Table 1). The germination of *S. alexandrina* increased from 1% to 7.5% when germination temperature increased from 15/25 °C to 25/35 °C. Similarly, the germination of *R. minima* increased from 1% to 11 and 13.5% when germination temperature increased from 15/25 °C to 20/30 °C and 25/35 °C, respectively. Additionally, the germination amount was considerably different between species. The average lowest germination, considering all treatments together, was 0.8% exhibited by *S. italica* while the highest germination, considering all treatments together, was 16.5% exhibited by *C. persica* (Fig. 1 and Table A1).

Table 2
Effects of the different scarification treatments (i.e. 6 h water, 12 h water, 5 min acid, 10 min acid), compared to the control treatment, on the germination of the five studied legumes.

Species	Predictor	Par. Est.	z-value
Crotalaria aegyptiaca	6 h water	1.0413	3.523***
	12 h water	0.7601	2.580**
	5 min acid	1.3323	4.450***
	10 min acid	2.5347	7.164***
Crotalaria persica	6 h water	−0.1164	−0.241n.s.
	12 h water	0.5390	1.251n.s.
	5 min acid	2.7294	6.955***
	10 min acid	2.7726	7.054***
Rhynchosia minima	6 h water	−5.264e-02	−0.162n.s.
	12 h water	−2.861e-15	0.000n.s.
	5 min acid	1.099e + 00	2.709**
	10 min acid	7.167e-01	1.941n.s.
Senna alexandrina	6 h water	−0.6554	−1.479n.s.
	12 h water	−0.1571	−0.396n.s.
	5 min acid	1.1687	3.419***
	10 min acid	2.9832	8.129***
Senna italica	6 h water	−0.7033	−0.570n.s.
	12 h water	−15.6742	−0.015n.s.
	5 min acid	2.8459	3.796***
	10 min acid	4.0925	5.515***

Signif. codes: n.s.: P > 0.05; * P < 0.05.
** P < 0.01.
*** P < 0.001.

3.2. Germination after scarification

The different scarification treatments showed to have, in general, a positive effect on the germination of all five species. *C. aegyptiaca* positively responded to all the treatments applied. However, the highest germination was recorded after the seeds were submerged for 10 min in sulfuric acid. *C. aegyptiaca* germination under this treatment was higher by a factor of 2.7 than under the control treatment (Table 2, Fig. 2 and Table A2). The germination of *C. persica*, *S. alexandrina* and *S. italica* was higher by a factor of 6.3, 2.4 and 13 after submerging the seeds in acid for 5 min compared to the control treatment, while germination of *C. persica*, *S. alexandrina* and *S. italica* was higher by a factor of 6.4, 4.9 and 27.5 when submerging the seeds for 10 min in sulfuric acid, respectively, compared with the control treatment (Table 2, Fig. 2 and Table A2). Finally, the germination of *R. minima* was higher by a factor of 1.2 after submerging the seeds in sulfuric acid for 5 min compared to the control treatment (Table 2, Fig. 2 and Table A2).

3.3. Seedling survival and growth

Survival of all the species was consistently higher when the seedlings were placed in a greenhouse compared to survival under field conditions (Fig. 3). The highest differences in survival were observed in *S. italica* and *C. aegyptiaca*, the survival of these species under greenhouse conditions was 69.4 and 95.9% while the survival registered under field conditions was 52.8 and 77.7%, respectively (Table A3).

Regarding growth variables, the seedlings' shoot and root length was in general less sensitive to the influence of the environment where the seedlings were placed (greenhouse vs. nursery) than the biomass variables (Fig. 4 and Fig. 5). However, *C. aegyptiaca* and *S. alexandrina* shoots were significantly taller when grown in the greenhouse (30.5 and 22.1 cm respectively) compared to the seedlings growing in the nursery (21.8 and 17.4 cm, respectively) (Fig. 4 and Table A4). Conversely, *S. italica* showed the opposite

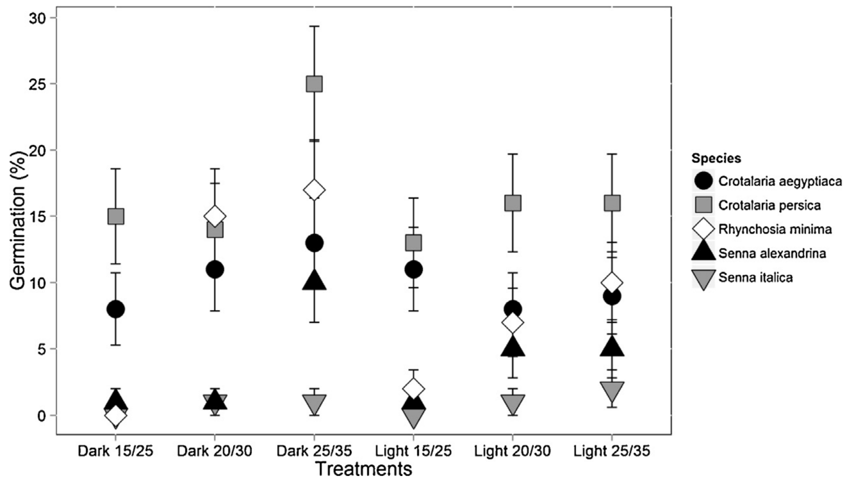

Fig. 1. Germination percentage as a function of the light (complete darkness or cycles of 12 h light and 12 h darkness) and temperature treatments (15/25, 20/30 and 25/35 °C). Error bars indicate standard error (n = 4).

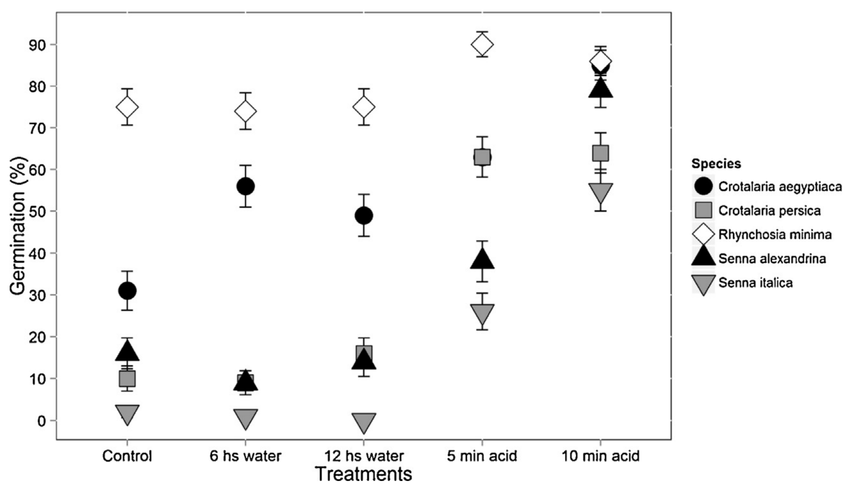

Fig. 2. Germination percentage as a function of the different scarification treatments. Error bars indicate standard error (n = 4).

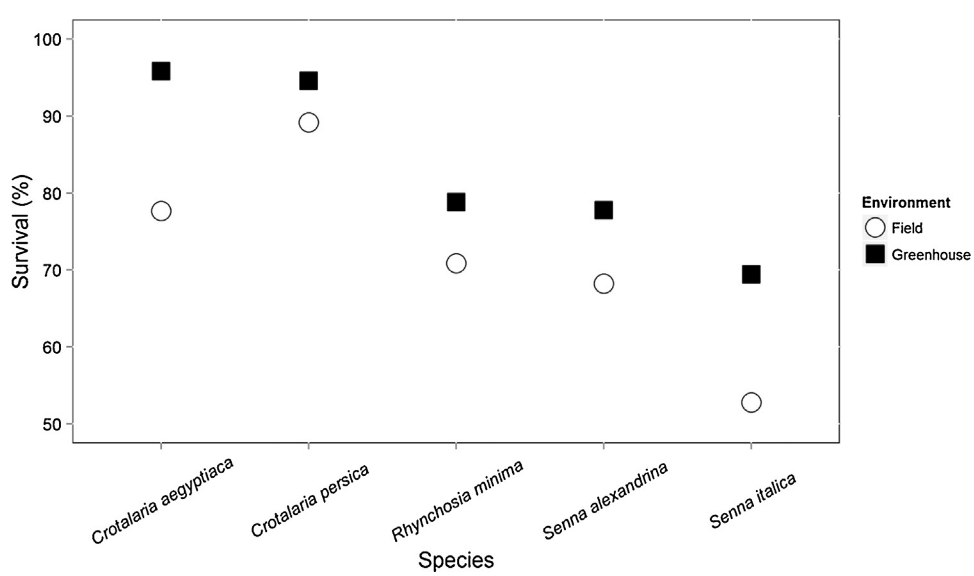

Fig. 3. Seedling survival after 90 days under greenhouse and nursery (field) conditions.

behavior (i.e. taller shoots were developed in the nursery than in the greenhouse). In contrast, only the root of *S. alexandrina* was significantly longer when grown in a greenhouse (27.3 cm) compared to the nursery (14.7 cm) (Fig. 4 and Table A4).

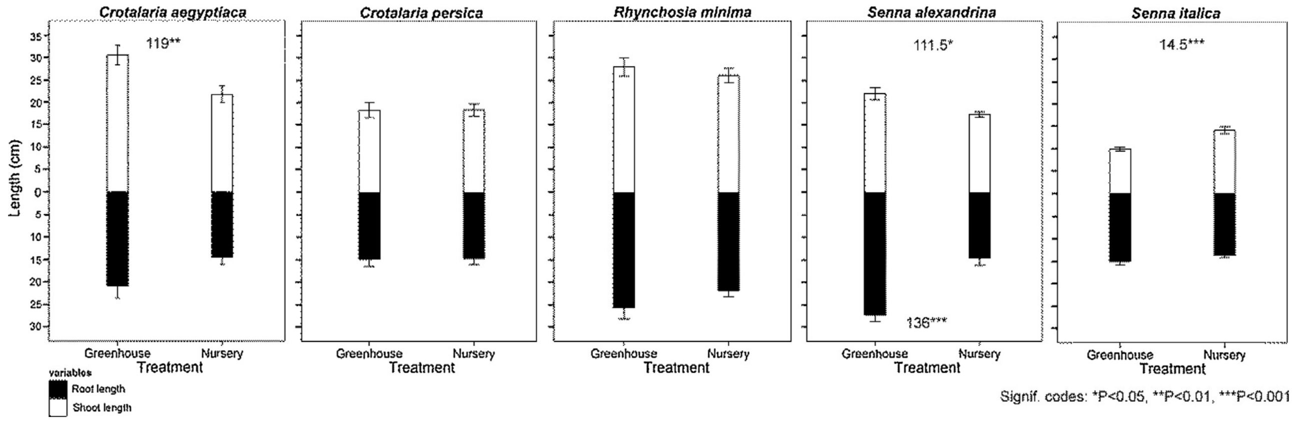

Fig. 4. Seedling shoot and root length under greenhouse and nursery conditions. W-values are reported in case of a significant effect on shoot and/or root length. Error bars indicate standard errors (n = 12).

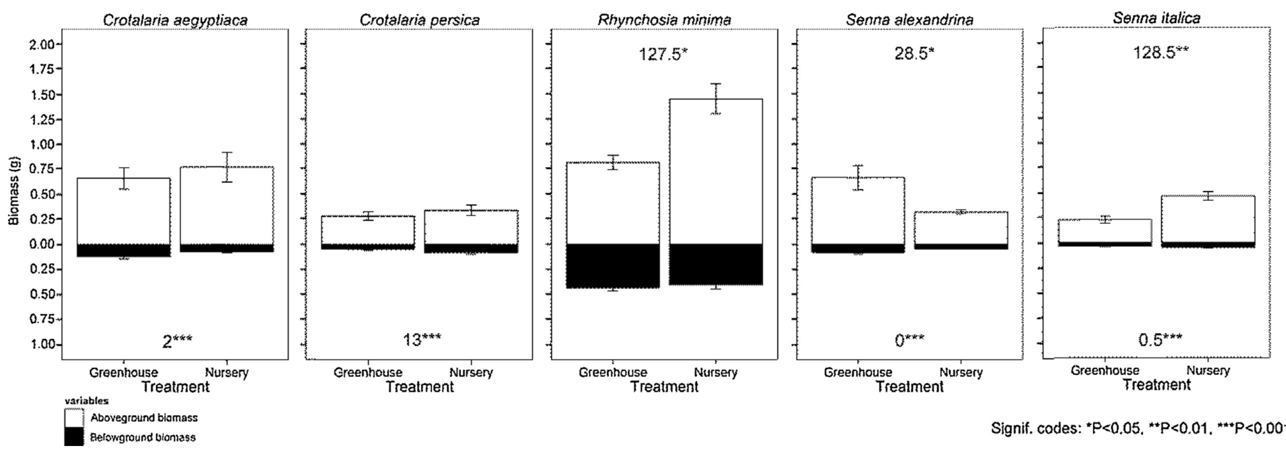

Fig. 5. Seedlings' aboveground and belowground biomass under greenhouse and nursery conditions. W-values are reported in case of a significant effect on aboveground and/or belowground biomass. Error bars indicate standard errors (n = 12).

Regarding biomass growth, only *S. italica*, *S. alexandrina* and *R. minima* showed an effect of the environmental conditions (greenhouse vs. nursery) on aboveground biomass. *S. alexandrina* seedlings showed more aboveground allocation when growing in a greenhouse (0.66 g) compared to the tree nursery (0.32 g) (Fig. 5 and Table A4). Conversely, the opposite response was observed in *S. italica* and *R. minima*, where aboveground biomass was higher when growing in a tree nursery (0.46 and 1.45 g, respectively) compared to the greenhouse (0.23 and 0.82, respectively) (Fig. 5 and Table A4). Regarding the belowground biomass, *C. persica* and *S. italica* showed more belowground allocation when grown in a nursery (0.05 and 0.08 g respectively) compared with the greenhouse (0.04 and 0.05 g, respectively) (Fig. 5 and Table A4).

4. Discussion

Despite the great ecological significance of legumes, their seedling emergence is difficult due to the presence of hard seed coats. Under controlled conditions (laboratory), germination of all the studied species was very poor, probably due to the presence of an impermeable seed coat that acts as a barrier to water and oxygen uptake, or by its mechanical resistance to radicle protrusion (Taylor, 2005). Prevention of germination by the hard seed coat in the studied species might have different ecological advantages such as favoring the formation of persistent seed banks, i.e. spreading germination over time by avoiding the risks of synchronous germination and increasing the chance that some seeds will germinate, survive and establish (Keeley and Fotheringham, 2000). The results of the present study indicate that there might be only few seeds of the species studied here able to germinate directly in the field unless scarified. Several factors such as high soil temperature, soil burial of seed, microbial attack, temperature fluctuations, humid atmospheric conditions and passage through the digestive system of animals can contribute to increasing seed coat permeability of legumes and, therefore, increase germination percentage (Taylor, 1985; Baskin and Baskin, 1998; Baskin et al., 2000; Scott, 2006).

The studied species did not show any difference in seed germination in response to light (cycles of 12 h of light and 12 h of darkness vs. complete darkness), as reported by Van Assche et al. (2003) for 14 species of legumes belonging to six genera. In the present study, seeds of most of the legume species (except *S. italica*) showed slightly better germination at higher temperature under laboratory conditions. These temperature requirements for germination seem to be related to the ecological adaptation of these species to their natural habitats. In nature, seeds of these species mature and disperse in summer when the temperature is very high and chances of rainfall are very low (Islam et al., 2009). However, these species would be also able to germinate in the next season, just before starting of the summer (between March and April) when the monthly average temperatures are around 22.9–31.4 °C and the probabilities of rainfall are higher (Islam et al., 2009). When seeds (without scarification treatment) were sown in the greenhouse, with higher temperature (39.6 °C maximum and 35.7 °C minimum), they showed relatively better germination compared to laboratory conditions, especially in *C. aegyptiaca, R. minima* and *S. alexandrina* (Tables A1 and A2). These results indicate that seeds of these species come out of dormancy better at high and more or less constant temperature (greenhouse) than at low and fluctuating temperature (laboratory condition), similarly to results reported by Jayasuriya et al. (2009) for other species with hard seed coats.

Different scarification treatments showed improvement in the germination percentage in the studied species. However, the species did not equally respond to the different tested treatments. These differences can be related to the specific seed coat characteristics (microstructure, texture, color, hardness, porosity and presence of scars and appendages) (Vaughan et al., 1987; Hopkinson, 1993; Souza and Marcos-Filho, 2001). Although we did not collect data about the seed coat characteristics of these species, our results suggest that the different species differ in their seed coat characteristics and therefore responded differently to the scarification treatments. In the present study *C. aegyptiaca* and *R. minima* seeds were able to germinate even when they were only soaked in water. However, *R. minima* seeds need to be submerged in sulfuric acid for 5 min in order to attain maximum germination, while seeds of other species required to be submerged in sulfuric acid for 10 min.

In the present study, *C. aegyptiaca, C. persica, S. alexandrina* and *S. italica* seeds showed maximum germination when they were submerged for 10 min in sulfuric acid. Scarification of seeds with sulfuric acid is known to be highly effective in improving germination of legumes seeds (Cavalheiro et al., 2007; Youssef, 2008; Can et al., 2009; Alderete-Chavez et al., 2010). *R. minima* and *C. persica* seeds did not show much difference in germination amount after been submerged in sulfuric acid for 5 and 10 min. This indicates that the time under acid (5 or 10 min) did not have any destructive effect on embryo and that the seed coat becomes permeable after a short time submerged in acid. However, increasing time duration (>10 min) might lead to damaging the embryo as reported in other species (Soomarin et al., 2010). Water soaking seems to be effective only in *C. aegyptiaca* and *R. minima,* probably due to the presence of a less hard seed coat that allows the seed to absorb water without pretreatment. Generally, water soaking of seeds promotes germination by softening the hard seed coat, diluting the effects of inhibitors, and activating hydrolytic enzymes (Hartman and Kester, 1979; Kucera et al., 2005; Kumar et al., 2012). On the other hand, *R. minima* did not show any significant difference in germination response between control and different water soaking treatments. During laboratory experiments, we observed that *R. minima* seeds leached a yellowish substance that might have caused the lower seed germination under laboratory conditions.

All the studied species showed higher seedling survival percentage inside the greenhouse than under field condition (i.e. nursery). *S. italica* and *C. aegyptiaca* showed bigger differences than the other species indicating that *S. italica* and *C. aegyptiaca* can perform well at higher temperature. In general higher temperatures enhance physiological processes as long as the threshold temperature is not exceeded (Saxe et al., 2001; Wan et al., 2004). Additionally, it is important to consider that the combination of limited water availability and high temperature is the major factor that hampers seedling survival under natural desert conditions (Ehleringer and Cooper, 1992; Valladares and Pearcy, 1997). In the present study, the average temperature and relative humidity was higher inside the greenhouse and there was not much fluctuation in these two factors inside the greenhouse compared to the nursery condition, where seedling survival is conditioned not only by abiotic factors but also by biotic factors and their interaction (Sacchi and Price, 1992). Moreover, considering that we added water to each seedling on every alternate day (in both greenhouse and nursery conditions) we assume that plants received sufficient water and therefore they survived well under the greenhouse conditions despite the higher temperature recorded inside it. Further, this may vary from species to species as depicted in the present case. These findings are in accordance with those of Kennedy and Sousa (2006), who reported that seedling survival was always highest under the greenhouse condition due to less fluctuation in temperature, light and relative humidity as compared to open areas. Seedlings did not show much difference in terms of shoot and root length when they were placed inside the greenhouse or the nursery. Only *C. aegyptiaca* and *S. alexandrina* produced maximum shoot length under greenhouse conditions, while *S. italica* exhibited the maximum shoot height under nursery conditions. However, in terms of root length, only *S. alexandrina* produced maximum root length under greenhouse conditions. The higher elongations of the roots in the greenhouse probably allow the seedlings to reach a bigger soil volume and can partially compensate for the higher evapotranspiration under greenhouse conditions caused by the higher temperatures inside the installation. Further, higher temperatures tend to increase water absorption in association with greater root length (Dhakal et al., 2007; Bernier et al., 2009), which seems to be favorable to plants under desert conditions. However, other species did not show any significant difference in shoot and root length between greenhouse and nursery conditions suggesting that this can be a species-specific behavior.

Knowledge about allocation of biomass between above- and belowground parts is important to understand the performance of individual plants when coping with abiotic and biotic stress (Weiner, 2004; Poorter et al., 2012). *Senna alexandrina* seedlings showed more aboveground allocation when grown in a greenhouse compared to the nursery. However, the opposite response was observed in *S. italica* and *R. minima*. Regarding belowground biomass only *C. persica* and *S. italica* showed higher belowground allocation when grown in the nursery compared to the greenhouse. Previous studies reported that plants have the ability to modify their phenotypic characteristics to maximize fitness according to the environmental conditions (Sustani et al., 2014). For instance, plants can change their leaf properties and biomass allocation pattern in accordance with light, water supply and nutrient conditions but, frequently, with species-specific responses (Poorter, 1999; Hermans et al., 2006; Okano and Bret-Harte, 2015). The variation in biomass allocation pattern in the present case might be related to the variation in environmental factors inside the greenhouse and nursery. Therefore, different patterns of biomass allocation by different species in terms of above- and below ground biomass can be explained by the variation in their growth habit and morphology.

All the studied species have the potential to be used for landscaping purposes because they are well adapted to the water deficient desert environment and also have the ability to perform well in nitrogen stressed soils due to the ability to fix atmospheric nitrogen. Our study has significant implications for successful germination and nursery production of legume species that could be used for the rehabilitation and restoration of Arabian desert land. We found that all the studied species required to be scarified in order to break physical dormancy. Acid scarification is the most effective method of improving germination in these species. We also recommend that all these species need to grow inside a greenhouse in order to achieve higher seedling survival and growth before transplanting.

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Annexure

Table A1
Germination percentages as a function of the temperature and light treatments (n = 4).

Treatment		*Crotalaria aegyptiaca*	*Crotalaria persica*	*Rhynchosia minima*	*Senna alexandrina*	*Senna italica*
15/25 × Dark	Mean	8.0	15.0	0.0	1.0	0.0
15/25 × Dark	SE	2.7	3.6	0.0	1.0	0.0
20/30 × Dark	Mean	11.0	14.0	15.0	1.0	1.0
20/30 × Dark	SE	3.1	3.5	3.6	1.0	1.0
25/35 × Dark	Mean	13.0	25.0	17.0	10.0	1.0
25/35 × Dark	SE	3.4	4.4	3.8	3.0	1.0
15/25 × Light	Mean	11.0	13.0	2.0	1.0	0.0
15/25 × Light	SE	3.1	3.4	1.4	1.0	0.0
20/30 × Light	Mean	8.0	16.0	7.0	5.0	1.0
20/30 × Light	SE	2.7	3.7	2.6	2.2	1.0
25/35 × Light	Mean	9.0	16.0	10.0	5.0	2.0
25/35 × Light	SE	2.9	3.7	3.0	2.2	1.4

Table A2
Germination percentages as a function of the scarification treatments (n = 4).

Treatment		*Crotalaria aegyptiaca*	*Crotalaria persica*	*Rhynchosia minima*	*Senna alexandrina*	*Senna italica*
Control	Mean	31.00	10.00	75.00	16.00	2.00
Control	SE	4.65	3.02	4.35	3.68	1.41
6 h water	Mean	56.00	9.00	74.00	9.00	1.00
6 h water	SE	4.99	2.88	4.41	2.88	1.00
12 h water	Mean	49.00	16.00	75.00	14.00	0.00
12 h water	SE	5.02	3.68	4.35	3.49	0.00
5 min acid	Mean	63.00	63.00	90.00	38.00	26.00
5 min acid	SE	4.85	4.85	3.02	4.88	4.41
10 min acid	Mean	85.00	64.00	86.00	79.00	55.00
10 min acid	SE	3.59	4.82	3.49	4.09	5.00

Table A3
Seedling survival under greenhouse and nursery conditions.

Species	Survival% greenhouse	Survival% nursery
Crotalaria aegyptiaca	95.87	77.69
Crotalaria persica	94.59	89.19
Rhynchosia minima	78.87	70.90
Senna alexandrina	77.78	68.25
Senna italica	69.44	52.78

Table A4
Growth variables as a function of the environment (greenhouse vs. nursery) (n = 12)

Variable	Environment		*Crotalaria aegyptiaca*	*Crotalaria persica*	*Rhynchosia minima*	*Senna alexandrina*	*Senna italica*
Shoot height	Greenhouse	Mean	30.52	18.36	27.98	22.06	9.97
Shoot height	Greenhouse	SE	2.18	1.68	2.05	1.37	0.47
Shoot height	Nursery	Mean	21.78	18.38	26.11	17.43	14.15
Shoot height	Nursery	SE	1.86	1.36	1.64	0.59	0.76
Shoot height	Original size	Mean	8.58	9.78	21.38	10.68	9.21
Shoot height	Original size	SE	0.98	0.80	2.58	0.52	0.37
Root length	Greenhouse	Mean	20.94	14.92	25.79	27.32	15.14
Root length	Greenhouse	SE	2.78	1.64	2.51	1.44	0.83
Root length	Nursery	Mean	14.54	14.75	21.93	14.65	13.70
Root length	Nursery	SE	1.66	1.35	1.31	1.63	0.58
Root length	Original size	Mean	5.95	4.53	13.37	5.99	8.51
Root length	Original size	SE	0.62	0.74	1.41	1.05	0.99
Above	Greenhouse	Mean	0.66	0.28	0.82	0.66	0.23
Above	Greenhouse	SE	0.11	0.04	0.07	0.12	0.03
Above	Nursery	Mean	0.77	0.34	1.45	0.32	0.46
Above	Nursery	SE	0.15	0.05	0.15	0.02	0.04
Above	Original size	Mean	0.10	0.07	0.28	0.10	0.10
Above	Original size	SE	0.02	0.00	0.03	0.01	0.01
Below	Greenhouse	Mean	0.12	0.05	0.43	0.08	0.04
Below	Greenhouse	SE	0.02	0.01	0.03	0.01	0.00
Below	Nursery	Mean	0.07	0.08	0.40	0.04	0.05
Below	Nursery	SE	0.01	0.01	0.04	0.00	0.00
Below	Original size	Mean	0.01	0.01	0.03	0.00	0.01
Below	Original size	SE	0.00	0.00	0.00	0.00	0.00

References

Abu Sukar, H.K., Almerri, F.H., Almurekki, A.A., 2007. Agro-Hydro-Meteorological Databook for the State of Qatar. DAWR, Qatar.

Alderete-Chavez, A., Aguilar-Marin, L., De la Cruz-Landero, N., Guerra-Santos, J.J., Brito, R., Guevara, E., Gelabert, R., 2010. Effects of scarification chemical treatments on the germination of *Crotalaria retusa* L. seeds. J. Biol. Sci 10, 541–544.

Ali, H.H., Tanveer, A., Nadeem, M.A., Asghar, H.N., 2011. Methods to break seed dormancy of *Rhynchosia capitata:* a summer annual weed. Chil. J. Agric. Res. 71, 483–487.

Ali, H.H., Tanveer, A., Nadeem, M.A., 2012. Evaluation of some seed dormancy breaking methods. Pak. J. Weed Sci. Res. 18, 423–432.

Athar, M., 2005. Nodulation of native legumes in Pakistani rangelands. Agric. Conspec. Sci. 70, 49–54.

Baskin, C.C., Baskin, J.M., 1998. Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination. Academic Press, San Diego.

Baskin, J.M., Nan, X., Baskin, C.C., 1998. A comparative study of seed dormancy and germination in an annual and a perennial species of *Senna* (Fabaceae). Seed Sci. Res. 8, 501–512.

Baskin, C.C., Baskin, J.M., Li, X.J., 2000. Taxonomy: anatomy and evolution of physical dormancy in seeds. Plant Spec. Biol. 15, 139–152.

Bernier, J., Serraj, R., Kumar, A., Venuprasad, R., Impa, S., Gowda, R.P.V., 2009. The large-effect drought-resistance QTL *qtl12.1* increases water uptake in upland rice. Field Crops Res. 110, 139–146.

Bhatt, A., Bisht, A.K., Dhar, U., 2007. Assessment of status and biomass of *Swertia angustifolia*: a high value Himalayan medicinal plant. Afr. J. Plant Sci. 1, 1–6.

Böer, B., 1997. An introduction to the climate of the United Arab Emirates. J. Arid Environ. 35, 3–16.

Burrows, C.J., 1997. Reproductive ecology of New Zealand forests: 2: Germination behaviour of seeds in varied conditions. N. Z. Nat. Sci. 23, 53–69.

Büyükkartal, H.N., Çölgeçen, H., Pinar, N.M., Erdoğan, N., 2013. Seed coat ultrastructure of hard-seeded and soft-seeded varieties of *Vicia sativa*. Turk. J. Bot. 37, 270–275.

Can, E., Celiktas, N., Hatipoglu, R., Avci, S., 2009. Breaking seed dormancy of some annual *Medicago* and *Trifolium* species by different treatments. Turk. J. Field Crops 14, 72–78.

Cavalheiro, A.L., Pimenta, J.A., Torezan, J.M.D., 2007. Effect of some physical and chemical treatments on germination of *Colubrina glandulosa* seeds. Seed Sci. Technol 35, 744–748.

Crews, T.E., 1999. The presence of nitrogen fixing legumes in terrestrial communities: evolutionary vs ecological considerations. Biogeochemistry 46, 233–246.

De Paula, A.S., Delgado, C.M.L., Paulilo, M.T.S., Santos, M., 2012. Breaking physical dormancy of *Cassia leptophylla* and *Senna macranthera* (Fabaceae: caesalpinioideae) seeds: water absorption and alternating temperatures. Seed Sci. Res. 22, 259.

Dhakal, H.N., Zhang, Z.Y., Richardson, M.O.W., 2007. Effect of water absorption on the mechanical properties of hemp fiber reinforced unsaturated polyester composites. Compos. Sci. Technol. 67, 1674–1683.

Ehleringer, J.R., Cooper, T.A., 1992. On the role of orientation in reducing photoinhibitory damage in photosynthetic-twig desert shrubs. Plant Cell Environ. 15, 301–306.

Franz, G., 1993. The *Senna* drug and its chemistry. Pharmacology 47, 2–6.

GSAS (Global Sustainability Assessment System), 2014. An Overview. Gulf Organization for Research and Development, Doha, Qatar, pp. 1–35.

Hartman, H.T., Kester, D.E., 1979. Plant Propagation: Principles and Practices, 4th ed. Prentice Hall of India, Ltd., New Delhi.

Hermans, C., Hammond, J.P., White, P.J., Verbruggen, N., 2006. How do plants respond to nutrient shortage by biomass allocation? Trends Plant Sci. 11, 610–617.

Hopkinson, J.M., 1993. The strophiole of legume seeds. International Herbage Seed Production Research Group Newsletter 18, pp. 7–8.

Hu, X.W., Wang, Y.R., Wu, Y.P., Baskin, C.C., 2009. Role of the lens in controlling water uptake in seeds of two Fabaceae (Papilionoideae) species treated with sulphuric acid and hot water. Seed Sci. Res. 19, 73–80.

Islam, M.D., Kubo, I., Ohadi, M., Alili, A.A., 2009. Measurement of solar energy radiation in Abu Dhabi, UAE. Appl. Energy 86, 511–515.

Jayasuriya, K.M.G., Baskin, J.M., Baskin, C.C., 2009. Sensitivity cycling and its ecological role in seeds with physical dormancy. Seed Sci. Res. 19, 3–13.

Jongbloed, M., 2003. The Comprehensive Guide to the Wild Flowers of the United Arab Emirates. Environmental Research and Wildlife Development Agency, Abu Dhabi, UAE.

Jurado, E., Flores, J., 2005. Is seed dormancy under environmental control or bound to plant traits? J. Veg. Sci. 16, 559–564.

Kak, A., Devi, C., Gupta,T., 2006. Response of seed treatment on seed germination in wild *Crotalaria* species. First international conference on indigenous vegetables and legumes. December 12–15, ICRISAT Campus, Patancheru, Hyderabad, India, p. 66.

Keeley, J.E., Fotheringham, C.J., 2000. Role of fire in regeneration from seed. Seeds: The Ecology of Regeneration in Plant Communities 2, 311–330.

Kelly, K.M., VanStaden, J., Bell, W.E., 1992. Seed coat structure and dormancy. Plant Growth Regul. 11, 201–209.

Kennedy, P.G., Sousa, W.P., 2006. Forest encroachment into a Californian grassland: examining the simultaneous effects of facilitation and competition on tree seedling recruitment. Oecologia 148, 464–474.

Kucera, B., Cohn, M.A., Leubner-Metzger, G., 2005. Plant hormone interactions during seed dormancy release and germination. Seed Sci. Res. 15, 281–307.

Kumar, R., Misra, K.K., Misra, D.S., Brijwal, M., 2012. Seed germination of fruit crops: a review. HortFlora Res. Spectr. 1, 199–207.

Molares, S., Ladio, A., 2011. The usefulness of edible and medicinal Fabaceae in Argentine and Chilean Patagonia: environmental availability and other sources of supply. Evid. Based Complement. Altern. Med., http://dx.doi.org/10.1155/2012/901918.

Morpeth, D.R., Hall, A.M., 2000. Microbial enhancement of seed germination in *Rosa corymbifera* 'Laxa'. Seed Sci. Res. 10, 489–494.

Morris, E.C., Tieu, A., Dixon, K., 2000. Seed coat dormancy in two species of *Grevillea* (Proteaceae). Ann. Bot. 86, 771–775.

Norton, J., Majid, S.A., Allan, D., Safran, M.A., Böer, B., Richer, R., 2009. An Illustrated Checklist of the Flora of Qatar. Browndown Publications, Gosport.

Okano, K., Bret-Harte, M.S., 2015. Warming and neighbor removal affect white spruce seedling growth differently above and below tree line. SpringerPlus 4, 79.

Phondani, P.C., Bhatt, A., Elsarrag, E., Horr, Y.A., 2015. Ethnobotanical magnitude towards sustainable utilization of wild foliage in Arabian Desert. J. Tradit. Complement. Med., http://dx.doi.org/10.1016/j.jtcme.2015.03.003.

Poorter, H., Niklas, K.J., Reich, P.B., Oleksyn, J., Poot, P., Mommer, L., 2012. Biomass allocation to leaves: stems and roots: meta-analyses of interspecific variation and environmental control. New Phytol. 193, 30–50.

Poorter, L., 1999. Growth responses of 15 rain-forest tree species to a light gradient: the relative importance of morphological and physiological traits. Funct. Ecol. 13, 396–410.

R Core Team, 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria http://www.R-project.org.

Sacchi, C.F., Price, P.W., 1992. The relative roles of abiotic and biotic factors in seedling demography of arroyo willow (*Salix lasiolepis* Salicaceae). Am. J. Bot. 3, 395–405.

Saxe, H., Cannell, M.G.R., Johnsen, O., Ryan, M.G., Vourlitis, G., 2001. Tree and forest functioning in response to global warming. New Phytol. 149, 369–400.

Scott, K.A., 2006. Seed coat morphology of *Parkinsonia aculeata* L. & pattern of heat-induced fractures. In: Proceedings of the 15th Australian Weeds Conference (Adelaide, SA, Australia, 24–28 September 2006), Weed Management Society of South Australia Adelaide, SA, pp. 268–271.

Simões, K., Du, J., Kretzschmar, F.S., Broeckling, C.D., Stermitz, F.S., Vivanco, J.M., Braga, M.R., 2008. Phytotoxic catechin leached by seeds of the tropical weed *Sesbania virgata*. J. Chem. Ecol. 34, 681–687.

Singh, A., Satanker, N., Kushwaha, M., Disoriya, R., Gupta, A.K., 2013. Ethno-botany and uses of non-graminaceous forage species of Chitrakoot region of Madhya Pradesh. Indian J. Nat. Prod. Res. 4, 425–431.

Skujins, J., 1991. Semiarid Lands and Deserts: Soil Resource and Reclamation. CRC Press.

Soomarin, S.J., Alipoor, S.H., Mahmoodabad, R.Z., 2010. Evaluation of sulfuric acid application in breaking dormancy of goosefoot and red-root amaranth seeds. Plant Ecophysiol. 2, 127–131.

Souza, F.H., Marcos-Filho, J.Ú.L.I.O., 2001. The seed coat as a modulator of seed-environment relationships in Fabaceae. Brazil. J. Bot. 24, 365–375.

Sustani, F.B., Jalali, S.G., Sohrabi, H., Shirvani, A., 2014. Biomass allocation of chestnut oak (*Quercus castaneifolia* CA Mey) seedlings: effects of provenance and light gradient. J. Forensic Sci. 60, 443–450.

Tauro, T.P., Nezomba, H., Mtambanengwe, F., Mapfumo, P., 2009. Germination, field establishment patterns and nitrogen fixation of indigenous legumes on nutrient-depleted soils. Symbiosis 48, 92–101.

Taylor, G.B., 1985. Effect of tillage practices on the fate of hard seeds of subterranean clover in a ley farming system. Aust. J. Exp. Agric. 25, 568–573.

Taylor, G.B., 2005. Hard seededness in Mediterranean annual pasture legumes in Australia: a review. Aust. J. Agric. Res. 56, 645–661.

Valladares, F., Pearcy, R.W., 1997. Interactions between water stress sun-shade acclimation, heat tolerance and photoinhibition in the sclerophyll *Heteromeles arbutifolia*. Plant Cell Environ. 20, 25–36.

Van Assche, J.A., Debucquoy, K.L., Rommens, W.A., 2003. Seasonal cycles in the germination capacity of buried seeds of some Leguminosae (Fabaceae). New Phytol. 158, 315–323.

Vaughan, D.A., Bernard, R.L., Sinclair, J.B., Kunwar, I.K., 1987. Soybean seed coat development. Crop Sci. 27, 759–765.

Wan, S., Norby, R.J., Pregitzer, K.S., Ledford, J., O'Neill, E.G., 2004. CO_2 enrichment and warming of the atmosphere enhance both productivity and mortality of maple tree fine roots. New Phytol. 162, 437–446.

Weber, H., Borisjuk, L., Wobus, U., 1996. Controlling seed development and seed size in *Vicia faba*: a role for seed coat-associated invertases and carbohydrate state. Plant J. 10, 823–834.

Weiner, J., 2004. Allocation: plasticity and allometry in plants. Perspect. Plant Ecol. Evol. Syst. 6, 207–215.

Werker, E., 1981. Seed dormancy as explained by the anatomy of embryo envelopes. Israel J. Bot. 29, 22–44.
Wolde-Meskel, E., Berg, T., Peters, N.K., Frostegard, A., 2004. Nodulation status of *Acacia* spp. and other native woody legumes: and phenotypic characteristics of associated rhizobia in soils of southern Ethiopia. Biol. Fert. Soils 40, 55–66.
Youssef, A.M., 2008. Seed germination of some desert plants from Egypt. J. Appl. Sci. Res. 5, 144–150.