Seedling Evaluation of Native Perennials for Implementing Large-scale Revegetation Projects in Arid Lands

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ABSTRACT

Understanding seedling development and germination processes is crucial for the successful planning and execution of revegetation and restoration initiatives on a large scale. Due to shifting environmental conditions, monitoring seed viability, dormancy, and germination success in the wild is challenging. This study seeks to investigate the optimal germination conditions for seedlings from five distinct wild populations of perennial plants commonly used in local restoration and revegetation projects in Kuwait. Kuwait has a desert climate with summer temperatures that can get as high as 46°C and minimal annual precipitation (< 112 mm). Kuwait's dry climate is home to a restricted range of flora, most of which are desert shrubs that have adapted to the severe weather. Among the well-known perennials studied at The Public Authority of Agriculture Affairs and Fish Resources (PAAF) nurseries in Kuwait were Rhanterium epapposum, Farsetia aegyptia, Calligonum comosum, Panicum turgidum, and Pennisetum divisum. In a controlled greenhouse setting, seedling germination experiments were conducted under consistent environmental conditions. The seeds were obtained from well-developed mother plants, washed, thoroughly dried, and stored in a cold, dry environment without undergoing any dormancy-breaking treatments. As a result, all five species were able to exhibit a high rate of germination, and the proportion of seedlings that emerged between 37 and 55 days ranged from 78.2% for Pennisetum divisum producing the fewest seedlings, while Farsetia aegyptia produced the most 95.4%. This study provides essential information to land restoration managers for them to implement appropriate strategies and achieve good results for large-scale revegetation projects. However, to determine seedling growth and establishment in revegetated sites, an active ecological monitoring technique is required.

Keywords: Arid climate; Desert plain ecosystem; Germination; Native plants; Native perennials; Revegetation; Seedlings evaluation.

INTRODUCTION

Arid ecosystems face the challenge of intensive deterioration due to anthropogenic activities and climate change. The flora has been adversely damaged by human activities, such as unsustainable agricultural practices, destructive camping, gravel quarrying, oil extraction, urban growth, war-related damage, and natural processes such as soil erosion and soil compaction leading to desertification (Khordagui and Al-Ajmi, 1993; Al-Awadih, 2001; Baby et al., 2014). The United Nations Environment Programme (UNEP) has defined desertification as ‘land degradation in arid, semi-arid, and dry sub-humid areas, resulting mainly from adverse human impact and partially from climatic factors’ (UNEP, 1994).

Desertification is a severe ecological issue that affects nearly all arid lands, placing natural resources under severe stress. A combination of climatological and geological processes is the major driver of desertification, with extensive human activities in sandy areas accelerating these processes. Desertification processes are influenced by climatic variables through the following phenomena: (1) the scarcity and irregularity of rainfall, (2) the frequency of drought periods, and (3) the occurrence of strong winds during the dry season, which encourages sand transport and soil erosion, and (4) the occurrence of intense rainfall in a single storm, which results in the accumulation of massive amounts of primarily sand and silt outwash material, which then contributes to sand supply (Al-Awadhi et al., 2003).

Recently, revegetation efforts in Kuwait have been launched to restore ecosystem functionality, increase biodiversity, and enhance sustainability. The United Nations Compensation Commission’s Governing Council (GC-UNCC) approved compensation payments of US$ 3 billion to be spent on six significant claims resulting from war-related damage, requiring extensive remediation and restoration initiatives (UNCC, 2005). In 2006, the Kuwaiti government formed the Kuwait Environmental Remediation Program (KERP) with this funding. Due to military activities that impacted the desert soil surface and vegetation, contributing to wind erosion and sand mobilization, one of the initiatives under the KERP

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The objective of this study is to assess the planting phases and germination patterns of five indigenous plant species commonly employed in Kuwait for initiatives related to revegetation, forage production, soil stabilization, conservation practices, and restoration of Kuwait's deteriorated natural habitats. The findings of this study are intended to enhance our comprehension of the recruitment dynamics and performance of these species in the absence of seed dormancy-breaking treatments, thereby facilitating the selection of suitable species for incorporation into revegetation schemes. The study aims to address the following inquiries: (1) What is the germination percentage of seeds for each species without the application of seed dormancy-breaking techniques? (2) How does the germination rate vary among different wild populations of these species? (3) What is the feasibility of cultivating diverse seedlings in nurseries for large-scale revegetation accomplishments?

MATERIALS AND METHODS

Study location

This work was conducted at The Public Authority of Agriculture Affairs and Fish Resources (PAAF) nurseries, which are located at Al-Abdali agricultural lands.
areas in the northern part of Kuwait City. Kuwait is located in the northeastern part of the Arabian Peninsula, sharing borders with Iraq to the north and Saudi Arabia to the south. The topography is mostly flat with slight undulation and generally arid landscape with no rivers, except a coastline stretches along the Arabian Gulf to the east. The predominant soil type is mainly characterized by sandy soil except for the saline soils influenced by the proximity to the sea. Kuwait is characterized as an arid ecosystem with hot summers having an average maximum temperature ranges from 42 to 46 °C, short moderate winters with an average minimum temperature ranges from 3 to 13 °C, and occasional rainfall of an average of 112 mm annually. PAAF nurseries' primary goal is to produce a large amount of native plant seedlings to revegetate and restore desert ecosystem. The nursery's facility is divided into three key regions: greenhouses for seed germination, green shaded areas used as a transitional area for plant adaption to the outdoor environment, and external irrigated field areas for establishing native mother plants and harvesting seeds Figure (1).

**Planting phases**

Schematic diagrams illustrating the planting phases carried by PAAF are shown in Figure (3). The germination process underwent three major phases summarized below:

**Phase 1**

Greenhouse: germinating seeds and establishing seedlings inside the greenhouse under a controlled environment (25.0 ± 2 °C, under 10/14 hrs of light/dark photoperiod, and relative humidity ranged between 40-60%).

**Phase 2**

Green shaded area: seedlings transfer from seedling trays, medium sized pots and shift to a green shaded net area outside the greenhouse (the net lowers the temperature, and avoid direct sunlight, allowing plants to adapt to the outer environmental factors).

**Phase 3**

Re-vegetation site: the seedling pots are transported to the re-vegetation sites and planted during favorable environmental conditions around 25 °C (between October-December).

**Germination assays**

The germination process was studied using trays containing 50 cells each (measuring 54 cm x 28 cm x 5.7 cm) in a greenhouse at Al-Abdali Public Authority for Agriculture Affairs and Fish Resources (PAAF) nurseries from September to November 2020. Prior to seed sowing, the trays were filled with a potting soil mixture comprising peat moss and sandy soil in a 1:1 ratio. Seeds were then placed into each cell, sown approximately 1 cm deep and covered with soil. A total of fifty planting trays, containing 2,500 seedling inserts, were examined, with each species treatment replicated in 10 trays, totaling 500 counts for each species.

In the greenhouse, the trays were positioned on tables within a controlled setting, with periodic watering to prevent soil desiccation. The irrigation was facilitated using a mixture of desalinated seawater and brackish groundwater. The germination assays were carried out under constant conditions: a temperature of 25°C± 2°C, a light period of 10 hrs followed by a dark period of 14 hours, and a relative humidity maintained between 40-60%. These specific parameters were selected to mimic the natural climatic conditions of Kuwait's environment, particularly during the period from February to April. Conspicuously, no treatments were applied to the seed coatings to induce dormancy breakage in this study.

**Data analysis**

The total germination percentage was recorded when no more seeds germinated for each treatment. One-way analysis of variance (ANOVA) was used to evaluate seedling germination means and investigate if there were any significant differences across species. In addition, to test the relationship between the seedlings of different species pairwise comparisons were applied using the least square difference (LSD) method.
**Figure (2):** The photomicrograph represents the following five plant species: (A) Rhanterium epapposum Oliv; (B) Farsetia aegyptia Turra; (C) Panicum turgidum Forssk; (D) Calligonum comosum L’Herit., and (E) Pennisetum divisum (Forssk. ex J.F.Gmel.) Henrard. (Photo Credit: Modhi Al-Dosari).

**Table (1):** Description of the studied five native plants: scientific names, families, morphology, phenology, ecological, and economic uses.

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Family</th>
<th>Morphology/ Phenology</th>
<th>Ecological/ Economical uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farsetia aegyptia Turra.</td>
<td>Brassicaceae</td>
<td>Sub-shrub, perennial, height not exceeding 50 cm, leaves: covered with tiny white hair alternate 4-5 cm long, flowers: numerous each with 4 white free petals, stem: very thin, root: taproot system. Seeds: at maturity pods split open release seeds. Flowering duration: March-April.</td>
<td>Fodder, sand stabilizer, medicinal (AbdElAal et al., 2015; Bidak et al., 2015)</td>
</tr>
<tr>
<td>Calligonum comosum L’Herit</td>
<td>Polygonaceae</td>
<td>Shrub, perennial, height 1-2 m, leaves: reduced and inconspicuous, flowers: white with pink stamens, stem: numerous, slender, and intricately branched (modified stems: cladodes), root: deep root system. Seeds: winged capsule containing seeds, Flowering duration: March-April.</td>
<td>Fodder, fuel (wood), tanning, medicinal, sand stabilizer, drought resistant, shading, wind break (Rathore et al., 2015).</td>
</tr>
<tr>
<td>Panicum turgidum Forssk.</td>
<td>Poaceae</td>
<td>Perennial grass, height 1 m, leaves: linear, lanceolate, or narrowly ovate in shape, stem: culms are densely tufted with swollen nodes. Seeds: flowers develop into seeds within the spikelet. Flowering duration: March-May</td>
<td>Fodder (grazed pastures), edible, sand stabilizer, soil fertility, shading (Bhatt et al., 2020)</td>
</tr>
<tr>
<td>Pennisetum divisum (Forssk. ex J.F.Gmel.) Henrard</td>
<td>Poaceae</td>
<td>Perennial grass, height 1-1.5 m, leaves: linear, narrow, and can be up to 50 cm long, stem: erect, slender culms that arise from a central point, Inflorescence: feathery, cylindrical spike-like structure, each spikelet contains both male and female flowers. Flowering duration: February-April.</td>
<td>Fodder (grazed pastures), sand stabilizer, soil fertility (Bhatt et al., 2020)</td>
</tr>
</tbody>
</table>
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Significance was set to $p \leq 0.05$ for all pairwise comparisons. The statistical analysis ANOVA and LSD method were conducted using JMP® statistical analysis software (SAS Institute, Inc., Cary, NC, version 17.2.0, 2023).

**RESULTS**

**Seedlings germination assays**

In each of the five wild populations evaluated, different percentages of seeds germinated, with highest seed germination rate was represented by *Farsetia aegyptia*, 95.4%, while the lowest germination rate was *Pennisetum divisum*, 78.2%. A summary of each species is given below and represented in Table (2).

In detail, the germination percentage of *Rhanterium epapposum* seedlings fluctuated between 72% and 90% within 37 days of germination, with a mean germination rate of 84.6%. For *Farsetia aegyptia*, the germination rate ranged from 88% to 100% after 55 days, with a mean germination rate of 95.4%. *Calligonum comosum* exhibited a germination range of 78% to 98% after 30 days, with an average germination rate of 86.4%. *Panicum turgidum* showed a germination percentage between 76% and 98% after 47 days, with a mean germination rate of 88.2%. Lastly, *Pennisetum divisum* had a germination range of 60% to 96%, with a mean germination rate of 78.2% (Table 2).

**Seedlings germination variation**

The results from one-way ANOVA showed significant variation between germination mean and variation within the species, represented by $F$-value 6.07, and a highly significant value of $p \leq 0.0005$ (Figure 4). The most significant germination variation was represented by *Farsetia aegyptia* followed by *Rhanterium epapposum* seedlings and the least significant variation was represented by *Pennisetum divisum* seedlings (Figure 4).

The mean differences in total seed germination and the number of days treated using a pairwise least square difference (LSD) were also compared. For LSD comparison, no significant differences were found between the germination mean of *Rhanterium epapposum* and *Pennisetum divisum*, and *Calligonum comosum* and *Panicum turgidum* while significant difference was found for *Farsetia aegyptia*, $p \leq 0.05$.

**DISCUSSION**

**Planting seedlings for revegetation**

Understanding the variation in species germination is critical for developing efficient revegetation and restoration strategies (Lázaro-González et al., 2023; Marty and Kettenring, 2017). Our findings show that if time and logistics is not an obstacle, transplanting seedlings technique to revegetation sites is recommended over seed scattering technique. Our results showed that native seeds of various species yield high germination

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**Table (2): Germination performance of studied plant species**

<table>
<thead>
<tr>
<th>Measured parameter</th>
<th><em>Rhanterium epapposum</em></th>
<th><em>Farsetia aegyptia</em></th>
<th><em>Calligonum comosum</em></th>
<th><em>Panicum turgidum</em></th>
<th><em>Pennisetum divisum</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Germinated seeds/Total seed number$^*$</td>
<td>423/ 500</td>
<td>477/ 500</td>
<td>432/ 500</td>
<td>441/ 500</td>
<td>391/ 500</td>
</tr>
<tr>
<td>Germination mean (±SE)</td>
<td>42.3 ±2.98 $^b$</td>
<td>47.7 ±1.89 $^a$</td>
<td>43.2 ±3.42 $^ab$</td>
<td>44.1 ±4.12 $^b$</td>
<td>39.1 ±6.19 $^b$</td>
</tr>
<tr>
<td>Mean Germination (%)</td>
<td>84.6</td>
<td>95.4</td>
<td>86.4</td>
<td>88.2</td>
<td>78.2</td>
</tr>
<tr>
<td>Germination period (day)</td>
<td>37</td>
<td>55</td>
<td>30</td>
<td>47</td>
<td>47</td>
</tr>
</tbody>
</table>

$^*$10 tray, contained 50 seeds, were used per each plant species
percentages without interfering with dormancy-breaking techniques. Within 30-55 days, the succession rate ranged from 88.2% (Pennisetum divisum) to 95.4% (Farsetia aegyptia). Furthermore, the three shrubs (Rhanterium epapposum, Farsetia aegyptia, and Calligonum comosum) germinated into seedlings within 30-55 days, while the two grasses (Pennisetum divisum and Panicum turgidum) germinated into seedlings within 47 days. Given that dormancy levels may fluctuate widely among native plant populations due to a variety of reasons, including environmental and genetic changes, the data on the germination of the five wild seeds should be regarded as preliminary (Duncan et al., 2019; Almulla et al., 2020). Given this, people interested in learning more about the germination technique of these species may find our research to be of great assistance.

Similar studies on native plants of Kuwait showed that untreated seeds of Haloxylon salicornicum resulted in the highest germination rate (86%) compared to the treated ones (using Gibberellic acid and heat methods), which varied in germination (44-76%) (Almulla, 2014). Additionally, in agreement with our findings, Nitraria retusa, a native perennial shrub, demonstrated that untreated seeds needed 55 days to achieve 79% of germination, whereas treatments considerably quicker (Gibberellic acid) allowed them to achieve 91% of germination in just 20 days (Suleiman et al., 2008). On the other hand, some untreated native seeds resulted in very low germination (55%) due to the deep-dormancy cycles (Suleiman et al. 2011a). Furthermore, Bhatt et al. (2020) research demonstrated that seed germination variation between different populations of the same species of Panicum turgidum and Pennisetum divisum occurred, showing inter-population variabilities.

**Revegetation planning strategies**

Decision-makers should consider choosing a healthy ecosystem for a higher succession rate of seedling adaptation and revegetation success. The revegetation and restoration areas should have sufficient nutrients for plant growth and development (Mashaly et al., 2015; Salama et al., 2018).

Signs of good restoration sites could be explored in the field using the concept of green water areas. According to Yang et al. (2015), a green water area is defined by vegetation and soils that aid in water absorption, infiltration, and storage. As a result, green water areas significantly impact plant biomass growth (Simiyu et al., 2022). Furthermore, Abdullah et al. (2021b) study observed that soil characteristics improved in northern regions of Kuwait due to the presence of high annual plant coverage (conserving soil moisture), high levels of phosphorus present, and soils rich in organic matter.

Therefore, green water areas with high annual density and coverage could be ideal revegetation sites for introducing seedlings of perennial shrubs (Nafea, 2015). In addition, the floristic composition at the site should be investigated for any possibilities of adaptation or competition with the introduced seedlings. Also, it is crucial to remember that sometimes, using seedlings or applying plant seeds is not the most effective option. Direct sowing with seedling supplementation, a combination of the two strategies, is frequently used in practice to maximize the restoration efforts since it optimizes the benefits of each option (St. Clair et al., 2020; Lázaro-González et al., 2023).

For the choice of revegetation sites, maps of possible green water areas in Kuwait should be employed. Abdullah et al. (2022) and Asadalla et al. (2021) established maps for large-scale revegetation and restoration planning, by combining remote sensing techniques and GIS (Geographic Information System) with the Maxent model, that identifies green water areas and hotspot locations through the analysis of numerous environmental variables related to vegetation coverage. Furthermore, it is important to assess and monitor the biodiversity changes occurring at the revegetation sites in order to follow the progress and study the vegetation succession rate. Monitoring methods have been employed lately in Kuwait using remote sensing techniques, GIS, and Unmanned Aerial Vehicles (UAVs) to capture and analyse high-resolution imagery and monitor the progress level of each revegetation site (Abdullah et al., 2021a; Asadalla et al., 2021; Abdullah et al., 2022).

![Figure (4): Histogram showing the germinated number of seeds for five native species.](image-url)
CONCLUSION

To restore Kuwait's damaged desert ecosystem, effective restoration projects and revegetation activities are required. If money and logistics are not an issue, the seedling technique evaluated in this study is recommended for large-scale revegetation projects in Kuwait. As a result, increasing seedling establishment rates will aid in the implementation of revegetation projects. It is also critical to explore seed collection from diverse populations and locations of the same species to boost the gene pool variation of the seedlings. Kuwait can improve its biodiversity, restore ecosystem services, and reduce the environmental impact of human activities by expanding the knowledge of ecological dynamics and implementing effective revegetation and restoration measures. The effectiveness of restoration programs is dependent on continuing investigations, long-term monitoring, and, most crucially, stakeholder participation.

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تمكين الشتلات للنباتات المعمرة المستوطنة لتنفيذ مشاريع إعادة الغطاء النباتي على نطاق واسع في الأراضي الجافة

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الممدوح العربي

إن مفهوم تطور الشتلات وزراعةها على نطاق واسع بهدف الإنتاج أمر بالغ الأهمية وذلك تخليطًا لمبادرات نجاحية لإعادة الغطاء النباتي. نظرًا للظروف البيئية المتغيرة، فإن مراقبة انتاج البذور، ونجاح الزراعة في البرية يمثل تحديًا. تهدف هذه الدراسة إلى تحديد ظروف انبات الشتلات لخمسة أنواع مختلفة من النباتات المعمرة التي تستخدمن بشكل دوري في الكويت. وذلك تم دراسة انبات البذور، موضوع الدراسة، في حضانات الهيئة العامة للزراعة والثروة السمكية في الكويت. انتهِت الدراسة على انبات البذور للنباتات المعمرة، والتي تم الحصول على بذورها من الأمهات المعمرة، المجففة تماماً، Calligonum comosum، Farsetia aegyptia، Rhanterium epapposum، Panicum turgidum، Pennisetum divisum.


النتائج تبين أن جميع البذور وباستثناء البذور المصمّمة، نجحت معدل مراجع من البذور، وتراوحت نسبة الشتلات التي نجحت أكثر من 95.4%. Farsetia aegyptia، Pennisetum divisum، Panicum turgidum، دون معاجة لكرس مرحلة الائع. Pennisetum divisum، Panicum turgidum.

تقدم هذه الدراسة معلومات أساسية لأصحاب القرار من أجل تقديم الاستراتيجيات المناسبة وتحقق نتائج جيدة لمشاريع نجاحية واسعة النطاق. ومع ذلك، هناك حاجة إلى تقنيات حديثة للاستخدامات الجديدة لهذه الطرق واستخدامها في المواقع التي تم زراعتها.

Abdullah et al.,