Postprint: Biological Characteristics of Seeds from Spring- and Autumn-Germinating Erodium oxyrhynchum

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Abstract

The seed biological characteristics of *Erodium oxyrhynchum* are of great significance for its survival and reproduction in extreme environments. Seeds from spring-emerging and autumn-emerging *Erodium oxyrhynchum* plants were collected as experimental materials, and the differences in biological characteristics such as 100-seed weight, water absorption rate, and seed germination were investigated through a combination of indoor simulation and field experiments. The results showed that: (1) The seeds of autumn-emerging plants matured approximately one week earlier than those of spring-emerging plants, and there was a significant difference in the 100-seed weight between the two at different maturation and dispersal times. (2) Without seed coat scarification, seeds from both spring-emerging and autumn-emerging *Erodium oxyrhynchum* plants exhibited the highest germination rate at 25 ℃/10 ℃; after seed coat scarification, germination rates under temperatures of 15 ℃/5 ℃, 20 ℃/5 ℃, and 25 ℃/10 ℃ all exceeded 80% and were significantly different from other temperature conditions. (3) The water absorption rate and natural germination rate of seeds from spring-emerging plants were significantly higher than those of autumn-emerging plants, and light had no significant effect on seed germination of either spring-emerging or autumn-emerging plants. (4) The dormancy type of both spring-emerging and autumn-emerging *Erodium oxyrhynchum* seeds was physical dormancy; before seed coat scarification, germination rates were less than 20%, whereas after scarification, germination rates exceeded 90%.

Full Text

Study on Seed Biological Characteristics of Spring-Emergence and Autumn-Emergence Plants of the Ephemeral Plant *Erodium oxyrrhynchum*

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Abstract

The biological seed characteristics of *Erodium oxyrrhynchum* are of great significance for its survival and reproduction in extreme environments. We collected seeds from both spring-emergence and autumn-emergence plants as experimental materials and used a combination of laboratory simulations and field experiments to explore differences in biological characteristics such as 100-seed weight, water absorption rate, and seed germination. The results revealed that: (1) The seed maturation time of autumn-emergence plants was approximately one week earlier than that of spring-emergence plants, and there were significant differences in 100-seed weight between the two groups at different maturation and dispersal times. (2) With intact seed coats, seeds from both spring- and autumn-emergence plants exhibited the highest germination rate at 25 °C/10 °C. After seed coat scarification, germination rates exceeded 80% at 15 °C/5 °C, 20 °C/5 °C, and 25 °C/10 °C, showing significant differences from other temperature conditions. (3) The water absorption rate and natural germination rate of spring-emergence plants were significantly higher than those of autumn-emergence plants, while light conditions had no significant effect on seed germination of either plant type. (4) The dormancy type of both spring- and autumn-emergence seeds was physical dormancy; germination rates were less than 20% with intact seed coats but exceeded 90% after seed coat scarification.

Keywords: *Erodium oxyrrhynchum*; spring-emergence; autumn-emergence; seed germination

Introduction

Ephemeral plants represent a unique group in temperate desert regions that can rapidly germinate using winter snowmelt and early spring precipitation, completing their life cycle before summer arrives. Most ephemeral plants exhibit both spring and autumn germination phenomena. This unique survival and regeneration strategy is fundamental to ensuring population persistence in harsh desert environments. These plants possess special physiological functions including rapid growth and development, high photosynthetic efficiency, strong reproductive capacity, and high seed-setting rates, making them primary contributors to spring sand stabilization and excellent forage resources. Under global climate change, the climate of the Junggar Desert is shifting from warm-dry to warm-wet conditions, with precipitation increasing annually. Therefore, in-depth study of seed biological characteristics of spring- and autumn-emergence plants is crucial for predicting future population trends.

Erodium oxyrrhynchum is a dominant species in the ephemeral plant layer of the Gurbantunggut Desert and exhibits both spring and autumn germination. Field observations show that spring-emergence plants appear in early March with a growth period of about 90 days, avoiding the summer high temperatures and winter freezing periods. Autumn-emergence plants emerge in October but cannot complete their life cycle in the same year, overwintering and resuming growth the following March. Previous studies have examined various aspects including ecological and biological characteristics, external morphological features, relationships with arbuscular mycorrhizal fungi, and effects of water and nitrogen addition on life history. However, comprehensive research combining seed biological characteristics of both spring- and autumn-emergence plants remains limited. Zhang et al. compared ecological and biological features such as crown width, biomass, phenology, and mycorrhizal infection rates between spring- and autumn-emergence plants. Zeng Xiaolin investigated biomass during seedling stages, root length, seedling mortality, single-plant seed yield, and modeled autumn germination characteristics and evolutionary trends. Tian Jiaojiao studied 100-seed weight, germination types, water absorption rates, and dormancy types. Chen Zhichao et al. examined growth characteristics and spatial distribution patterns of autumn-emergence ephemeral plants. Zhang Yin studied soil seed banks and seedling spatial patterns in the Gurbantunggut Desert, including *E. oxyrrhynchum*.

Materials and Methods

1. Experimental Materials

To accurately and conveniently collect seeds from both spring- and autumn-emergence plants, we selected three sample plots in the research area in early March. In mid-March, we used circular wire (specifications 1000 mm × 1500 mm) to mark uniformly distributed, well-growing, and generally consistent spring-emergence *E. oxyrrhynchum* plants in the first two plots to meet experimental requirements, while removing autumn-emergence plants from these plots. In the third plot, we similarly marked autumn-emergence plants while removing spring-emergence plants. To ensure no human interference throughout the growth cycle, we enclosed both spring- and autumn-emergence plots with light-transmitting, well-ventilated mesh before seed maturation to prevent seeds from being blown away by wind or contamination from external seeds. After maturation, we collected fully mature, plump seeds daily. Since *E. oxyrrhynchum* exhibits continuous rather than concentrated flowering, and autumn-emergence seeds mature about one week earlier than spring-emergence seeds, we conducted large-scale seed collection during late April to early May when both plant types reached peak seed maturation and dispersal, ensuring consistent and representative seed samples for subsequent experiments.

2.1 Study Area Overview

The sample plots were established in the Beishawo Experimental Area, located on the southern edge of the Gurbantunggut Desert in the Junggar Basin. This region features a typical temperate continental climate with annual accumulated temperature reaching 3500 °C, annual precipitation of 150 mm, and annual potential evaporation of 3500 mm. The native arboreal vegetation is dominated by *Haloxylon ammodendron*, while the herbaceous layer consists mainly of ephemeral and pseudo-ephemeral plants, which constitute the primary plant community and account for the majority of species diversity.

2.2 100-Seed Weight Measurement

To understand the dynamic changes in 100-seed weight of spring- and autumn-emergence plants at different maturation and dispersal times, we collected mature seeds daily from both plant types after seed maturation. After removing impurities, we weighed the seeds using a Sartorius BS124S electronic balance (precision 0.0001 g). We set up three replicates, with 100 seeds per replicate.

2.3 Seed Water Absorption Rate Measurement

Water absorption experiments were conducted at room temperature (20–25 °C air temperature, 30–40% relative humidity). We selected seeds from both spring- and autumn-emergence plants and divided them into two groups for imbibition experiments, with 50 seeds per group. The first group received seed coat scarification using a surgical blade to carefully wound each seed' s coat, while the second group remained untreated. Each treatment had three replicates. Seeds were completely immersed in distilled water in 100 mL petri dishes. At set time intervals (1, 2, 3, 4, 5, 6, 8, 10, 12, and 24 hours), we removed seeds, blotted surface moisture with absorbent paper, and weighed them using the Sartorius BS124S balance to calculate water absorption at different time points. To determine the water absorption curve, we calculated the percentage increase in water absorption weight using the formula: $W = (W - W_0)/W_0 \times 100\%$, where W is the seed weight after water absorption at time i, and W_0 is the initial seed weight.

2.4 Temperature Effects on Seed Germination

Based on average monthly maximum and minimum temperatures in the Gurbantunggut Desert, we established six variable temperature treatments in incubators (model GXZ-288B): 5 °C/1 °C, 15 °C/5 °C, 20 °C/5 °C, 25 °C/10 °C, 30 °C/15 °C, and 35 °C/20 °C, labeled a–f respectively. Experimental materials were freshly collected mature seeds placed in covered petri dishes (diameter 9 cm) lined with filter paper. Each temperature treatment had three replicates, with 50 seeds per replicate. The incubator provided a 12-hour light/12-hour dark cycle representing natural day-night alternation. During germination, we added distilled water daily to maintain filter paper moisture. Germinated seeds (defined as those with radicles protruding from the seed coat) were counted and removed daily for 15 days. Germination rate was calculated as: (number of germinated seeds / total seeds) × 100%.

2.6 Data Analysis

Statistical analysis was performed using SPSS 19.0 software. One-Way ANOVA was used to analyze differences in 100-seed weight, water absorption rate, and germination data between spring- and autumn-emergence seeds. Least significant difference (LSD) tests were used for multiple comparisons of germination rates under different treatments ($\alpha = 0.05$). Graphs were created using Graphpad Prism 8 software, with germination rates expressed as percentages.

Results

3.1 100-Seed Weight

During the seed maturation period from late April to early May, both the maximum and minimum temperatures in the study area gradually increased. The 100-seed weight of spring-emergence seeds ranged from 0.3651–0.4395 g, while autumn-emergence seeds ranged from 0.3499–0.4814 g. Autumn-emergence seeds matured approximately one week earlier than spring-emergence seeds. Over time, the 100-seed weight of both plant types showed a decreasing trend, with spring-emergence seeds following a pattern similar to autumn-emergence seeds. Throughout the maturation and dispersal period, significant differences existed between the 100-seed weights of spring- and autumn-emergence plants [Figure 1: see original paper].

3.2 Seed Water Absorption Rate

As shown in [Figure 2: see original paper], after seed coat scarification, the water absorption rates of both spring- and autumn-emergence seeds increased extremely significantly compared to the control group. With intact seed coats, spring-emergence seeds showed significantly higher water absorption rates than autumn-emergence seeds, but this difference disappeared after scarification. In terms of absorption time, seeds absorbed water rapidly during the first 0–4 hours, with the rate slowing between 4–8 hours and nearly plateauing after 8 hours.

3.3 Temperature Effects on Seed Germination

With intact seed coats, both spring- and autumn-emergence seeds exhibited the highest germination rates at 25 °C/10 °C, which differed significantly from other temperature conditions [Figure 3: see original paper]. After seed coat scarification, germination rates exceeded 80% at 15 °C/5 °C, 20 °C/5 °C, and 25 °C/10 °C for both plant types, showing significant differences from 5 °C/1 °C, 30 °C/15 °C, and 35 °C/20 °C [Figure 4: see original paper]. This indicates that both low and high temperatures inhibit germination, likely by suppressing enzyme activities related to germination. Except for the low germination rates at 5 °C/1 °C and 35 °C/20 °C, germination rates under other temperature treatments were relatively high, suggesting a broad temperature range for germination that corresponds to spring and autumn temperatures in the Gurbantunggut Desert. We hypothesize that under suitable soil moisture conditions (after rainfall or snowmelt), seeds that have broken dormancy will germinate en masse during both seasons.

3.4 Dark and Seed Coat Scarification Experiments

As shown in [Figure 5: see original paper], seed germination rates of both spring- and autumn-emergence plants differed significantly from the control group after seed coat scarification. With intact seed coats, spring-emergence seeds showed significantly higher germination rates than autumn-emergence seeds, but this difference disappeared after scarification. Under dark conditions, germination rates of both scarified and non-scarified seeds from both plant types showed no significant differences from the control group.

Discussion

Seed Size Variation

Seed size is a key and relatively stable trait in plant life history, influenced by both genetics and environment as an adaptation to local conditions. It is closely related to seed dispersal, seedling competitiveness, plant longevity, and seed bank persistence. Research has shown that seed mass within a single species or individual plant can vary greatly in response to environmental conditions. Larger seeds generally have stronger resource acquisition capabilities due to greater nutrient reserves, faster germination rates, higher germination percentages, and better stress resistance. The significant differences in 100-seed weight between spring- and autumn-emergence *E. oxyrrhynchum* at different maturation times suggest that larger seeds producing autumn-emergence seedlings may have greater advantages for winter survival and life cycle completion.

Water Absorption and Germination

A hard seed coat or pericarp is the primary cause of physical dormancy, with impermeable palisade cells preventing water and gas exchange, blocking inhibitor leakage, reducing light penetration, and mechanically constraining germination. This mechanism benefits soil seed bank maintenance and population persistence. Both spring- and autumn-emergence seeds showed physical dormancy, with germination rates below 20% for intact seeds but exceeding 90% after scarification. The significantly higher water absorption and natural germination rates of spring-emergence seeds compared to autumn-emergence seeds may be attributed to differences in seed coat hardness resulting from different maturation times. Since autumn-emergence seeds began maturing and dispersing in late April while spring-emergence seeds started in early May, our experimental seeds (collected in late April to early May) represented late-stage autumn-emergence seeds and early-stage spring-emergence seeds. We hypothesize that these maturation time differences led to varying degrees of seed coat hardness, resulting in the observed differences in water absorption and natural germination rates.

Light is another major factor affecting seed germination, acting as a stimulus signal to break dormancy. However, under dark conditions, germination rates of both scarified and non-scarified seeds showed no significant differences from the control group, indicating that light intensity is not a limiting factor for germination of seeds settled at different soil depths. This may represent an adaptive strategy evolved over time.

Temperature Effects on Germination

Temperature is a crucial factor influencing seed germination, and determining optimal germination temperature is important for predicting natural germination timing. Although germination rates were highest at 25 °C/10 °C with intact seed coats, the dormancy phenomenon prevented accurate assessment of optimal temperature. After scarification, high germination rates (>80%) were observed across 15 °C/5 °C, 20 °C/5 °C, and 25 °C/10 °C, while rates were low at 5 °C/1 °C and 35 °C/20 °C, indicating inhibition by extreme temperatures. The relatively broad temperature range for germination corresponds to spring and autumn temperatures in the Gurbantunggut Desert, suggesting that seeds breaking dormancy will germinate extensively when soil moisture is adequate.

Mechanisms of Spring-Autumn Germination Phenomenon

The spring-autumn germination phenomenon in *E. oxyrrhynchum* has attracted considerable research attention. Based on our results, possible mechanisms include: (1) The conical seeds with long awns experience varying degrees of coat damage through friction with soil during settlement, creating differences in dormancy-breaking timing. (2) Natural breaking of physical dormancy requires prolonged exposure to environmental factors like temperature and moisture. Seeds settled in microhabitats with different temperature and moisture conditions will break dormancy at different times. (3) Inconsistent seed coat hardness leads to varied dormancy-breaking times. Consequently, when dormancy is broken under suitable temperature and moisture conditions, some seeds germinate in early spring while others germinate in autumn, creating the characteristic spring-autumn germination phenomenon.

In conclusion, the physical dormancy of spring- and autumn-emergence seeds benefits species survival by preserving seeds during unfavorable conditions and reducing the risk of mass germination due to stochastic events, ensuring population renewal under suitable conditions. The differential timing of physical dormancy breaking under natural conditions may be a primary reason for the spring-autumn germination phenomenon in *E. oxyrrhynchum* populations.

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