

Effect of Temperature, Water Potential and Salinity on Seed Germination of Four Native Perennial Grasses of the Monte (Argentina)

Efecto de la temperatura, potencial agua y salinidad en la germinación de cuatro especies de gramíneas perennes nativas del Monte (Argentina)

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ABSTRACT

Seed germination is critical for successful restoration in degraded desert ecosystems. This study aimed to determine thermal requirements and tolerance limits to water and salt stress of four key forage species: *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum*, and *Leptochloa crinita*. Controlled laboratory experiments were conducted to evaluate constant temperature regimes (5, 15, 20, 25, 30, 35, 40, and 45°C), one alternating-temperatures regime (45-15°C), water potentials (0, -0.38, -0.58, -0.97, -1.30, -1.52, and -1.77 MPa) simulated with Polyethyleneglycol (PEG) solutions, and NaCl concentrations (0.1, 0.3, and 0.5 M). We recorded final germination percentage and germination rate (Maguire Index). The species exhibited different environmental plasticity. *L. crinita* and *P. caespitosum* showed the broadest thermal ranges, achieving optimal germination (>80%) between 25 and 35°C. *P. caespitosum* demonstrated the highest tolerance to salinity and water stress, being the only species capable of germinating in 0.5 M NaCl solutions (20%) and at -1.77 MPa (20%). In contrast, *A. mendocina** and *D. californica** were the most sensitive; the former restricted its optimum to 20-30°C, and both reduced their germination by half with just 0.1 M NaCl.

Keywords

temperatures • drought • NaCl • *Pappophorum caespitosum* • *Digitaria californica* • *Aristida mendocina* • *Leptochloa crinita* • restoration

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RESUMEN

La germinación de semillas es una de las fases más críticas para asegurar el éxito de la restauración en ecosistemas degradados de zonas áridas. El objetivo de este trabajo fue determinar los requerimientos térmicos y los límites de tolerancia al estrés hídrico y salino de cuatro especies forrajeras clave: *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum* y *Leptochloa crinita*. Se realizaron ensayos controlados de laboratorio evaluando: 1) temperaturas constantes (5, 15, 20, 25, 30, 35, 40, 45°C) y alternantes (45-15°C); 2) potenciales hídricos (0, -0,38, -0,58, -0,97, -1,30, 1,52 y -1,77 MPa) simulados mediante soluciones de Polietilenglicol (PEG); y 3) concentraciones salinas de NaCl (0,1, 0,3 y 0,5 M). Se registró el porcentaje final de germinación y la velocidad de germinación mediante el Índice de Maguire. Las especies mostraron una clara diferenciación en su plasticidad ambiental. *L. crinita* y *P. caespitosum* presentaron los rangos más amplios, con germinaciones óptimas (>80%) entre 25 y 35°C. *P. caespitosum* se destacó por una alta tolerancia salina e hídrica, siendo la única capaz de germinar en soluciones de 0,5 M de NaCl (20%) y bajo un estrés hídrico de -1,77 MPa (20%), condiciones donde el éxito de las demás especies fue nulo. Por el contrario, *A. mendocina* y *D. californica* resultaron ser las más sensibles; la primera restringió su óptimo a los 20-30°C y ambas redujeron su germinación a la mitad con sólo 0,1 M de NaCl.

Palabras clave

temperatura • sequía • NaCl • *Pappophorum caespitosum* • *Digitaria californica* • *Aristida mendocina* • *Leptochloa crinita* • restauración

INTRODUCTION

Seed germination and seedling emergence are critical phases for the successful establishment of new plants in desert ecosystems. Only about 5 to 10% of seeds develop into established seedlings (Kildischeva *et al.*, 2016). Germination is influenced by genotype and abiotic factors such as temperature, water stress, salinity, and photoperiod (Baskin & Baskin, 2014; Dágata *et al.*, 2021; Guden *et al.*, 2024; Gutterman, 1993; Okumus & Şekerci, 2024).

In deserts, germination relies on water availability to ensure subsequent seedling growth (Bewley & Black, 1994; Corvalán Videla *et al.*, 2021). Some desert species only germinate after rainfall exceeding 12-15 mm. Furthermore, a 15 mm rainfall is more effective at removing germination water-soluble inhibitors when it occurs over several hours rather than in a single hour (Lundholm & Larson, 2004; Schwinning & Sala, 2004). This provides seeds with a trigger mechanism that guarantees germination when soil moisture supports seedling establishment and growth (Bewley & Black, 1994). For example, *Leptochloa crinita* and *Pappophorum caespitosum* need 40 mm of water to trigger seedling emergence (Greco *et al.*, 2013; Sartor *et al.*, 2024).

Soil temperature and salinity also influence seed germination. Seeds germinate within a defined temperature range (Bewley & Black, 1994), and the time required to reach maximum germination, *i.e.*, germination rate or germinative energy, varies with temperature (Kigel, 1995; Mnif Fakhfakh *et al.*, 2025). On the other hand, soil interface in desert ecosystems is an extremely harsh environment. Intense solar radiation and low air humidity cause water evaporation and rapid desiccation of the soil surface, facilitating salt accumulation on or near the surface. This hinders germination in surface layers even after rainfall events (Kigel, 1995; Baskin & Baskin, 2014). In this sense, seed sensitivity to saline solutions constitutes one mechanism for seeds to detect when rainfall is sufficient (Bewley & Black, 1994; Mansouri & Kheloufi, 2024; Singh, 2025; Nikolic *et al.*, 2023).

Monte is a biogeographic province characterized by shrubby steppes composed of *Zygophyllaceae* species, with an herbaceous stratum dominated by perennial grasses (Roig, 1970a; Roig *et al.*, 2009). Grass cover in the Monte Desert is affected by climatic settings, particularly scarce, erratic, and highly variable rainfall (Noy-Meir, 1973; Villagra *et al.*, 2011), and by the presence of cattle and human-induced conditions (overgrazing and fire). The C4 species *Pappophorum caespitosum*, *Digitaria californica*, *Aristida mendocina*, and *Leptochloa crinita* are dominant perennial and summer-cycle

species in the area (Cavagnaro, 1988). Given their distribution and nutritional quality, native perennial grasses constitute an important forage resource for extensive livestock farming (Guevara *et al.*, 1997; 2009). At some places, fire, grazing, or deforestation has reduced cover to less than 20% of its potential (Guevara *et al.*, 1997, 2009; Marchi *et al.*, 1991). In this context, the addition of seeds is mentioned as a successful strategy for restoration in arid livestock areas (Quiroga *et al.*, 2018). Beyond their natural environments, these species are gaining value for xerophytic gardens and as inter-row permanent cover in drip-irrigated crops (Ferrari & Parera, 2015). Even considering these significant instances, knowledge about germination conditions of these perennial species is scarce.

Although these perennial grasses coexist in arid and semiarid conditions, they inhabit different soils and precipitation gradients. *L. crinita* is associated with clayey and saline soils, *D. californica* and *A. mendocina* grow in sandy soils, and *P. caespitosum* is found in sandy-loam and saline soils (Candia & Guevara, 1973; Flores *et al.*, 2015; Roig, 1970b). On the other hand, *L. crinita*, *P. caespitosum*, and *A. mendocina* inhabit areas with 100 to 600 mm of precipitation, while *D. californica* is frequently found between 300 and 600 mm (Cabido *et al.*, 1993). Habitat differences among these perennial grass species could be due to different seed germination strategies.

Previous studies mention seed germination of *L. crinita* and *D. californica* under abiotic stress (Ferrari & Parera, 2015). Meglioli *et al.*, 2024 studied temperature and light on germination of *L. crinita*, *P. caespitosum*, and *D. californica*; Zabala *et al.*, (2011) studied temperature, seed weight, and maternal effects in *L. crinita* and *L. pluriflora*, while Marinoni *et al.*, (2018, 2022) registered seed germination under osmotic and saline stress and seed coating (Meglioli *et al.*, 2026). While one study observed germination of *L. crinita* and *Digitaria eriantha* subjected to osmotic stress at different temperatures (Di Giambattista *et al.*, 2010), Quiroga *et al.*, (2018) investigated the importance of rain and temperature on the conserved climatic niche of *L. crinita* in North and South America. This underlines the relevance of arid conditions in species adaptation.

Thus, germination strategies under different temperatures, water potentials, and salinity, especially in these opportunistic species, ensure successful seedling establishment. To the best of our knowledge, no previous studies have assessed temperature effects on germination of *A. mendocina*, nor seed response of *A. mendocina*, *P. caespitosum* and *D. californica* to different saline solutions and water potentials. We aimed to describe germination responses to temperature, salinity, and drought in the native perennial species *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum*, and *Leptochloa crinita*.

MATERIALS AND METHODS

Seeds of *Aristida mendocina*, *Digitaria californica*, and *Pappophorum caespitosum* were collected at the Experimental Field of the Centro Científico Tecnológico (CCT), Mendoza, Argentina. Seeds of *Leptochloa crinita* Genotype N°3 (Ñacuñán) were harvested from the genotype collection of the Facultad de Ciencias Agrarias (Universidad Nacional de Cuyo), Mendoza, Argentina. Seeds were kept in paper envelopes, in the dark. Before the experiments, *D. californica*, *P. caespitosum*, and *L. crinita* were threshed, while *A. mendocina* seeds were directly sown. Seed viability was tested *via* the Tetrazolium test (ISTA, 2021) before germination assays.

All germination assays were performed in 9 cm diameter Petri dishes, with cotton and filter-sterilized paper discs on top. To avoid fungal infection, we moistened each disc with 10 ml of a 0.1% Benomyl solution in distilled water. We carried out all assays in darkness, using incubators (Precision Scientific Model Inc. 818) with automatic temperature control ($\pm 0.1^\circ\text{C}$).

The emergence of a 1 mm radicle indicated germinated seeds. All trials lasted 10 days. Germination was recorded as percentage of germinated seeds (%), and germination rates were calculated using the Maguire equation (Maguire, 1962):

$$M = n_1/t_1 + n_2/t_2 + \dots + n_9/t_9$$

where:

$n_1, n_2, \dots, n_9$ = number of germinated seeds at each date.

And $t_1, t_2, \dots, t_9$ = times in days.

Germination Assay at Different Temperatures

Seeds germinated in incubators at 5°C, 15°C, 20°C, 25°C, 30°C, 35°C, 40°C, 45°C, and 50°C. The trial was completely randomized, with 5 replicates of 25 seeds per treatment and genotype.

Germination Assay at Constant and Alternating Temperatures

Five Petri dishes with 30 seeds per species were placed in growth chambers under the following treatments: a) 16 hours at 15°C and 8 hours at 45°C; b) continuous 30°C; c) continuous 45°C.

Germination Assay at Different Water Potentials

The trial consisted of a completely randomized design with 4 replicates of 50 seeds per treatment. All Petri dishes were placed in an incubator at 30°C. We conducted 8 treatments: a control with distilled water and Polyethylene glycol (PEG) solutions. PEG solutions were prepared at 143.18, 213.64, 267.98, 313.88, 354.36, 390.99 g PEG L⁻¹ distilled water. Osmotic potentials at 30°C were -0.38, -0.58, -0.97, -1.3, -1.52, and -1.77 MPa, respectively. Ten mL of each solution was initially added to each Petri dish.

Germination Assay with Saline Solutions

This trial was completely randomized with 4 replicates of 50 seeds per treatment. Petri dishes were placed in an incubator at 30°C. We used 4 treatments: a control with distilled water and 3 different Sodium Chloride (NaCl) solutions. Molal solutions of NaCl were 0.1, 0.3, and 0.5 mol kg⁻¹, weighing 5.84 g/L, 17.53 g/L and 29.22 g/L, respectively. Twenty mL of the corresponding solution was added to each Petri dish. Osmotic potential at 30°C was -0.47 MPa, -1.39 MPa, and -2.32 MPa, respectively.

Statistical Analysis

Final germination percentages were transformed *via* arcsine of the square root (arcsine ($\sqrt{x}$)) and germination rates were transformed with the square root ($x + 0.5$) to meet ANOVA assumptions. Both variables were analyzed using ANOVA and Tukey test ($p < 0.05$).

RESULTS

Germination at Different Temperatures

None of the four species germinated at 5, 45, or 50°C (figure 1, page 5).

A. mendocina seed germination was 60-70% (maximum for this species) at 20, 25, and 30°C (figure 1, page 5). Germination reached 27% at 15°C, and 10% at 35 and 40°C on the same date. Similarly, equal germination rates were recorded at 20, 25, and 30°C (table 1, page 5), with significant differences from 15°C, 35°C, and 40°C.

D. californica seed germination was 64% at 35°C (maximum for this species), and 50% between 25 and 30°C, with no significant differences among these treatments. At 20 and 40°C, 30% of seeds germinated, while only 15% germinated at 15°C (figure 1, page 5). The highest germination rate was obtained at 25, 30, and 35°C (table 1, page 5).

P. caespitosum germination was 94% at 25°C, 89% at 35°C, 74% at 30°C, 67% at 20°C, 55% at 40°C and 24% at 15°C. Significant differences were observed at 25 and 35°C with respect to the other treatments. Forty percent of the seeds germinated at 30 and 35°C on day one of incubation, corresponding to the highest germination rates (table 1, page 5).

L. crinita achieved 95-100% at 25, 30, and 35°C on day 2 of incubation. On day 7, at 20 and 40°C, this percentage significantly dropped to 88%. On day 9 at 15°C, 69% of seeds germinated, significantly differing from the other treatments (figure 1, page 5). Notably, a high proportion of seeds from this species germinated on day 1 of incubation at 25, 30, and 35°C, with the highest germination rates at 30 and 35°C (table 1, page 5).

Different letters indicate significant differences in temperature within each species at $p < 0.05$.

Las letras diferentes indican diferencias significativas entre las temperaturas dentro de cada especie, $p < 0,05$.

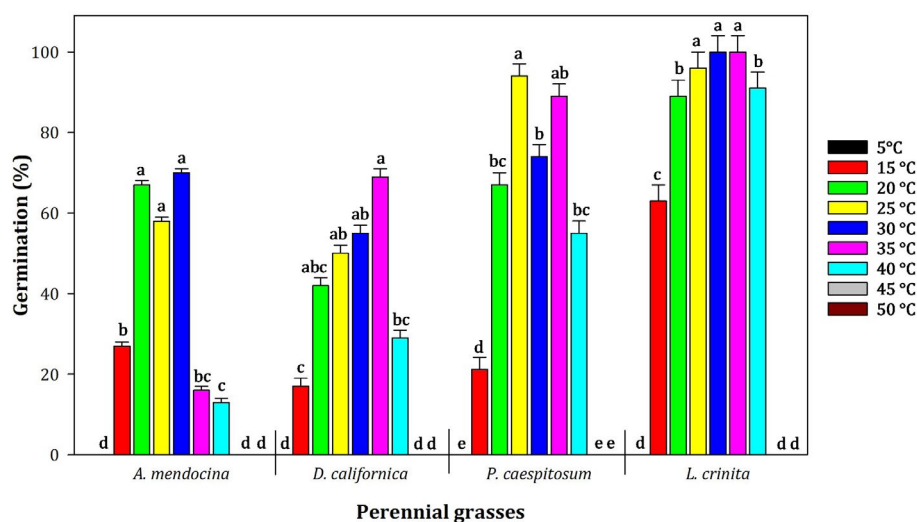


Figure 1. Average percentage of germinated seeds (+ standard error) of *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum*, and *Leptochloa crinita* incubated at different temperatures (5, 15, 20, 25, 30, 35, 40, 45°C).

Figura 1. Porcentaje promedio de semillas germinadas (+ error estándar) de *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas a distintas temperaturas (5, 15, 20, 25, 30, 35, 40, 45°C).

Table 1. Germination rates (Maguire Index $\pm$ standard error) of *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum* and *Leptochloa crinita* incubated at different temperatures.

Tabla 1. Tasas de germinación (Índice de Maguire $\pm$ error estándar) de semillas de *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas a diferentes temperaturas.

Temperature (°C)	<i>A. mendocina</i>	<i>D. californica</i>	<i>P. caespitosum</i>	<i>L. crinita</i>
15	0.80 $\pm$ 0.10 b	0.49 $\pm$ 0.09 c	0.76 $\pm$ 0.14 e	2.63 $\pm$ 0.68 e
20	2.84 $\pm$ 0.25 a	2.40 $\pm$ 0.23 bc	3.82 $\pm$ 0.30 d	8.25 $\pm$ 0.72 d
25	3.34 $\pm$ 0.42 a	5.66 $\pm$ 1.02 b	11.08 $\pm$ 0.67 b	18.41 $\pm$ 0.76 bc
30	3.63 $\pm$ 0.22 a	6.04 $\pm$ 0.52 ab	13.05 $\pm$ 0.49 ab	23.30 $\pm$ 0.58 a
35	0.80 $\pm$ 0.39 b	9.55 $\pm$ 1.59 a	14.31 $\pm$ 0.73 a	20.90 $\pm$ 0.91 ab
40	0.81 $\pm$ 0.33 b	5.00 $\pm$ 0.82 b	7.36 $\pm$ 0.74 c	15.90 $\pm$ 1.15 c

Different letters indicate significant differences between treatments for the same species at $p < 0.05$.

Letras diferentes indican diferencias significativas entre tratamientos para una misma especie a $p < 0,05$.

Germination at Constant and Alternating Temperatures

No germination occurred at 45°C. Alternating temperatures (15- 45°C) did not affect germination in *P. caespitosum* (table 2, page 6). *A. mendocina*. and *L. crinita* showed lower germination percentages when alternating temperature than under constant 30°C (figure 2, page 6). Similarly, germination rates of *A. mendocina* and *L. crinita* decreased by approximately threefold when seeds were incubated at alternating temperatures under 30°C (table 2, page 6). *D. californica* seeds did not germinate due to fungal infection in Petri dishes.

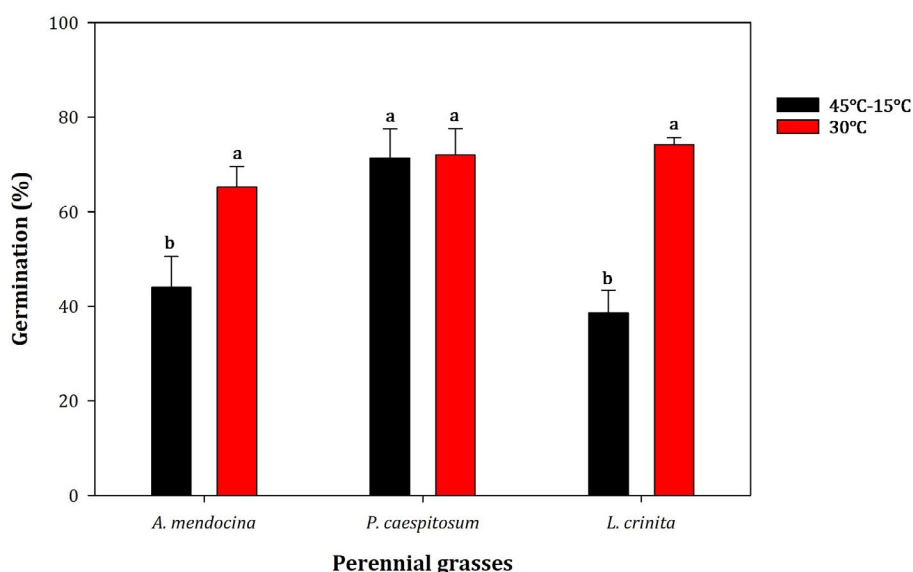
Table 2. Germination rates (Maguire Index $\pm$ standard error) of *Aristida mendocina*, *Pappophorum caespitosum*, and *Leptochloa crinita* incubated at constant (30°C) and alternating temperatures (15-45°C).

Tabla 2. Tasas de germinación (Índice de Maguire $\pm$ error estándar) de semillas de *Aristida mendocina*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas a temperaturas alternantes (15-45°C) y a temperatura constante (30°C).

Temperature (°C)	<i>A. mendocina</i>	<i>P. caespitosum</i>	<i>L. crinita</i>
15 -45	2.65 $\pm$ 0.47 b	7.52 $\pm$ 0.72 b	5.63 $\pm$ 1.06 b
30	8.24 $\pm$ 0.57 a	20.94 $\pm$ 1.70 a	19.56 $\pm$ 0.66 a

Different letters indicate significant differences between treatments for the same species at $p < 0.05$.

Letras diferentes indican diferencias significativas entre tratamientos para una misma especie a $p < 0,05$.



Different letters indicate significant differences in temperature within each species at $p < 0.05$.

Las letras diferentes indican diferencias significativas entre las temperaturas dentro de cada especie, $p < 0,05$.

Figure 2. Average percentage of germinated seeds (+ standard error) of *Aristida mendocina*, *Pappophorum caespitosum*, and *Leptochloa crinita* incubated at alternating temperatures of 45 and 15°C, and at a constant 30°C.

Figura 2. Porcentaje promedio de semillas germinadas (+ error estándar) de *Aristida mendocina*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas a temperaturas alternantes de 45 y 15°C y a temperatura constante de 30°C.

Germination at Different Water Potentials

Final germination of *A. mendocina* was similar between -0.38 MPa and control conditions. However, -0.58, -0.97, and -1.3 MPa solutions significantly decreased final germination. Null germination was recorded at -1.5 and -1.7 MPa (figure 3, page 7). Under increasing PEG solutions, germination rates decreased (table 3, page 7).

P. caespitosum seeds germinated in all PEG solutions. Even at -1.3 and -1.7 MPa, *P. caespitosum* achieved 60% and 20%, respectively (figure 3, page 7). Germination rates followed the same pattern as final germination percentage (table 3, page 7).

Seed germination percentage in *L. crinita* significantly decreased compared to the control, from -0.97 MPa onward, with no germination under -1.5 MPa (figure 3, page 7). Germination rates decreased from -0.58 onward (table 3, page 7).

D. californica seeds did not germinate due to fungal infection in the Petri dishes.

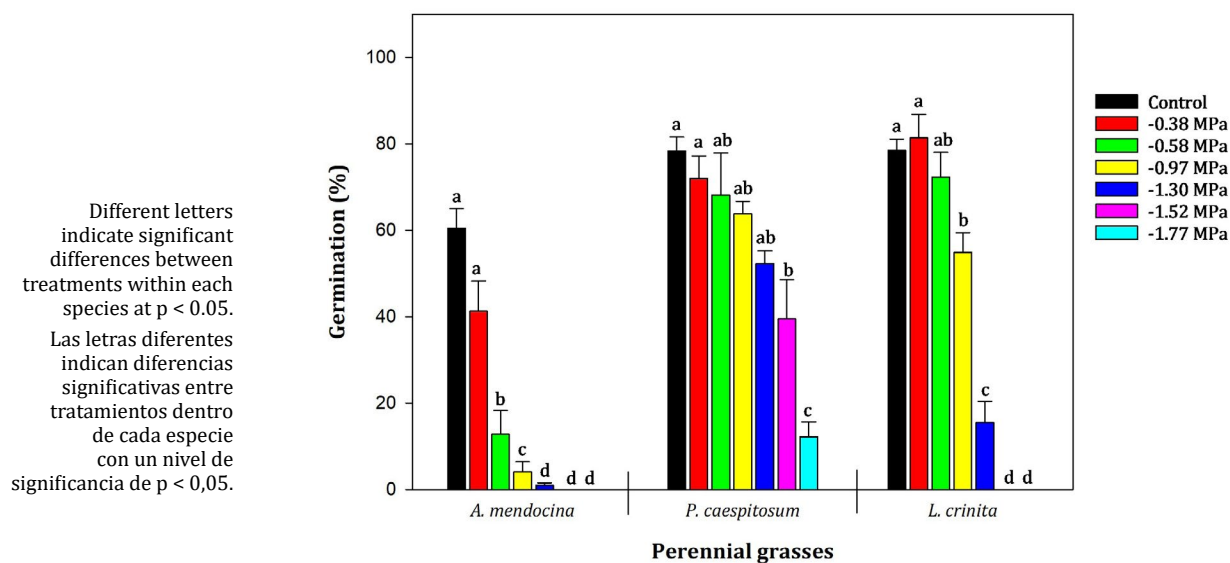


Figure 3. Average percentage of germinated seeds (+ standard error) of *Aristida mendocina*, *Pappophorum caespitosum*, and *Leptochloa crinita* incubated at different water potentials (control, -0.38, -0.58, -0.97, -1.30, -1.52, and -1.77 MPa).

Figura 3. Porcentaje promedio de semillas germinadas (+ error estándar) de *Aristida mendocina*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas a diferentes potenciales agua (control, -0.38 MPa, -0.58 MPa, -0.97 MPa, -1.30 MPa, -1.52 MPa y -1.77 MPa).

Table 3. Germination rates (Maguire Index $\pm$ standard error) of *Aristida mendocina*, *Pappophorum caespitosum*, and *Leptochloa crinita* incubated at different water potentials.

Tabla 3. Tasas de germinación (Índice de Maguire $\pm$ error estándar) de semillas de *Aristida mendocina*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas a diferentes potenciales agua.

Water potential (MPa)	<i>A. mendocina</i>	<i>P. caespitosum</i>	<i>L. crinita</i>
Control	11.37 $\pm$ 1.98 a	36.18 $\pm$ 2.51 a	36.15 $\pm$ 1.71 a
-0.38	4.77 $\pm$ 0.56 b	32.06 $\pm$ 2.21 ab	33.27 $\pm$ 0.63 a
-0.58	2.17 $\pm$ 0.68 bc	27.26 $\pm$ 4.42 abc	23.19 $\pm$ 2.06 b
-0.97	0.61 $\pm$ 0.35 c	17.93 $\pm$ 2.67 bcd	9.79 $\pm$ 0.96 c
-1.30	0.13 $\pm$ 0.08 c	15.87 $\pm$ 3.53 cd	2.16 $\pm$ 0.62 d
-1.52	0 $\pm$ 0 d	12.52 $\pm$ 3.99 d	0.21 $\pm$ 0.10 d
-1.77	0 $\pm$ 0 d	4.58 $\pm$ 1.47 d	0.13 $\pm$ 0.13 d

Different letters indicate significant differences between treatments for the same species at $p < 0.05$.

Letras diferentes indican diferencias significativas entre tratamientos para una misma especie a $p < 0.05$.

Germination in Different Saline Solutions

Neither *A. mendocina* nor *D. californica* germinated at 0.3 and 0.5 M NaCl treatments (figure 4, page 8). At 0.1 M, the percentage of germinated *A. mendocina* seeds was halved compared to the control. The percentage of germinated seeds for control *D. californica* did not reach 25%. Germination rates of both species at 0.1M were lower than the control (table 4, page 8).

Despite *P. caespitosum* seeds incubated in 0.1 M NaCl reached equal germination percentages as the control, their germination rate was slower (table 4, page 8). Significant differences were found between 0.3, 0.5 M NaCl, and control treatments (figure 4, page 8).

L. crinita seeds germinated (figure 4) in equal proportions and rates (table 4) in 0.1M and distilled water. The 0.3 M treatment germinated 5.5%, and the 0.5 M had no germination.

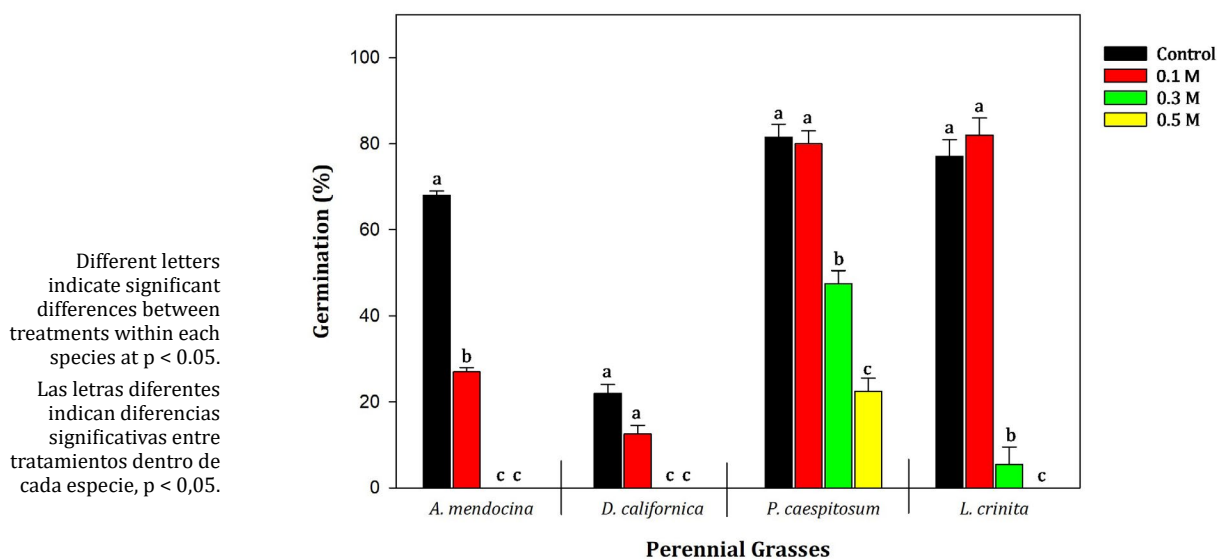


Figure 4. Average percentage of germinated seeds (+ standard error) of *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum*, and *Leptochloa crinita* incubated with different saline solutions (control, 0.1, 0.3, and 0.5M NaCl).

Figura 4. Porcentaje promedio de semillas germinadas (+ error estándar) de *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas con diferentes soluciones salinas (control, 0.1 M, 0.3 M y 0.5 M NaCl).

Table 4. Germination rates (Maguire Index $\pm$ standard error) of *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum*, and *Leptochloa crinita* incubated in different saline solutions.

Tabla 4. Tasas de germinación (Índice de Maguire $\pm$ error estándar) de semillas de *Aristida mendocina*, *Digitaria californica*, *Pappophorum caespitosum* y *Leptochloa crinita* incubadas en diferentes soluciones salinas.

Treatments (M NaCl)	<i>A. mendocina</i>	<i>D. californica</i>	<i>P. caespitosum</i>	<i>L. crinita</i>
Control	14.56 $\pm$ 2.50 a	6.69 $\pm$ 0.65 a	34.24 $\pm$ 3.07 a	28.22 $\pm$ 1.96 a
0.1	3.87 $\pm$ 0.73 b	2.61 $\pm$ 0.97 b	24.42 $\pm$ 2.29 b	25.05 $\pm$ 2.04 a
0.3	0 $\pm$ 0 b	0 $\pm$ 0 c	6.37 $\pm$ 1.20 c	0.62 $\pm$ 0.08 b
0.5	0 $\pm$ 0 b	0 $\pm$ 0 c	2.99 $\pm$ 0.78 c	0 $\pm$ 0 b

DISCUSSION

Germination of *A. mendocina*, *D. californica*, *P. caespitosum*, and *L. crinita* differs in response to temperature, water potential, and salinity. *P. caespitosum* and *L. crinita* germinated at a wider range of temperatures, salinity, and water potential than *A. mendocina* and *D. californica*. Besides, *L. crinita* germinated at a wider range of temperatures than *P. caespitosum*, but the latter germinated at lower water potential and more saline solutions than *L. crinita*. *A. mendocina* germinated at a narrower temperature range than the other

species. These results may explain landscape-scale differences exhibited by these species within the Monte Desert, where *P. caespitosum* and *L. crinita* inhabit saline soils and clay or sandy textures, and *A. mendocina* and *D. californica* only inhabit sandy soils (Candia & Guevara, 1973; Roig, 1970; Vega Riveros *et al.*, 2020).

These four perennial grasses germinate during the warm rainy season in the Monte desert (Labraga & Villalba, 2009). The highest germination percentage of *L. crinita* was recorded at 25, 30, and 35°C. Our data agree with previous reports of 85% at 28 and 35°C (Zabala *et al.*, 2011), 90% at 25 and 45°C (Di Giambattista *et al.*, 2010), and 70% at 20, 25, and 35°C (Meglioli *et al.*, 2024). We also recorded germination rates close to 90% at 20 and 40°C, showing slightly higher thermal tolerances than previously reported.

We obtained the fastest germination in darkness at 30 and 35°C, in accordance with Meglioli *et al.*, (2024) at 35°C. About 90% of *P. caespitosum* seeds germinated at 25 and 35°C, but germination at 20, 30, and 40°C was between 55% and 80%. However, Meglioli *et al.*, (2024) reported the highest germination percentage at 30°C (74%).

The fastest emergences occurred at 30 and 35°C, as previously reported (Meglioli *et al.*, 2024). However, maximum germination percentages of *D. californica* occurred at 35°C, in contrast with Meglioli *et al.*, (2024), who reported dramatic germination decreases at that temperature, and optimum at 25°C. Even after preventive Benomyl applications, fungal infection of *D. californica* in our assays might explain lower germination percentages than in previous studies (Ferrari & Parera, 2015; Meglioli *et al.*, 2024). *Aristida mendocina* germinated between 60-70% at 20, 25, and 30°C, its optimal range. Outside this range (15, 35, and 40°C), germination significantly dropped. Notably, 45 and 50°C are lethal to all species. Also, alternating temperatures reduced germination in *A. mendocina* and *L. crinita*, compared to constant 30°C.

In the Monte Desert, perennial grasses establish in unusually wet years (Marone *et al.*, 2000). In sandy soils, *L. crinita* and *P. caespitosum* require a minimum pulse of 40 mm to emerge (Greco *et al.*, 2013; Sartor *et al.*, 2024). Di Giambattista *et al.* (2010) conducted *L. crinita* germination tests at osmotic potentials of 0 MPa (control), -0.5, -1, and -1.5 MPa and under 17°C, 25°C, and 35°C, finding the highest germination percentages at 0 and -0.5 MPa, sharply falling at -1 MPa, regardless of temperature. Even using a finer scale, our results were similar, showing maximum germination (80%) at 0, -0.38, and -0.58 MPa, close to 50% at -0.97 MPa, and a sharp drop from -1.3 MPa onwards. Osmotic stress tolerance during germination of this species is tightly related to seed weight (Marinoni *et al.*, 2022). Populations with heavier seeds produced heavier seedlings under osmotic stress.

P. caespitosum was the most drought-tolerant species in the group, germinating at all evaluated potentials, and reaching a remarkable 60% germination at -1.3 MPa while maintaining 20% even at -1.77 MPa. In contrast, *A. mendocina* showed low tolerance to water stress. Although -0.38 MPa showed no significant differences with the control, germination dramatically declined at -0.58, -0.97, and -1.3 MPa, being completely absent at -1.5 and -1.7 MPa. Variations in water stress tolerance among these species likely account for their different distribution across the Monte landscape. In drying fine-textured soils, water potential becomes more negative than in coarse-textured soils. Considering this, only *P. caespitosum* and *L. crinita* could germinate in loamy or clayey soils.

Similarly, germination results at different salinities are consistent with the abundance of *P. caespitosum* and *L. crinita* in saline soils. In this study, *P. caespitosum* was the only species capable of germinating in high salt concentrations, achieving 50% germination at 0.3 M NaCl and maintaining 20% at 0.5 M. At 0.1 M, germination percentage equaled control. *L. crinita* at 0.1 M NaCl germinated at the same rates and speeds as the control. However, germination was low at 0.3 M and null at 0.5 M. Similarly, at a slightly higher concentration (0.12 M), Marinoni *et al.*, (2018) observed a significantly lower emergence percentage than the control, suggesting a strict tolerance limit for this species close to 0.1 M. On the other hand, *A. mendocina* and *D. californica* proved to be salt-sensitive. At 0.1 M NaCl, their germination percentage was lower than the control, and zero at 0.3 M and 0.5 M.

These results were obtained under controlled laboratory conditions; therefore, responses in natural environments may differ due to complex ecological interactions. Further studies should consider multiple environmental interactions.

CONCLUSIONS

Even considering the four perennial grasses studied are C4 photosynthetic types and originated from the same phytogeographic region (Monte, Argentina), they showed different temperature requirements and exhibited dissimilar germination tolerances to salinity and water stress.

The four species germinated between 15 and 40°C. No germination occurred at 5 or 45-50°C. *A. mendocina* optimally germinated between 20 and 30°C, while *D. californica*, *P. caespitosum*, and *L. crinita* had an optimal range between 25 and 35°C, with peaks at 25-30°C for *A. mendocina* and at 35°C for *D. californica*. In saline solutions, *D. californica* and *L. crinita* did not germinate under high concentrations of 0.3 M and 0.5 M, while *P. caespitosum* showed some tolerance in 0,3M and 0,5 M ClNa solutions. Regarding water potential, *L. crinita* and *P. caespitosum* germinated under moderate stress (approximately -0.38 to -0.97 MPa), with *P. caespitosum* reaching 60% germination, even at -1.3 MPa.

Different germination traits explain species segregation in the Monte Desert. The tolerant species *P. caespitosum* and *L. crinita* inhabit clayey and saline soils, while the sensitive *A. mendocina* is restricted to sandy ones. These findings allow for the optimization of genotype selection aimed at ecological and productive restoration programs in environments with varying levels of degradation.

REFERENCES

- Baskin, C. C. & Baskin, J. M. (2014). *Seeds: Ecology, biogeography, and evolution of dormancy and germination*. Academic Press.
- Bewley, J. D. & Black, M. (1994). *Seeds: Physiology of development and germination*. Springer Science and Business Media. 445 pp.
- Cabido, M., González, C., Acosta, A. & Díaz, S. (1993). Vegetation changes along a precipitation gradient in Central Argentina. *Vegetatio*, 109(1), 5-14. <https://doi.org/10.1007/BF00149541>
- Candia, R. J. & Guevara, J. C. (1973). Las comunidades vegetales del campo fiscal de La Llave y su valor forrajero. *Deserta*, 4.
- Cavagnaro, J. B. (1988). Distribution of C3 and C4 grasses at different altitudes in a temperate arid region of Argentina. *Oecologia*, 76, 273-277.
- Corvalán Videla, M. E., Aranibar, J. N. & Greco, S. (2021). Biological soil crusts from the Monte desert affect soil moisture and nutrients, and improve *Leptochloa crinita* grass development. *Acta Oecologica*, 110, 103712. <https://doi.org/10.1016/j.actao.2021.103712>
- Dagata, S., Fernández, M. E. & Passera, C. B. (2021). Environmental factors affecting germination of *Mimosa ephedroides* (Fabaceae), an endemic shrub from Monte Desert, Argentina. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo*. 53(1), 139-149. <https://doi.org/10.48162/rev.39.014>
- Di Giambatista, G., Garbero, M., Ruiz, M. & Pedranzani, A. G. H. (2010). Germinación de *Trichloris crinita* y *Digitaria eriantha* en condiciones de estrés abiótico. *Pastos y Forrajes*, 33(4), 1-10.
- Ferrari, F. N. & Parera, C. A. (2015). Germination of six native perennial grasses that can be used as potential soil cover crops in drip-irrigated vineyards in semiarid environs of Argentina. *Journal of Arid Environments*, 113, 1-5. <https://doi.org/10.1016/j.jaridenv.2014.09.002>
- Flores, D. G., Suvires, G. & Dalmaso, A. (2015). Distribución de la vegetación nativa en ambientes geomorfológicos cuaternarios del Monte Árido Central de Argentina. *Revista Mexicana de Biodiversidad*, 86(1), 72-79.
- Greco, S. A., Sartor, C. E. & Villagra, P. E. (2013). Minimum water input event for seedling emergence of three native perennial grasses of the Central Monte desert (Argentina) influenced by the effect of shade and the season of the year. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo*, 45(2), 197-209.
- Guden, B., Kiemde, O., Akşahin, M. Ç. & Uzun, B. (2024). Effects of salt stress on germination, seedling growth, and ion content of sweet sorghum. *Mediterranean Agricultural Sciences*, 37(2), 91-98.
- Guevara, J. C., Cavagnaro, J. B., Estevez, O. R., Le Houerou, H. N. & Stasi, C. R. (1997). Productivity, management and development problems in the arid rangelands of the central Mendoza plains (Argentina). *Journal of Arid Environments*, 35, 575-600.
- Guevara, J. C., Grunwaldt, E. G., Estevez, O. R., Bisigato, A. J., Blanco, L. J., Biurrun, F. N., Ferrando, C. A., Chirino, C. C., Morici, E., Fernández, B., Allegratti, L. I. & Passera C. B. (2009). Range and livestock production in the Monte Desert, Argentina. *Journal of Arid Environments*, 73(2): 228-237. <https://doi.org/10.1016/j.jaridenv.2008.02.001>
- Gutterman, Y. (1993). *Seed Germination in Desert Plants*. By Y. Gutterman. Berlin and Heidelberg: Springer-Verlag (1993), pp. 252, DM 198.00.
- International Seed Testing Association. (2021). International Rules for Seed Testing. <https://www.seedtest.org/en/publications/international-rules-seed-testing.html>

- Kigel, J. (1995). Seed germination in arid and semiarid regions. In: *Seed development and Germination*. Ed. by Kigel & Galili. Dekker, New Cork. 645-701.
- Kildisheva, O. A., Erickson, T. E., Merritt, D. J. & Dixon, K. W. (2016). Setting the scene for dryland recovery: an overview and key findings from a workshop targeting seed-based restoration. *Restoration Ecology*, 24(2): 36-42.
- Labraga J. C. and Villalba, R. (2009). Climate in the Monte Desert: Past trends, present conditions, and future projections. *Journal of Arid Environments*, 73(2): 154-163.
- Lundholm, J. T. & Larson, D. W. (2004). Experimental separation of resource quantity from temporal variability: Seedling responses to water pulses. *Oecologia*, 141(2), 346-352. <https://doi.org/10.1007/s00442-003-1454-6>
- Maguire, J. D. (1962). Speed of germination: aids in selection and evaluation for seedling emergence and vigor. *Crop Science*, 2: 176-177.
- Mansouri, L. M. & Kheloufi, A. (2024). Salinity effects on germination of *Portulaca oleracea* L.: A multipurpose halophyte from arid rangelands. *Journal of Applied Research on Medicinal and Aromatic Plants*, 41, 100549.
- Marchi, A., Guevara J. C., Borsetto, O., Estevez, O. R., Stassi, C. R., Candia, R. J., Silva, J. H., Oriente, E. L. (1991). *La cría de bovinos en el centro de la llanura de Mendoza. Posibilidades y limitaciones*. IADIZA-INTA. Boletín de Información Técnica N°1. Pp 2.
- Marinoni, L., Zabala, J. M., Parra-Quijano, M., Fernández, R. J. & Pensiero, J. F. (2018). Genetic and environmental variation of seed weight in *Trichloris* species (*Chloridoideae*, *Poaceae*) and its association with seedling stress tolerance. *Plant Ecology and Diversity*, 11(2), 173-184. <https://doi.org/10.1080/17550874.2018.1449262>
- Marinoni, L., Richard, G. A., Bustos, D., Taleisnik, E., Pensiero, J. F. & Zabala, J. M. (2020). Differential response of *Trichloris crinita* ecotypes from different habitats to drought and salt stress. *Theoretical and Experimental Plant Physiology*, 32, 213-229. <https://doi.org/10.1007/s40626-020-00182-x>
- Marinoni, L., Zabala, J. M., Quiroga, R. E., Richard, G. A. & Pensiero, J. F. (2022). Seed Weight and Trade-Offs: An Experiment in False *Rhodes* Grasses under Different Aridity Conditions. *Plants (Basel)*, 11(21): 2887. DOI: 10.3390/plants11212887
- Marone, L., Horno, M. & Gonzalez del Solar, R. (2000). Post dispersal fate of seeds in the Monte desert of Argentina: patterns of germination in successive wet and dry years. *Journal of Ecology*, 88, 1-11.
- Meglioli, C., Scaglia, J. A. & Parera, C. A. (2024). Factores que afectan la germinación de tres pastos de zonas áridas: *Leptochloa crinita*, *Pappophorum caespitosum* y *Digitaria californica* (*Poaceae*). *Acta Botánica Mexicana*, (131).
- Meglioli, C., Kuchen, B., Ormeño, L., Vazquez, F., Parera, C. A. (2026). Statistical Optimization of Seed Coating in Arid-Zone Grass Species Used as Cover Crops in Woody Agroecosystems. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo*. 58(1): 1-14. DOI: <https://doi.org/10.48162/rev.39.189>
- Mnif Fakhfakh, L., Abassi, S., & Chaieb, M. (2025). Effect of temperature, salinity and water potential on seed germination of annual grass *Stipa capensis*. *Arid Land Research and Management*, 39(1), 87-103.
- Nikolić, N., Ghirardelli, A., Schiavon, M. & Masin, R. (2023). Effects of the salinity-temperature interaction on seed germination and early seedling development: a comparative study of crop and weed species. *BMC Plant Biology*, 23(1), 446.
- Noy-Meir, I. (1973) Desert Ecosystems: Environment and Producers. *Annual Review of Ecology and Systematics*, 4, 25-51.
- Okumuş, O. & Şekerci, A. D. (2024). Effects of different salt stress and temperature applications on germination in mung bean (*Vigna radiata* (L.) R. Wilczek) genotypes. *Black Sea Journal of Agriculture*, 7(3), 310-316.
- Quiroga, R. E., Premoli, A. C. & Fernández, R. J. (2018). Climatic niche shift in the amphotropical disjunct grass *Trichloris crinita*. *PLoS ONE*. 13(6): e0199811. <https://doi.org/10.1371/journal.pone.0199811>
- Roig, F. A. (1970a). Bosquejo fisonómico de la vegetación de la provincia de Mendoza. *Boletín de la Sociedad Argentina de Botánica*, 13 (Suppl.): 49-80.
- Roig, F. A. (1970b). Flora y Vegetación de la Reserva Forestal de Ñacuñán. *Deserta*, 1:25-222.
- Roig, F., Roig-Juñent, S. & Corbalán, V. (2009). Biogeography of the Monte desert. *Journal of Arid Environments*, 73(2), 164-172. <https://doi.org/10.1016/j.jaridenv.2008.07.016>
- Sartor, C. E., Greco, S. A., Allegretti, L. I., Arancibia, C., Pucheta, E., Villagra, P. E. & Passera, C. B. (2024). Influence of *Neltuma flexuosa* and rainfall event on the germination of *Leptochloa crinita* and *Pappophorum caespitosum* in two different locations along a stress gradient in the central Monte desert. *Ecological Research*, 40(1), 65-75. <https://doi.org/10.1111/1440-1703.12517>
- Schwinning, S. & Sala, O. E. (2004). Hierarchy of responses to resource pulses in arid and semi-arid ecosystems. *Oecologia*, 141(2), 211-220. <https://doi.org/10.1007/s00442-004-1520-8>
- Singh, G. (2025). Seed Germination. In *Seed Biology and Biotechnology*. Editors: H. V. Bhoot, P. Karthikeyan, Dr. Geetika Singh, Pavithra Sivakumar and Akanksha Lakra. Haryana 136118 (India). P. 1-17.

- Vega Riveros, C., Villagra P. & Greco S. (2020). Different root strategies of perennial native grasses under two contrasting water availability conditions: implications for their spatial distribution in desert dunes. *Plant Ecology*, 221:633-646
- Villagra, P. E., Giordano, C., Alvarez, J. A., Cavagnaro, J. B., Guevara, A., Sartor, C. E., Passera, C. B. & Greco, S. (2011). Ser planta en el desierto: Estrategias de uso de agua y resistencia al estrés hídrico en el Monte Central de Argentina. *Ecología Austral*, 21(1), 29-42.
- Zabala, J. M., Widenhorn, P. & Pensiero, J. F. (2011). Germination patterns of species of the genus *Trichloris* in arid and semiarid environments. *Seed Science and Technology*, 39, 338-353.