

SODIUM CHLORIDE EFFECTS ON SEED GERMINATION AND POSTGERMINATIVE GROWTH OF ANABASIS ARTICULATA (FORSSK.) MOQ. (AMARANTHACEAE), AN ALGERIAN WILD HALOPHYTE

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Abstract

Anabasis articulata, is a wild halophyte mainly found in the Algerian Sahara Desert and used in traditional medicine by natives for their medicinal properties. Salinity is well documented to have an impact on the germination and development of many species. In Algeria, the behavior of *A. articulata* halophyte at germination and postgerminative stage is rather poorly understood. In the present study, we discuss the level of their seed tolerance during the process of germination under laboratory conditions. Therefore, the response of seed germination and postgerminative growth parameters of *A. articulata* to salinity level were investigated. Seven salinity concentrations (50, 100, 150, 200, 250, and 300 mM NaCl) were applied to seeds obtained from the Saharan rangeland desert of Algeria, and they were then incubated at 25°C in the dark. The salinity had a big impact on seedling growth parameters and germination indices. The non-saline treated seeds had the highest germination percentage (GP; 98%) up until 150 mM NaCl, however they continue to germinate at significant rates.

Ungerminated *A. articulata* seeds germinated well after being transferred to distilled water, demonstrating that germination was limited by osmotic potential rather than particular ion toxicity and thus *A. articulata* may be classified as a salt resistant plant. Furthermore, the growth characteristics (i.e., aSL) decreased with rising salinity levels, particularly at 250mM. While the aRL grew dramatically with increasing salt concentrations until 200 mM NaCl, it then declined significantly. The seedling vigour index (SVI) followed a similar trend to that of germination. All of these features suggest that *A. articulata* seeds may germinate in extreme salinity conditions, making it a good choice for restoring degraded rangelands.

Key words: *Anabasis articulata*, Germination, Salinity, Tolerance, Conservation, Algeria.

Introduction

Halophytes are adapted to tolerate harsh saline and arid conditions (salinity, drought and low rainfall and high rates of evaporation), in both temperate and tropical climates by synthesizing a number of active chemicals to maximize their fitness, they can serve as a source of valuable secondary metabolites with use in agro-forestry and conservation, food, forage, pharmacognosy, cosmetic, and nutraceuticals with many of which are a source of potent medicine against a number of chronic ailments (Khan *et al.*, 2014; Öztürk *et al.*, 2014; Grigore & Oprica, 2015; Öztürk *et al.*, 2023).

Plants of the *Amaranthaceae* family (formerly Chenopodiaceae) are used for their richness in bioactive substances. The xerophytic genus *Anabasis*, which is included in the subfamily *Salsoloideae* (tribe *Salsoleae*), is considered one of the earliest C₄ clades within the *Chenopodiaceae* family (Kadereit *et al.*, 2012; Schüssler *et al.*, 2016). This genus encompasses a total of 28 species worldwide (Hedge, 1997; Sukhorukov, 2008). This genus assumes a significant role in the facilitation of favourable rangeland conditions, as well as in the stabilisation of wind-blown sand dunes and the expansion of arid regions. This particular species exhibits an impressive capacity for drought resistance, owing to its C₄ photosynthetic pathway. Mature plants have the capacity to endure extended periods of drought, potentially spanning many years (Al-Joufi *et al.*, 2022).

In Algeria, only *Anabasis articulata* species is found in arid and semi-arid rangelands (Ozenda, 2004). *Anabasis articulata* (Forssk.) Moq. commonly known as Adjrem or Baguel, is a Saharan endemic species native to Saharo- Arabian regions (Lauterbach *et al.*, 2019). This wild species is classified as a dwarf-shrub (chamaephyte) and is known to thrive in saline environments. It has the ability to reach a maximum height of 2 metres and is commonly found in the northern region of the Sahara Desert in Algeria. It has a wide distribution across many types of terrain, including sandy, gravelly, and chalky slopes. This particular species exhibits a high degree of salt tolerance and demonstrates robust growth on arid sand dunes and soils affected by salinity (Ozenda, 2004).

Stems are woody for at least half their length, are stout and twisted, and are a very pale bluish-green colour; the upper bracts are arranged in spikes (Fig. 1 (a)). The branches are articulated opposed, with more or less equal internodes, and almost leafless (Fig. 1 (b)). Flowers up to 5 mm in diameter, solitary and opposite. Segments of the perianth are membranous. Five long-extended stamens; thick, orbicular-ovate, papillose staminodal appendages. Ovary papillose; dense, papillose stigmas. *A. articulata* produces fruit with wings that are dispersed by the wind; wing size ranges from 5 to 7 millimetres (Fig. 1(c)). The seeds are extremely minute (approximately 2 mm thick), green, and subspherical (Fig. 1 (d)). Typically, flowering occurs between December and January (Al-Oudat & Qadir, 2011).

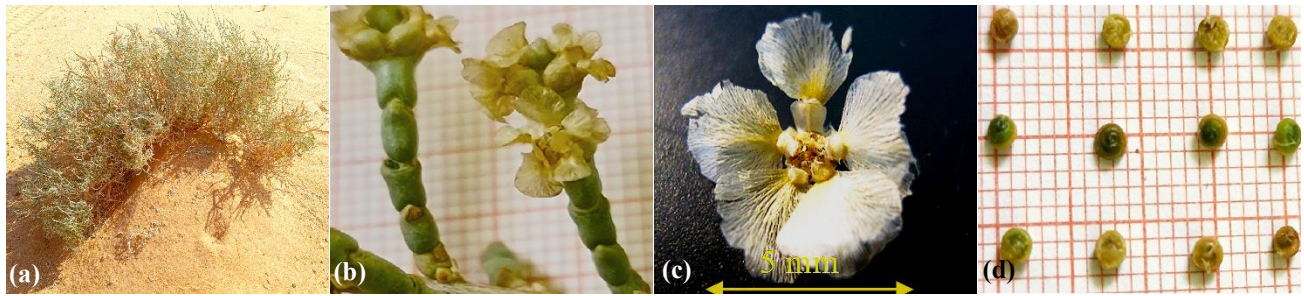


Fig. 1. *Anabasis articulata* species: (a) Vegetative stage (b) Fruiting stage (c) Winged fruit (d) Seeds.

The plant under consideration has been widely utilised in traditional local medicine for various therapeutic purposes. It has been documented as an effective treatment for conditions such as eczema, headaches, and kidney infections (Hammiche & Maiza, 2006). Additionally, it has demonstrated potential as an anti-diabetic (Kambouche *et al.*, 2009; Metwally *et al.*, 2012), anti-inflammatory (Abdallah *et al.*, 2014), antioxidant (Benhammou *et al.*, 2013; Ghembaza *et al.*, 2016), and anti-angiogenic agent (Abdulsahib *et al.*, 2016), and an anti-ulcer agent (Gamal *et al.*, 2021).

The entire plant is pharmacologically rich in flavonoids, tannins, sterols/triterpenes, and coumarins, which can be used as a natural preservative for food or cosmetic products (Benzineb *et al.*, 2019). This species is also very digestible by cattle and weakly appreciated by camels (Ozenda, 2004; Chehma, 2006).

Successful germination activity can tell us a lot about how plants get established, how well they can handle abiotic factors, and how they change over time in drylands (Gorai *et al.*, 2009; Trabelsi & Kherraze, 2020).

Germination is a critical stage in the plant life cycle, with the primary purpose of establishing a new plant in a suitable environment. Several environmental conditions influence it, including salinity, temperature, light, and soil moisture (Öztürk *et al.*, 1997; El-Keblawy & Al-Rawai, 2005; Gorai & Neffati, 2007).

Soil salinity is an environmental stress factor and significant impediment to ecological restoration and reconstruction. It profoundly restricts seed germination and plant growth by diminishing the soil water potential, thereby impeding water uptake. Additionally, the presence of specific ions in excessive amounts can have toxic effects, leading to imbalances in nutrient uptake and disruption of various metabolic processes (Öztürk *et al.*, 2006; Hasanuzzaman *et al.*, 2014; Trabelsi & Kherraze, 2020). In arid and semi-arid areas, most salinity-infested lands are due to natural causes or salts accumulation. Indeed, 80% of the salinized lands have a natural origin on the African continent. The predominant salinity in the saline dry areas of Algeria is chloride-sodium (Idder *et al.*, 2014).

According to Gairola *et al.*, (2020), the stages of germination and early seedling growth in the plant life cycle exhibit heightened sensitivity to salinity stress, particularly in the case of desert plants. It has been observed that salinity can have detrimental effects on seed production, as well as delay the commencement of germination and lower seedling survival. Additionally,

salinity has been found to decrease the rate of germination and increase the dispersion of germination events. These combined effects ultimately lead to reductions in plant growth and a decrease in the utilisation of seed reserves (Ahmad & Bano, 1992; Öztürk *et al.*, 2006, 2019).

Salt stress may impact seed production and the formation of heteromorphic seeds with varying germination and seedling survival rates (Chedly *et al.*, 2008; Ashraf *et al.*, 2009; Hasanuzzaman *et al.*, 2019).

The germination response of halophyte populations in salt deserts is a significant factor contributing to their success (Tlig *et al.*, 2008). Halophytes' responses to different stress factors, such as salinity, moisture, light, and temperature, as well as their interactions, exhibits a significant degree of variability. Hence, it is imperative to conduct a study on the impact of NaCl on the process of germination and initial growth of *A. articulata*, a wild halophytic plant of Algeria. This research holds significant theoretical and practical implications as it contributes to our understanding of the adaptive mechanisms employed by desert plants to cope with high salinity levels (Song & Wang, 2015). Primarily, it holds immense importance in the conservation of endangered medicinal halophytes, management of desertification, and the promotion of sustainable development in dry regions.

Material and Methods

Seed collection site: Mature fruits from a total of 20-30 randomly chosen individuals of *A. articulata* were collected during December 2021, from populations growing on sandy soil in Oued Righ region (32°54'N, 05°50'E; South-Eastern part of Algeria). The seeds were combined to illustrate the genetic variability within the populations of the species under investigation. This region is dry, under Mediterranean climate, characterized by a summer that is very dry, scarcity and irregularity of rains, large temperature range, high temperatures, high luminosity, very intense evapotranspiration, severe and long drought episodes, low relative humidity and extreme weather events such as heat waves and extreme wind events (Le Houerou, 1990; Abd El-Ghani *et al.*, 2017).

Treatments and experimental conditions: The germination test was conducted in an incubator adjusted to 25°C with continuous dark (Trabelsi & Kherraze, 2020). Seven different NaCl solutions were used to treat the seeds: 50, 100, 150, 200, 250 and 300 mM, and the control (0 mM). The experiment was carried out in Petri

dishes measuring 9 cm and containing two discs of filter paper. Four replicate dishes containing 25 seeds each were saturated with 4mL for each treatment. To prevent exposure to light, the Petri dishes were enveloped in aluminum foil. A seed was considered germinated when the radicle measured a length of 2 millimeters. Following germination, seedlings were enumerated every other day for ten days (Hanif *et al.*, 2017). Seed germination was determined by the emergence of radicles with a length of 2 mm.

To determine whether the inhibitory impact of salt was caused by ion toxicity or osmotic effects, seeds that did not germinate in solutions after 10 days were moved to deionized water and grown for an additional 10 days under the same conditions.

Data analyses

Germination experiment: The following germination features were recorded: (1) The kinetics of germination refers to the progression of cumulative germination percentages of seeds over time in various salt concentrations, starting from the day of planting to the conclusion of the experiment. (2) Germination Percentage (GP) was computed as the number of germinated seeds divided by the number of tested seeds multiplied by 100. (3) The rate of germination (GR) was assessed by employing a modified Timson's index of germination velocity, which is calculated as $= \sum G/t$, where G is the percentage of germinated seeds at each count; t represents the total germination duration (Khan & Ungar, 1984). The higher the value, the faster the germination process occurs. (4) Germination recovery. The calculation of the germination recovery index was performed using the formula described by Khan *et al.*, (2001); the expression $(a/b)/(c/b)*100$ represents a calculation in which a represents the total number of seeds that have germinated after being transferred to distilled water, b represents the total number of seeds that have germinated in saline solutions, and c represents the total number of seeds. The expression is multiplied by 100 to convert the result into a percentage.

Measurement of growth parameters: Ten seedlings from each treatment were randomly chosen from each Petri dish at the end of the germination phase (seven days later) in order to measure the growth parameters: the shoot length (SL = average shoot length ($n = 10$)), and root length (RL = average root length ($n = 10$)) and leaves length (LL = average leave length ($n = 10$)) using a Vernier caliper. The data on germination percentage and seedling length were utilised to compute the seedling vigour index for each treatment, employing the equation presented by Kumar *et al.*, (2011), and expressed as an integer value: Seedling vigor index (SVI): $SVI = [SL \text{ (mm)} + RL \text{ (mm)}] * GP \text{ (%)}$ where SL = Shoot length, RL = Root length, and GP = Germination percentage.

To facilitate a more comprehensive evaluation of seedling growth, we computed the decrease in growth as a percentage relative to the control group. Reduction percentage = $[(\text{salt treatment} - \text{control}) / \text{control}] * 100$.

Statistical analysis

The data analysis was conducted using STATISTICA 10 (StatSoft Inc., USA) software. One-way analysis of variance (ANOVA) at 5% significance level was carried out to demonstrate the effects of the salt concentration on the final germination percentage, rate of germination recovery percentage and seedling growth as dependent variables. The Tukey's honestly significant difference HSD test as post hoc analysis was used to estimate least significant range between means. Mean and standard error (SE) were determined for the replicate values. Normality and homogeneity of variance of data series were tested (Grigore *et al.*, 2012).

Results

Effects on Kinetic of germination: The delay of germination was recorded in 2 days. Seed germination was different at various treatment levels. The delay of germination was more obvious at 300 than with other concentrations but *A. articulata* seeds were able to continue to germinate at very high concentrations (Fig. 2).

Germination was observed in all salt concentrations during the initial 2 days with different germination percentages. Seed germination started rapidly in control, 50, 100 and 150 mM which maximum germination attained 95%, 95%, 88% and 85% respectively. The presence of NaCl depressed moderately germination at the lowest concentrations, minimum germination 48%, 45% and 30% was observed in NaCl (200, 250 and 300 mM) respectively.

The first phase of germination kinetic shape represents an exponential phase (from the 2nd day) corresponding to the time required for adequate seeds imbibition. A second phase (between 2 and 8 days) during which the germination rate increases until it reaches a maximum value from which germination stops in the 4th to 6th day in the control, 50, 100, 150 mM NaCl with a high value of 98%, 95%, 96% and 81% respectively. Seeds watered by 200 and 250 and 300 mM evolve slowly compared to the control. A third phase (after the 8th day) corresponding to a plateau where germination percentages increase slowly at first to stabilize until the end of the experiment.

Effects on final percentage and rate of germination: ANOVA revealed that salt content had a significant impact on the final percentage of germination of *A. articulata* seeds ($F = 487.78$, $P < 0.001$) (Fig. 3).

In the NaCl experiment, the maximum germination rates of 98%, 98%, 96%, and 95% were observed under control conditions and 50 mM NaCl, followed by 100 and 150 mM NaCl, respectively. Increasing the value of solution salinity, the final germination percentage decreased significantly from 82% to 80% at 200 and 250 mM NaCl, respectively. However, we did not observe a remarkable reduction in seed germination, and seeds continued to germinate at the highest NaCl concentrations, 300 mM NaCl, with 73%, respectively.

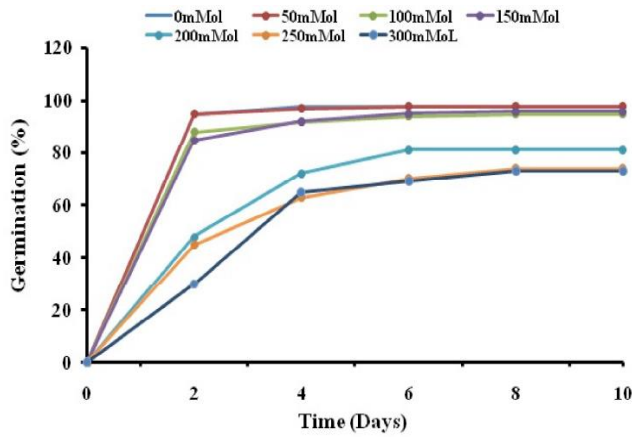


Fig. 2. Cumulative germination percentage of *A. articulata* seeds under NaCl salt stress (50-300 mM) (n=4).

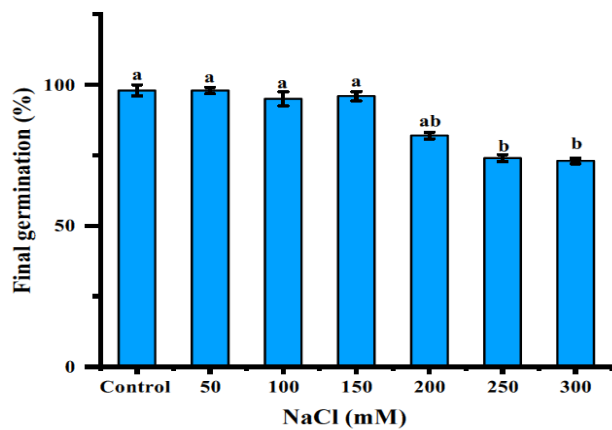


Fig. 3. Mean final germination (\pm SE, n=4) of *A. articulata* seeds under NaCl salt stress (50-300 mM). The Tukey's test indicates that values with the same letter are not statistically different at the 0.05 significance level.

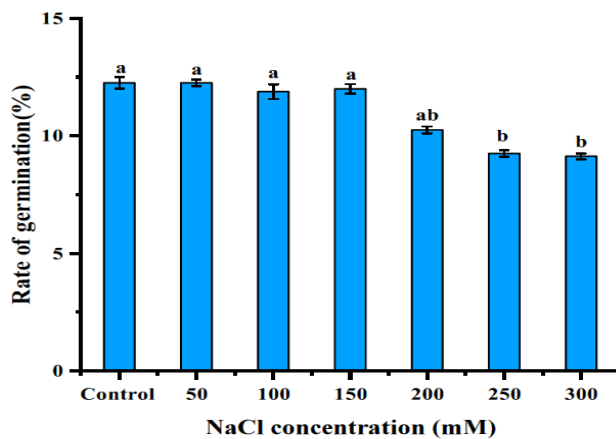


Fig. 4. Mean Rate of germination (\pm SE, n=4) of *A. articulata* seeds under NaCl salt stress (50-300 mM). The Tukey's test indicates that values with the same letter are not statistically different at the 0.05 significance level.

As salinity increased, the rate of germination dropped. Salinity has a substantial impact on germination rate, according to a one-way ANOVA ($F = 397.61$, $p < 0.0001$) (Fig. 4). Although higher salinity decreases germination, salinity does not really have a detrimental

effect on seed germination. At the highest concentrations, NaCl moderately inhibited germination.

A concentration of 200 mM was sufficient to decrease germination capacity up to 10.25%. MTG increased with salinity and we recorded 12.25% in both the control and 50 NaCl and 9.12% at 300 mM NaCl. Salinity stress moderately decreased the percentage and the rate of germination.

Effects on germination recovery: The transfer of seeds to deionized water following exposure to salt stress increased the number of germinated seeds (Table 1). Salt stress effects on germination recovery were statistically significant ($p < 0.05$). The results reveal that all ungerminated seeds recovered after being moved to distilled water.

Table 1. Effect salinity on germination recovery percentage of *A. articulata* seeds.

NaCl Concentration (mM)	Seed germination (% , mean \pm S.E, n=4)		
	Initial (b/c)*100	Recovery [(a-b)/(c-b)]*100	Total (a/c)*100
0	98 \pm 0.5 ^a	0 \pm 0.0	98 \pm 0.5 ^a
50	98 \pm 0.28 ^a	00 \pm 0.0	98 \pm 0.28 ^a
100	95 \pm 0.62 ^a	0 \pm 0.0	95 \pm 0.62 ^a
150	95 \pm 0.40 ^a	20 \pm 0.57	96 \pm 0.57 ^{bc}
200	82 \pm 0.28 ^{ab}	38 \pm 4.04	88 \pm 4.04 ^b
250	80 \pm 2.02 ^{ab}	95 \pm 10.11	93 \pm 10.11 ^{ab}
300	73 \pm 1.49 ^b	44 \pm 6.92	85 \pm 6.92 ^b

After the recovery treatment, many of the ungerminated seeds remained viable. Germination recovery was, in large extent, high and the highest recovery was about 95% for 250mM NaCl. At low NaCl (150mM), germination recovery is low (20%), while seeds subjected to high salt stress (300 mM NaCl) have experienced considerable germination recovery (44%).

Seedling growth responses to salinity effect: The aSL decreased significantly as the salt concentrations increased ($F(6; 63) = 11.93$; $p < 0.0001$, Table 2). However, the aRL increased significantly as salt concentrations were higher ($F(6; 63) = 185.04$; $p < 0.0001$, Table 1) at 50, 100, 150 and 200 mM NaCl, when the maximum aRL was shown by the seedlings germinated at 150 mM, then decreased significantly at 250 and 300 mM NaCl. Salinity levels had a significant influence on seedling vigour index ($P 0.0001$, for all seedling growth attributes).

The increase percentages in hypocotyls growth ranged between (49-10%), While for radicles elongation, the reduction percentages ranged between (10.02-46.38%) as compared to those of controls (Table 2). As a result, hypocotyl growth was more responsive to salt content than radicle growth, particularly at 50 and 200 mM NaCl. These data suggest that the seeds could germinate under sodium chloride treatment up to 300mM of NaCl. At 200 mM, a similar pattern of seedling growth was found, demonstrating that the seedling was slightly more responsive to increased salinity concentration than seed germination stage.

At 100 mM of salt concentration, we found a positive correlation between root length and shoot length ($r=0.75$; $p < 0.0113$). The regression equation ($y = 27.6643 + 0.4842 * x$) indicates that every 1mm extension from root, we will have 28.14mm extension from shoot, respectively. No correlation have been noted for the other concentrations.

Table 2. Effect salinity on seedling growth of *A. articulata* (Means followed by the same letter are not significantly different at the probability level of 5% according to HSD. Mean±SE).

Concentration (mM)	A root length (mm)	Increase (+) and reduction (-) percentage (%)	A shoot length (mm)	Reduction percentage (%)	Seedling vigor index
0	11,07 ± 0,56 ^b	0	42,90 ± 2,40 ^b	0	5289.06
50	21,70 ± 0,74 ^c	49	38,50 ± 1,36 ^{ab}	10.25	5899.6
100	22,80 ± 1,42 ^c	51.45	33,40 ± 2,03 ^{ac}	22.14	5395.2
150	25,10 ± 0,84 ^d	55.89	38,60 ± 2,68 ^{ab}	10.02	6051.5
200	12,30 ± 0,61 ^b	10	34,60 ± 2,14 ^{ab}	19.34	3870.4
250	0,57 ± 0,02 ^a	-94.85	27,80 ± 1,43 ^{cd}	25.19	2269.6
300	0,33 ± 0,01 ^a	-97.01	23 ± 1,37 ^d	46.38	1703.09

Discussion

Kinetic of germination: When NaCl was present, the germination of *A. articulata* seeds was slightly delayed but not significantly inhibited when the NaCl concentration was greater than 300 mM. Ecophysiologicaly, salt content had a significant impact on *A. articulata* but had no effect on seed viability. In fact, this finding shows that *A. articulata* would be able to form a viable seed bank at high saline levels, and that these seeds would eventually germinate after the salt is leaching from soil surface, by winter rains, during the spring. Similar tendencies have been observed in various *Atriplex* species as well as certain wild Saharan halophytes (El-Keblawy & Bhatt, 2015; Trabelsi & Kherraze, 2020). Our results sustain the hypothesis that salt stress typically reduces germination by inhibiting seed imbibition.

Effect of NaCl stress on seed germination: The maximum germination percentages and germination rates of *A. articulata* seeds were 95%, 88%, and 85%, respectively, under NaCl-stress conditions, compared to the control. However, as the intensity of salt stress increased (concentrations greater than 200 mM), seed germination percentages decreased significantly. It appears that *A. articulata* could germinate at concentrations of 300 mM NaCl.

The decline in germination rates resulting from elevated salinity levels can be attributed to the characteristics of salinity, which hinder the imbibitions of water due to a decrease in osmotic potential within the surrounding environment, as well as alterations in metabolic processes (Yupsanis *et al.*, 1994).

The seeds of annual *Zygophyllum simplex* show no germination under NaCl concentrations higher than 125 mM (Khan & Ungar, 1996). Similarly, germination *Diploaxis harra*, an annual glycophyte, was drastically reduced under 150 mM NaCl and entirely inhibited at 200 mM NaCl (Tlig *et al.*, 2008). In general, increased salinity inhibits or delays the germination of both halophytic and glycophytic seeds (Tlig *et al.*, 2008).

This response of *A. articulata* seed germination is dissimilar to other halophytes species from the same region like *Zygophyllum album* which had a priming effect in the highest salinity treatment (200mM of NaCl) (Hadjadj *et al.*, 2022). Other native halophyte in Sahara desert of Algeria like *Peganum harmala* did not germinate at 200 mM NaCl (Trabelsi & Kherraze, 2020).

At high concentrations of NaCl, *Panicum turgidum* seed germination was substantially reduced and slowed, and no germination was observed (El-Keblawy, 2004).

Similarly, seed germination was significantly reduced in *Anabasis setifera* seeds grown in Egypt under saline conditions (El-Keblawy *et al.*, 2016). Others, approximately 50 halophytes worldwide, have a reduced capacity to germinate when salinity levels are above 125 mM NaCl, and sometimes more in the case of species found in sabkha (Khan *et al.*, 2001; Öztürk *et al.*, 2011), when final germination percentages show that salt stress induced an inhibitory effect on their germination capacity (Gulzar & Khan, 2001). Other perennial halophytes, on the other hand, can germinate in salinities of 1000 mM NaCl or even more (Khan *et al.*, 2001; 2002; Huang *et al.*, 2003).

According to Öztürk *et al.*, (2009), salt stress adversely affects seed germination, through an osmotic mechanism, by reducing water uptake or through an ionic way, by causing an imbalance in nutrient assimilation and *via* a toxic effect through the accumulation of Na⁺ and Cl⁻. In addition, Othman *et al.*, (2006) stated that low moisture content under salt stress insuced a cessation of metabolism or inhibition of some steps in metabolic sequences of germination and reduces utilisation of seed reserves (Ahmad & Bano, 1992; Toderich *et al.*, 2023), representing an ecological strategy to adapt to hostile environmental conditions (Prado *et al.*, 2000; Mehrun *et al.*, 2007). In arid climates, this strategy was used after the rainy season to take advantage of the scarce soil moisture for germination and to eradicate competition (concurrence) with other co-existing species when excess of salts have been leached by rainfall (Liu *et al.*, 2013).

A. articulata thrives effectively in both saline and non-saline salt environments. Surprisingly, this species has only been found in non-saline habitats in Algeria's semi-arid and hyper-arid regions. El-keblawy *et al.*, (2016) observed a similar finding for *Anabasis setifera* from Egypt and *Suaeda aegyptiaca* from the UAE, seeds from non-saline habitat had higher germination in all salinities than seeds from saline habitat.

Effect of NaCl stress on recovery germination: Seeds in halophyte species can survive under high salinity for lengthy periods of time before germinating when the medium's osmotic potential is increased (Ungar, 1995). After 7 days of treatment with different salt concentrations, ungerminated *A. articulata* seeds regerminated considerably for the highest salt concentrations when transferred to distilled water. The percentages of recovery ranged from 20% to 95%. It is also worth noting that the total germination percentage dropped with increasing salt pretreatments.

According to Ungar (1995), seeds of halophyte species have the capacity to maintain their viability for extended durations even in the presence of high salt levels. These seeds then undergo germination at a later stage, when the osmotic potential of the surrounding medium is increased. After a period of 7 days of exposure to salinity regimes, the ungerminated seeds of *A. articulata* exhibited considerable regermination when afterwards transferred to distilled water, particularly in response to various salt concentrations. The observed recovery percentages exhibited a wide range, spanning from 20% to 95%. Additionally, it is crucial to note that the overall germination percentage exhibited a progressive decline as the salt pretreatments increased.

Nevertheless, halophytic species exhibit a variety of responses in terms of achieving full germination recovery upon the alleviation of salinity stress. The study conducted by Khan *et al.*, (2001) found that the ability of *Halogeton glomeratus* to recover germination was significantly reduced under higher salinity conditions. Similarly, Khan & Gulzar (2003) observed a similar trend in *Sporobolus ioclades*, with low recovery rates of germination at elevated salinities. Nevertheless, it was observed that seeds were not permanently damaged by elevated salinity levels, and the process of germination was completely restored when the seeds were relocated to distilled water in various other halophytes, such as *Suaeda fruticosa* and *Salicornia ramosissima* (Pujol *et al.*, 2000), as well as *Salicornia rubra* (Khan *et al.*, 2000).

According to Öztürk *et al.*, (2009), the seed germination inhibition induced by salt can be related to osmotic stress or specific ion toxicity. It has been found that halophytes seeds are able to germinate even after extended exposure to hypersaline conditions, as demonstrated by Keiffer & Ungar (1997). When exposed to salt stress for short durations, seeds of halophytic grasses recover rapidly (Gulzar & Khan, 2001).

This indicates that the species under study has no physiological need for salt to germinate. Even at 50 mM, the presence of salt in the medium severely inhibited the germination of this species. Several other studies (Katembe *et al.*, 1998; Khan *et al.*, 2001) confirm that halophytes, and glycophytes, as well, are notably sensitive to salinity during germination stage (Katembe *et al.*, 1998; Khan *et al.*, 2001). Although the percentage of germination decreases with increasing salinity levels and reaches a minimum at 200 mM (Tlig *et al.*, 2008), salt stress reduces both the rate and proportion of germination, but recovery is still possible as long as salinity level is kept minimal. In contrast, salt stress enhanced the uptake of toxic ions, which may have negatively affected the enzymatic or hormonal activity of developing seeds (Smith & Comb, 1991). In addition, salinity disrupts the balance of plant's hormones (Khan & Rizvi, 1994) and decreases seed utilisation (Ahmad & Bano, 1992).

According to Hadjadj *et al.*, (2022), the germination behaviour described above in response to salinity stress could be seen as a typical adapting mechanism for adjusting to the high osmotic pressure and/or ionic toxicity that are related to halophytes' life in a xeric (desert) environment.

According to our germination findings, *A. articulata* may germinate in environments containing up to 300 mM NaCl. This halophytic habit might be seen as an adaptation to the hypersaline environment that enables the species to live in salty soils.

Effect of NaCl stress on seedling length: Since the roots are in close contact with the soil and uptake water from here, the lengths of roots and shoots are the most significant indicators of salt stress. Roots absorb water from the soil, and then shoots transport it to into all organs of plant. Therefore, root and shoot lengths are significant indicators of a plant's reaction to salinity stress (Jamil & Rha, 2004).

The seedlings that germinated under non-saline treatments displayed the highest aSL, whereas the lowest aSL values were found at the highest (250 and 300 mM) salinity levels. While the largest aRL were found in seedlings that received a saline treatment (50, 100, 150, and 200 mM NaCl), the lowest aRL were found at the highest salinity levels (250 and 300 mM). More sensitive than radicle length was shoot length.

According to Xiong & Zhu (2002), salt stress reduced the effectiveness of translocation and assimilation of stored resources and may have had an impact on shoot growth. It is possible that the harmful effects of the NaCl utilised and the seedlings' uneven nutrient intake are responsible for the reduced root and shoot development. According to Hajibagheri *et al.*, (1989), it might be as a result of a root system's capacity to regulate ion access to the shoot, which is necessary for plant survival in the presence of NaCl.

Conclusion

The results show that the germination of *A. articulata* seeds decreases with increasing saline concentrations of salt treatments, and *A. articulata* seeds show a particular mechanism of responding to salt stress, being thus more resistant to sodium chloride concentrations. Seeds restored after being transferred in distilled water due to their tolerance and recovering capacity. This suggests that seeds have an increased capacity to recovery and that these treatments were not excessively harmful to affect the viability of seeds. Finally, the study on seeds germination is critical for creating a scientific and theoretical foundation for large-scale restoration, enhancement, and protection of *A. articulata* rangelands. This could also provide a frame for sustainable development in arid environments, as well as vegetation regeneration and reconstruction of damaged rangelands in Saharan Algeria. More research is needed to investigate the ecophysiological and biochemical alterations of this species with medicinal potential, under saline environments.

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