

EFFECT OF GROWTH REGULATORS AND OSMOTICA IN ALLEVIATING SALINITY EFFECTS ON THE GERMINATION OF *SALICORNIA UTAHENSIS*

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Abstract

Salicornia utahensis Tiderstrom is a perennial halophyte from the family Chenopodiaceae and is widely distributed in brackish water playas of northern Utah. *Salicornia utahensis* produces seeds under high salinity and deposits its seed on saline soil. Seeds showed only 65 % germination in distilled water. Seed germination decreased with the increase in salinity and less than 5 % seeds germinated at 900 mM NaCl. We determined the role of germination regulating chemicals in alleviating salinity stress. This germination was substantially enhanced with the inclusion of ethephon, fusicoccin (FC), and kinetin, under saline conditions while gibberellic acid, thiourea, proline and betaine had little effect. Rate of germination showed a similar pattern with that of percentage germination.

Introduction

Salicornia utahensis Tiderstrom is a member of the goosefoot family, the Chenopodiaceae and mostly occurs in inland salt playas of central Utah (Hansen & Weber, 1975). *Salicornia utahensis* is the principal succession species in the high salt playas and can tolerate 5 % salt in the soils (Ungar, 1974). The plant produces seeds by fall and most of them disperse around the plant while few seeds could float away.

Great Basin desert halophytes are reported to be very highly tolerant to NaCl (Khan, 2002) including *Salicornia europaea* (800 mM NaCl; Ungar, 1977), *Kochia americana* (1700 mM NaCl; Clarke & West, 1969), *Allenrolfea occidentalis* (800 mM NaCl; Gul & Weber, 1999), *Salicornia rubra* (1000 mM NaCl; Khan *et al.*, 2000), *Suaeda moquinii* (1000 mM NaCl; Khan *et al.*, 2001a), *Kochia scoparia* (1000 mM NaCl; Khan *et al.*, 2001b) and *Sarcobatus vermiculatus* (1000 mM NaCl; Khan *et al.*, 2002).

Most salt marsh and salt desert halophytes have physiological dormancy and is reported to be the main cause of the delay in seed germination in the halophytes (Baskin & Baskin, 1998). Germination regulating compounds like gibberellic acid and kinetin (Ungar, 1977, 1982, 1984; Okusanya & Ungar, 1984; Khan & Weber, 1986; Ismail, 1990; Yaniv *et al.*, 1995; Pylar & Proseus, 1996; Khan *et al.*, 1998; Khan & Ungar, 2001a) fusicoccin (Ismail, 1990; Gul & Weber, 1998; Gul *et al.*, 2000; Khan *et al.*, 2000, 2001a,b,c), and ethylene (Kepczynski & Karssen, 1985; Kepczynski, 1986; Gul *et al.*, 2000; Khan *et al.*, 2000, 2001a,b,c) are known to alleviate the effect of salinity on the germination of halophytes.

Many plants in saline or dry habitats are known to accumulate organic solutes such as glycine-betaine and proline, polyols, and others (Poljakoff-Mayber *et al.*, 1994). It is assumed that under stress conditions these substances serve as compatible cytoplasmic solutes that compensate osmotically for external osmolarity or for ions sequestered in the vacuole.

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Poljakoff-Mayber *et al.* (1994) reported that dry seeds of *Kosteletkyia virginica* contain a significant amount of betaine and proline. Betaine content decreased during germination in the presence of NaCl, while proline content increased, suggesting a possible role of proline during germination. Proline and betaine (0.1 mM) alleviated the innate dormancy in *Zygophyllum simplex* (Khan & Ungar, 1997) and in *Arthrocnemum indicum* (Khan *et al.*, 1998), and osmotica had little effect on germination of other species like *Salicornia rubra* (Khan *et al.*, 2002), *Sarcobatus vermiculatus* (Khan *et al.*, 2002) under saline conditions.

The present study is designed to study the effect of salinity and germination regulating chemicals on the seed germination of *Salicornia utahensis*.

Materials and Methods

Seeds of *Salicornia utahensis* were collected during August from a salt marsh situated 30 miles south of the Great Salt Lake, at Faust, Utah. Seeds were separated from the inflorescence and were stored at 4 °C. Germination studies were started in January. Seeds were surface sterilized using the fungicide Phygon. Germination was carried out in 50 x 9-mm (Gelman No. 7232) tight-fitting plastic Petri dishes with 5 mL of test solution. Each dish was placed in a 10-cm-diameter plastic Petri dish as an added precaution against loss of water by evaporation. Four replicates of 25 seeds each were used for each treatment. Seeds were considered to be germinated with the emergence of the radicle.

Seeds were germinated in a growth chamber at an alternating temperature regime of 25-35 °C, where the higher temperature coincided with the 12-h light period (Sylvania cool white fluorescent lamps, 25 $\mu\text{M}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, 400 - 750 nM) and the lower temperature coincided with the 12-h dark period. Ethephon concentration of 10 mM, fusicoccin concentration of 5 μM , gibberellic acid concentration of 3 mM, kinetin concentration of 0.05 mM Nitrate concentrations of 20 mM, thiourea concentration of 10 mM, proline and betaine concentrations of 0.1 and 1 mM and NaCl concentration of 0, 300, 600, and 900 mM NaCl solutions were used. Percent germination was recorded every alternate day for 20 days. The rate of germination was estimated by using a modified Timson index of germination velocity = $\Sigma G/t$, where G is percentage of seed germination at 2-days intervals, and t is total germination period (Khan & Ungar, 1985). The maximum value possible using this index with our data was 50 (*i.e.* 1000/20). The higher the value, the more rapid the seed germination.

Germination data were transformed (arcsine) before statistical analysis. An ANOVA analysis was used to determine if significant differences were present among means. A Bonferroni test was carried out to determine if significant ($P < 0.05$) differences occurred between individual treatments (SPSS 1996).

Results

The two-way ANOVA of the percentage germination showed a significant effect of salinity ($P < 0.0001$), germination regulating chemicals ($P < 0.0001$) and their interaction ($P < 0.0001$, Table 1). Seeds of *Salicornia utahensis* germinated (68 %) in non-saline control and the germination inhibited with the increase in salinity (Fig. 1). About 5 % seeds germinated at 900 mM NaCl treatment. Seed germination of *S. utahensis* reached its peak in few days and no further increase in germination was recorded in any salinity treatment (Fig. 2). Application of GA₃ had no effect on germination both under non-saline and saline conditions (Fig. 3). Kinetin, fusicoccin and ethephon significantly alleviated seed germination at all salinity treatments. Fusicoccin and kinetin also increased germination from 60-90 % in non-saline control (Fig. 3).

Table 1. F-ratios and significance (*) = P < 0.0001) for the results of a two-way analysis of variance of germination responses by regulator and salinity treatments.**

Dependent variable	Salinity	Regulator	Salinity x Regulator
Germination	377***	46***	8***
Rate of germination	283***	35***	6***

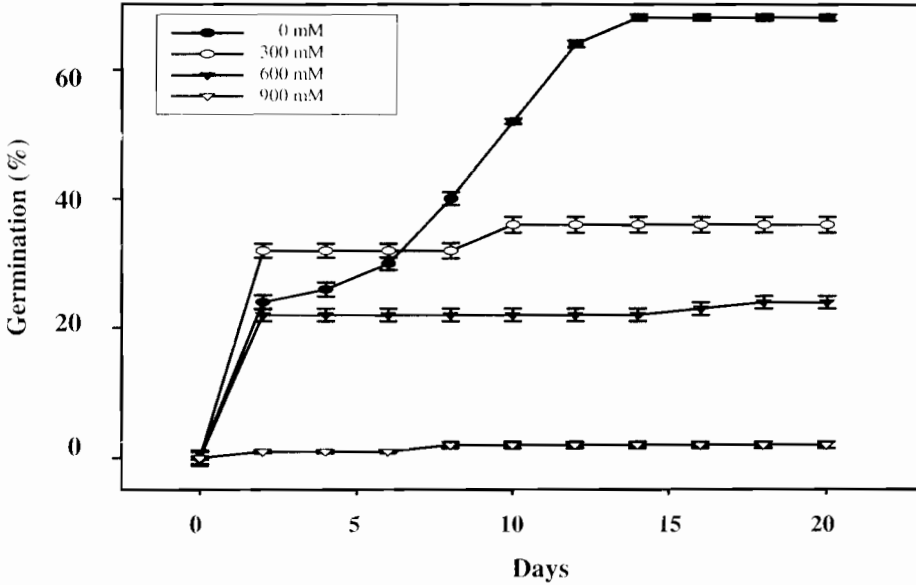


Fig. 1. Percent germination of *Salicornia utahensis* seeds at various NaCl concentrations.

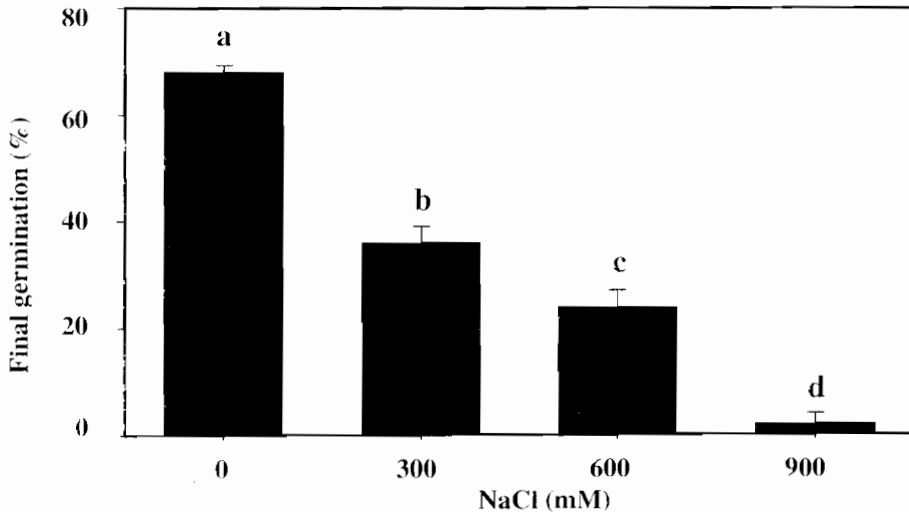


Fig. 2 Final germination percentages of *Salicornia utahensis* seeds at various concentrations of NaCl. Values having the same letter are not significantly different (p<0.05) from control (Bonferroni test).

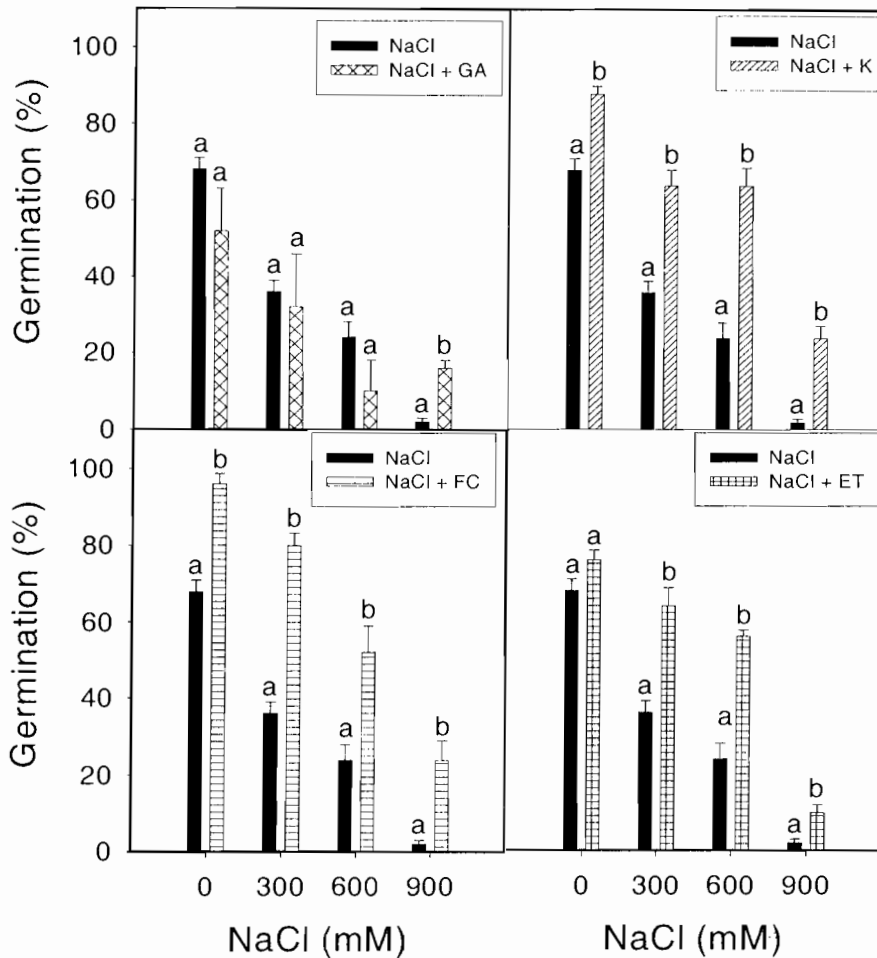


Fig. 3. Percent germination of *Salicornia utahensis* seeds in NaCl, gibberellic acid, kinetin, ethephon and fusicoccin. (Values at each salinity levels having the same letter are not significantly different ($p < 0.05$) from the control).

Osmotica like proline, betaine and nitrate have some alleviating effects at highest salinity treatment (Fig. 4). Thiourea, however, significantly alleviated seed germination in all salinity treatment (Fig. 4). A two-way ANOVA of the rate of germination showed a significant effect of salinity ($P < 0.0001$), germination regulating chemicals ($P < 0.0001$) and their interaction ($P < 0.0001$, Table 1). Rate of germination was significantly increased by the treatment of kinetin, fusicoccin and ethephon, while proline, betaine, nitrate and GA₃ effects were not significantly different from control (Table 1).

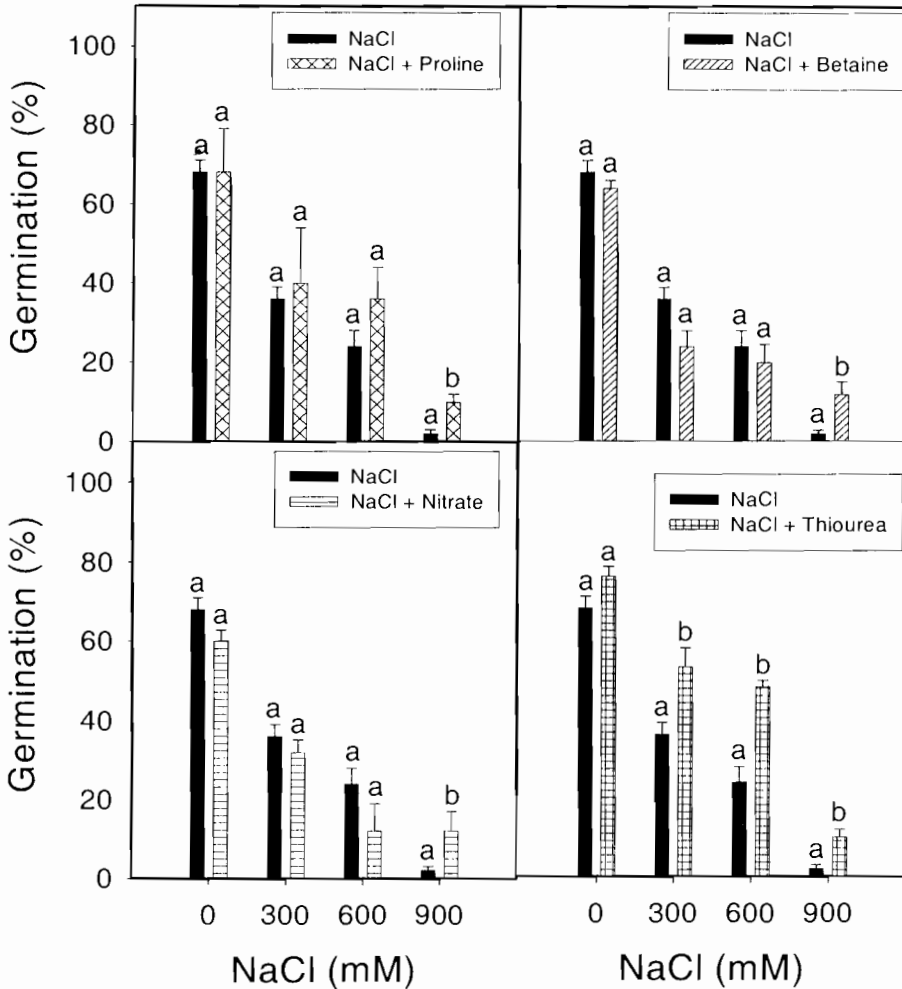


Fig. 4. Percent germination of *Salicornia utahensis* seeds in NaCl, Proline, Betaine, Nitrate and Thiourea. (Values at each salinity levels having the same letter are not significantly different ($p < 0.05$) from the control).

Discussion

Seeds of *Salicornia utahensis* showed about 70 % germination under non-saline control, while seed germination was inhibited with an increase in salinity and only 5 % seeds germinated at 900 mM NaCl. Fusicoccin, thiourea, kinetin, and ethephon alleviated the inhibitory effects of salinity on the germination, whereas GA_3 , proline, betaine and nitrate had little effect on germination at all salinities.

Table 2. Rate of seed germination of *Salicornia utahensis* under various salinity and germination regulating chemicals.

NaCl (mM)	Germination regulating chemicals									
	Water	Proline	Betaine	GA ₃	Kinetin	Thiourea	Nitrate	Fusicoccin	Ethephon	
0	38±1.0 ^a	33±0.8 ^a	31±0.9 ^a	24±5.6 ^a	36±3.3 ^a	32±2.4 ^a	22±2.0 ^a	36±2.0 ^a	33±1.8 ^a	
300	16±2.2 ^b	19±1.3 ^b	9±1.2 ^b	16±1.2 ^b	25±2.6 ^b	22±2.0 ^b	11±0.8 ^b	36±1.4 ^b	29±2.1 ^b	
600	11±1.9 ^c	16±0.4 ^c	9±0.5 ^c	5.2±1.0 ^b	28±3.1 ^b	20±1.7 ^c	2.8±0.5 ^c	24±3.4 ^c	23±0.6 ^c	
900	0.8±0.8 ^d	4.1±0.5 ^d	5±0.9 ^c	7±1.2 ^a	9.6±2.2 ^c	3.8±0.5 ^c	2.6±0.9 ^d	12±2.8 ^a	3±0.7 ^c	

Values in rows at each dormancy regulating chemicals having the same letter are not significantly different ($P > 0.05$) from control. Bonferroni test.

Innate and seed dormancies enforced by salinity were substantially alleviated by FC in *S. utahensis*. Alleviation of salinity effect on seed germination by fusicoccin was also reported in seeds of other halophytes like *Zygophyllum qatarensis* (Ismail, 1991), *Allenrolfea occidentalis* (Gul & Weber, 1998), *Atriplex stocksii* (Khan & Ungar, 2000), *Sporobolus arabicus* (Khan & Ungar, 2001a), *Halopyrum mucronatum* (Khan & Ungar, 2001b), *Salicornia rubra* (Khan *et al.*, 2002). This alleviation may be due to stimulation of ATPase production, which rapidly increases during the early phases of germination to facilitate proton extrusion and K⁺ uptake (Marre, 1979; Stout, 1988). The FC has the ability to remove the inhibitory effect of ABA on germination of normal seeds and on embryo growth of decoated seeds (Lado *et al.*, 1975). It is more likely that ABA production due to salinity stress could be counteracted by FC and alleviate the inhibitory effect of salinity.

Effect of salinity on the germination of *S. utahensis* seeds were alleviated with the presence of ethephon in the medium. Application of ethephon relieves dormancy in seeds of several species (Abeles & Lonski, 1969; Ketring, 1977; Adkins & Ross, 1981; Corbineau *et al.*, 1989; Whitehead & Nelson, 1992; Bewley and Black 1994) and reverse the inhibitory effect of abscisic acid and osmotic stress (Karsen, 1976; Schonbeck & Egle, 1981). Ethylene may act by stimulating the germination of non dormant seeds or by breaking dormancy in seeds that exhibit an embryo dormancy (Ketring & Morgan, 1969; Egle & Dale, 1970; Whitehead & Nelson, 1992; Sutcliffe & Whitehead, 1995). However, seeds of many plants do not respond to ethylene (Ismail, 1982) or some of the promotive effects are not substantial. Alleviation of salinity effects on the germination of halophytes by ethephon is quite variable. Ethephon completely alleviated the effect of salinity in *Allenrolfea occidentalis*, *Suaeda fruticosa*, *Kochia scoparia*, *Limonium stocksii*, and *Aeluropus lagopoides* (Gul & Weber, 1998; Gulzar & Khan, 2002; Khan, unpublished data), partially alleviated salinity effects on germination in *Arthrocnemum indicum*, *Salicornia rubra*, *Suaeda moquinii*, *Halogeton glomeratus*, *Salsola iberica*, *Sporobolus ioclados*, *Zygophyllum simplex*, and *Atriplex rosea* (Khan & Ungar, 2001c; Khan *et al.*, 2002; Khan, unpublished data) while in some species ethephon do not have any effect like *Triglochin maritima*, *Urochondra setulosa*, *Sarcobatus vermiculatus*, *Cressa cretica*, *Atriplex stocksii*, and *Atriplex prostrata* (Khan & Ungar, 1998, 2001a,b; Khan & Gulzar, 2002).

The GA₃ failed to alleviate the salinity effect on the germination of *S. utahensis* seeds both under saline and non-saline conditions. Gibberellic acid reported to have differential response to the germination of halophytes. Seed germination under saline conditions are almost completely alleviated in *Atriplexgriffithii* var. *stocksii* and *Zygophyllum simplex* (Khan & Ungar, 1997, 2000) while some positive effects were reported for *Atriplex triangularis*, *Allenrolfea occidentalis*, *Chrysothamnus nauseosus*, *Cressa cretica*, *Arthrocnemum macrostachyum*, *Polygonum aviculare* and *Salicornia rubra* (Khan *et al.*, 1987; Gul & Weber, 1998; Khan & Ungar, 1998, Khan *et al.*, 2002; Khan, unpublished data) while species like *Triglochin maritima*, *Sporobolus ioclados*, *Urochondra setulosa*, *Suaeda fruticosa*, *Salsola imbricata* and *Haloxyton stocksii* failed to respond to any gibberellic acid treatment to alleviate salinity effects on germination (Khan & Ungar, 2000; Gulzar & Khan, 2002; Khan, unpublished data).

Kinetin promoted germination in non-saline control and substantially alleviated seed germination of *S. utahensis* in salinities tested. Kinetin also had similar response in *Atriplex triangularis*, *Atriplex stocksii*, *Zygophyllum simplex* (Khan 2003), while kinetin has some effect in alleviating salinity on the seed germination of *Zygophyllum simplex*, *Arthrocnemum macrostachyum*, *Allenrolfea occidentalis*, *Triglochin maritima* and *Salicornia rubra* (Khan & Ungar, 1998, 2001a,b,c; Khan *et al.*, 1998, 2002) and has no

effect on the germination of *Cressa cretica*, *Sporobolus ioclados*, *Urochondra setulosa*, *Suaeda fruticosa*, *Salsola imbricata* and *Haloxylon stocksii* (Gulzar & Khan, 2002, Khan 2003).

Thiourea stimulated the germination of *S. utahensis* seeds under saline conditions but nitrate had no effect. The alleviating effect of thiourea on osmoinhibition gradually decreases with an increase in salinity. Some nitrogenous compounds such as nitrate, nitrite and thiourea are known to stimulate the germination of seeds (Esashi *et al.*, 1979; Aldasaro *et al.*, 1981; Yoshiyama *et al.*, 1996). Thiourea counteracts the effect of ABA and reduced the level of cytokinins in plant tissues (Kabar & Baltepe, 1989). These adverse hormonal changes occur when plant tissues are subjected to water stress induced by drought, salinity or high temperatures (Kabar & Baltepe, 1989). Treatment with thiourea is highly effective in alleviating the inhibition of germination by salinity or high temperatures (Esashi *et al.*, 1979; Gul & Weber, 1998). Thiourea is also known to break dormancy and overcome the negative effect of temperature on seed germination (Esashi *et al.*, 1979; Aldasaro *et al.*, 1981).

Proline and betaine had no effect on seed germination of *Salicornia utahensis* under both saline and non-saline conditions. Poljakoff-Mayber *et al.* (1994) studied the proline and betaine levels in *Kosteletzkya virginica* seeds during the process of germination. They found low concentration of proline and betaine levels in *Kosteletzkya virginica* seeds during the processes of germination. However, when seeds were germinated in a saline medium the proline content increased while their betaine concentration decreased. They suggested that proline could be the compatible osmotica for germinating seeds. They did not find any external application effect of proline and betaine in both control and saline medium on seed germination. Khan & Ungar (1997) reported that both proline and betaine alleviated the innate dormancy of the *Zygophyllum simplex* seeds but failed to improved salinity enforced dormancy.

Salicornia utahensis produces a large number of seeds at the end of autumn and beginning of winter. Seeds germinate readily if proper conditions are provided. Seeds in natural environment prevented from germination due to very cold temperature. Seeds start germinating very early during spring and germination decreased with the increase in salinity. This decrease in germination appears to be mediated through reduction in germination regulating chemicals like kinetin and germination inhibitors.

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