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ORIGINAL RESEARCH

Impact of dormancy regulating chemicals on salinity induced dormancy in *Lasiurus scindicus* and *Panicum turgidum*: two desert glycophytic grasses

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Abstract The indigenous forage grasses *Lasiurus scindicus* and *Panicum turgidum* are candidate species for the restoration of degraded desert rangelands. The impact of five dormancy regulating chemicals on overcoming salinity-induced germination inhibition was assessed under the best germination conditions in the two species. Seeds were germinated in a series of NaCl concentrations: 0–200 mM NaCl for *P. turgidum*, and 0–300 mM NaCl for *L. scindicus*. *Lasiurus scindicus* seeds were more tolerant to salinity than those of *P. turgidum*. Twenty percent of *P. turgidum* seeds germinated in 100 mM NaCl and none in the higher levels, but 47.5% and 8.8% of *L. scindicus* seeds germinated in 100 and 200 mM NaCl, respectively. The five studied chemicals (fusicoccin, GA_3, kinetin, nitrate and thiourea) did not succeed in improving germination of non-saline treated seeds of the two species, compared to the control, except thiourea in *P. turgidum*. The salinity-induced germination inhibition in *P. turgidum* was completely alleviated by the application of gibberellic acid (GA_3), partially alleviated by the application of fusicoccin, kinetin and thiourea, but not affected by nitrate. In *L. scindicus*, the germination inhibition was completely alleviated by fusicoccin, GA_3, nitrate and thiourea, but partially alleviated by kinetin. For using the two grass species in restoration of degraded rangelands affected by higher salinity, the results suggest using fusicoccin, GA_3, nitrate and thiourea with *L. scindicus* and GA_3 with *P. turgidum* seeds as a preseeding treatment can overcome the problem of reduced germination.

Keywords Desert grasses · Glycophytes · Salinity induced dormancy

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Introduction

Grasses are usually sensitive to salinity at the germination stage (Khan and Ungar 2001a) with germination typically inhibited by concentrations of NaCl in the range 250 to 350 mmol/L (mM) NaCl (Badger and Ungar 1989; Breen et al. 1997; Hester et al. 1998; Lombardi et al. 1998; Perez et al. 1998; Khan and Gulzar 2003). For example, it has been reported that grasses like *Panicum coloratum* (Perez et al. 1998) and *P. hemitimon* (Hester et al. 1998) germinated well in NaCl concentrations up to 200 mM, but halophytic (salt tolerant) grasses like *Sporobolus virginicus* (Breen et al. 1997 and *Hordeum vulgare* (Badger and Ungar 1989) germinated in salt concentrations up to 350 mM. Grasses of the Arabian Sea coast of Pakistan vary in their salinity tolerance during germination, but generally most of them are relatively less tolerant than other studied halophytic grasses. For example, *Halopyrum mucronatum* and *Sporobolus arabicus* were found to germinate in up to 200 mM NaCl (Khan and Ungar 2001b; Noor and Khan 1995). In addition, Khan and Gulzar (2003) studied salinity tolerance during germination in four halophytic grasses and found that few seeds of *H. mucronatum* germinated above 300 mM NaCl, while seeds of *Aeluropus lagopoides*, *Sporobolus ioclados*, and *Urochondra setulosa* germinated in up to 500 mM NaCl. Five desert grasses of the Arabian Gulf region, however, have lower salinity tolerance during

germination than all grasses mentioned above (El-Keblawy 2006). Seeds of *Dichanthium annulatum*, *Cenchrus ciliaris* and *Pennisetum divisum* germinated to 50, 12 and 20% in 100 mM NaCl, but seeds of *Lasiurus scindicus* and *S. arabicus* germinated to 10 and 5%, respectively, in 200 mM NaCl (El-Keblawy 2006).

Seed dormancy can help seed to define the suitable environmental conditions for its germination. The dormancy status is influenced by both the seed maturation environment and the ambient environmental conditions following their shedding in the soil (Baskin and Baskin 2004). High salt concentrations are known to induce dormancy in seeds of many species (Ungar 1978). Such dormancy could be explained by internal factors in the seeds such as the permeability of the integuments to water or oxygen, presence of inhibitors, or physiological maturation of the embryo (Khan 1977). For example, germination inhibition after exposing seeds to high salinity has been attributed to be caused by changes in the balance of various growth regulators due to high concentrations of several ions in seeds. Salinity stress usually results in imbalance in growth regulators causing an increased level of endogenous abscisic acid (ABA) and other germination inhibitors and a decrease in endogenous growth promoters such as gibberellins (GA) (Bewley and Black 1994). It has been documented that ABA is a positive regulator of dormancy induction and most likely also maintenance, while GA releases dormancy, promotes germination and counteracts the effects of ABA (Kucera et al. (2005). A decline in cytokinin and gibberellic acid (GA_3) concentrations, which can induce changes in membrane permeability and seed water relations, has been reported to be associated with salinity stress (Kabar and Baltepe 1989). Debez et al. (2001) indicated that the depressive effect of salinity on *Atriplex halimus* germination was the result of a decline in several endogenous hormones present in the seed coat and, hence, exogenous application of GA_3 and kinetin enhanced germination of seeds treated with up to 4% NaCl.

Dormancy regulating chemicals (DRCs) such as GA_3, fusicoccin, nitrate, thiourea and kinetin are known to alleviate the effect of salinity on the germination of many halophytes (Bewley and Black 1994; Khan and Gul 2006). However, the effect of these chemicals varies depending on the species and geographical region (Khan and Gul 2006). For example, the effect of salinity on the seed germination of subtropical halophytes was not alleviated by many DRCs, but was substantially alleviated by the application of various chemicals in aridland halophytes of Great Basin in North America (Khan and Gul 2006). For subtropical halophytes, little or no effect was observed for the DRCs in alleviating salinity induced germination inhibition in *Halopyrum mucronatum, Haloxylon stocksii, Salsola imbricata, Sporobolous ioclados, Suaeda fruticosa* and *Urochondra setulosa*, but many of these chemicals had some effects in *Atriplex stocksii* and *Zygophyllum simplex* (see references in Khan and Gul 2006). Generally, thiourea, ethephon and fusicoccin were most effective in alleviating the salinity effects on germination, followed by GA_3, kinetin and nitrate (Khan and Gul 2006). In Great Basin halophytes, however, several DRCs had significant effect in alleviating salinity induced dormancy in many of the studied species (e.g., *Allenrolfea occidentalis*, *Halogeton glomeratus*, *Kochia scoparia*, *Salicornia rubra*, *Salicornia utahensis, Sarcobatus vermiculatus*, *Suaeda moquinii* and *Triglochin maritime*), but not in others (e.g., *Atriplex rosea* and *Salsola iberica*) (see references in Khan and Gul 2006). Gibberellic acid, kinetin, fusicoccin, ethephon, and thiourea had the greatest effect on alleviating salinity induced germination inhibition (Khan and Gul 2006). Although many studies have examined salinity tolerance and the impact of DRCs on halophytes of aridlands, few studies have done so with glycophytic desert grasses.

Peacock et al. (2003) have assessed Arabian Peninsula desert species that have potential to be used either for fodder production or for rehabilitation and restoration, and selected both *Lasiurus scindicus* and *Panicum turgidum* (Poaceae) to be among a list of high-priority species both in the UAE and in the northern part of the Sultanate of Oman. Furthermore, *L. scindicus* has already been successfully used in major reseeding programs in the harsh desert ecosystems of northern India and Pakistan (Mohammad 1989; Yadav 1997; Yadav and Rajora 1999). The adoption of these indigenous grasses as fodders and in restoration of salty degraded rangelands requires information about their salinity tolerance and the impact of different DRCs on alleviating salinity-induced germination inhibition. Fresh seeds of *L. scindicus* have little dormancy; final germination of non-saline treated seeds was 76.3%. However, seeds of *P. turgidum* stored at room temperatures for up to two years did not germinate at all (Al-Shamsi 2009). Salinity significantly reduced germination of *P. turgidum* at 100 mM NaCl and completely inhibited it at 200 mM (El-Keblawy 2004; Al-Khateeb 2006; Al-Shamsi 2009). Similarly, seeds of *L. scindicus* germinated to only about 10% in 200 mM NaCl, so germination varies depending on light and temperature of incubation (El-Keblawy 2006; Al-Shamsi 2009). In this study we investigate the role of DRCs in germination and dormancy breaking in seeds of two glycophytic grasses: *L. scindicus* and *P. turgidum*.

Materials and methods

Seeds of *L. scindicus* were collected during May 2007 from natural populations around the roadsides of Al-Ain—Dubai highway, UAE (24°44′N, 55°46′E). Seeds of *P. turgidum*

were collected in July 2002 from the Zaranik nature protection area in the eastern part of Lake Bardawil (31°03′ N, 33°30′ E), on the Mediterranean coast of the Sinai Peninsula, Egypt. Spikes were air dried and threshed to separate caryopses (hereafter termed seeds) by using a hand-made rubber thresher. Seeds were randomly collected from about 50 plants of each species that represent the genetic diversity of the populations. Seeds of the two species were dry stored in brown paper bags at room temperature until their use in the germination experiment in November 2007.

Seeds were germinated in series of NaCl solutions at varying concentrations (0, 100, 200 and 300 mM NaCl for *P. turgidum* and 0, 50, 100, 150, and 200 mM NaCl for *L. scindicus*). The upper limits of salinity were selected for the two species based on the ability of the seeds to germinate or recover their germination when transferred from these salinities to distilled water (Al-Shamsi 2009). Fusicoccin (5 μM), gibberellic acid (3 mM), kinetin (0.5 mM), nitrate (20 mM) and thiourea (10 mM) were dissolved in each of the different saline solutions to assess their impact on germination.

Seeds were germinated in incubators adjusted to 25°C for *L. scindicus* and 30°C for *P. turgidum* under continuous illumination with daylight fluorescent tubes, 110 μmol photons/m^2/s, 400–700 nm). The highest germination in light was recorded at these temperatures in the two species (Al-Shamsi 2009). The germination was conducted in 9-cm tight-fitting Petri-dishes containing one disk of Whatman No. 1 filter paper, with 7.5 ml of test solution. Each dish was placed in a 10-cm plastic dish as an added precaution against water loss by evaporation. Four replicate dishes, each with 20 seeds, were used for each treatment. Seeds were considered to be germinated with the emergence of the radicles. Germinated seedlings were counted and removed every alternate day for 20 days following seed soaking.

The rate of germination was estimated using a modified Timson index of germination velocity = ΣG/t, where G is the percentage of seed germination at 2 days intervals and t is the total germination period (Khan and Ungar 1984). The maximum value possible using this index with these experiments was 1000/20 = 50. The higher the value, the more rapid is the germination.

Two-way Analyses of variance (ANOVA) were carried out to test the effects of DRC and salinity and their interaction on both final germination percentage and germination rate index of each species. Tukey test (Honestly significant differences, HSD) was used to estimate least significant range between means. The germination percentages were arcsine transformed to meet the assumptions of ANOVA. The transformation improved normality of distribution of data. All statistical methods were performed using SYSTAT, version 11.0.

Results

Effects on *Panicum turgidum*

For non-saline treated seeds of *P. turgidum* stored for more than 5 years, only thiourea significantly increased final germination, but kinetin significantly decreased it, compared to the non-DRC treated seeds (control). Final germination of seeds treated with fusicoccin, GA_3 and nitrate did not differ significantly from that of the control (Table 1). However, all DRCs significantly enhanced germination rate index of non-saline treated seeds of *P. turgidum* (Table 2).

Both NaCl concentration and DRCs and their interaction had significant effects on both final germination percentage and germination rate index of *Panicum turgidum* seeds ($P < 0.001$, Table 3). For non-treated seeds (control), final

Table 1 Effects of dormancy regulating chemicals (DRC) and NaCl concentration on final germination percentage (mean ± standard error) of *Panicum turgidum* seeds

DRC	NaCl concentration (mM)				
	0	100	200	300	Overall
Control	65.0 ± 3.4	20.0 ± 5.4	0.0 ± 0.0	0.0 ± 0.0	21.3 ± 7.0
Fusicoccin	67.0 ± 1.9	32.0 ± 2.3	3.0 ± 1.0	0.0 ± 0.0	25.5 ± 7.0
GA_3	71.0 ± 3.8	65.0*$^+$ ± 2.5	8.0* ± 1.6	0.0 ± 0.0	36.0 ± 8.4
Kinetin	47.0* ± 3.0	40.0* ± 1.6	0.0 ± 0.0	0.0 ± 0.0	21.8 ± 5.7
Nitrate	70.0 ± 2.0	17.0 ± 1.9	0.0 ± 0.0	0.0 ± 0.0	21.8 ± 7.4
Thiourea	74.0* ± 1.2	46.0* ± 2.6	3.0 ± 1.0	0.0 ± 0.0	30.8 ± 8.0
Overall	57.0 ± 4.5	31.4 ± 3.9	2.0 ± 0.6	0.0 ± 0.0	

Values with asterisk in the same salinity treatment significantly differ from the control of that treatment

$^+$ Not differ significantly from non-saline non-treated seeds

Table 2 Effects of dormancy regulating chemicals (DRC) and NaCl concentration on germination rate index (mean ± standard error) of *Panicum turgidum* seeds

DRC	NaCl concentration (mM)				
	0	100	200	300	Overall
Control	41.2 ± 0.6	34.9 ± 3.3	0.0 ± 0.0	0.0 ± 0.0	19.0 ± 5.0
Fusicoccin	48.3* ± 0.6	40.4*$^{+}$ ± 1.1	30.4*$^{+}$ ± 10.3	0.0 ± 0.0	29.8 ± 5.3
GA_3	49.4* ± 0.2	43.9*$^{+}$ ± 0.4	34.8*$^{+}$ ± 2.9	0.0 ± 0.0	32.0 ± 5.0
Kinetin	47.9* ± 0.5	44.0*$^{+}$ ± 0.7	0.0 ± 0.0	0.0 ± 0.0	23.0 ± 5.9
Nitrate	45.7* ± 1.3	39.0^{+} ± 2.1	0.0 ± 0.0	0.0 ± 0.0	21.2 ± 5.5
Thiourea	48.9* ± 0.3	38.8^{+} ± 1.0	17.9* ± 6.2	0.0 ± 0.0	26.4 ± 5.1
Overall	46.8* ± 0.6	34.4^{+} ± 2.8	11.9 ± 3.2	0.0 ± 0.0	

Values with asterisk in the same salinity treatment significantly differ from the control of that treatment

$^{+}$ Not differ or significantly greater than non-saline non-treated seeds

Table 3 Two-way ANOVA showing the effect of NaCl concentration and dormancy regulation chemicals (DRC) on final germination percentage and germination rate index of *Panicum turgidum* and *Lasiurus scindicus* seeds

Source of variation	df	Mean-square	F-ratio	P
Panicum turgidum				
A: Final germination percentage				
NaCl conc.	3	2.810	1167.1	<0.001
DRC	5	0.077	31.4	<0.001
NaCl conc. * DRC	15	0.048	20.0	<0.001
Error	72	0.002		
B: Germination rate index				
NaCl conc.	3	82.521	329.5	<0.001
DRC	5	2.960	11.82	<0.001
NaCl conc. * DRC	15	2.580	10.30	<0.001
Error	72	0.250		
Lasiurus scindicu				
A: Final germination percentage				
NaCl conc.	4	0.984	14.60	<0.001
DRC	5	0.072	10.62	<0.001
NaCl conc. * DRC	20	0.049	7.23	<0.001
Error	90	0.007		
B: Germination rate index				
NaCl conc.	4	0.325	50.56	<0.001
DRC	5	0.206	32.16	<0.001
NaCl conc. * DRC	20	0.018	2.73	<0.01
Error	90	0.006		

germination was significantly reduced in 100 mM and completely inhibited in 200 and 300 mM NaCl. The germination inhibition in 100 mM NaCl was completely alleviated by the application of GA_3, partially alleviated by fusicoccin, kinetin and thiourea, but not affected by nitrate. Germination of seeds treated with 100 mM NaCl + GA_3 attained the same value as that of non-saline, non-DRC treated seeds (65%), but was significantly lower than that of seeds treated with 100 mM NaCl + thiourea, kinetin and fusicoccin (46, 40 and 32%, respectively). However, seeds treated with 100 mM NaCl + thiourea, kinetin or fusicoccin attained significantly higher germination than those treated with only 100 mM NaCl. In 200 NaCl, little germination took place in seeds treated with GA_3 (8%), fusicoccin (3%) and nitrate (3%, Table 1).

Unlike the effect on final germination, salinity did not negatively affect germination rate index. Germination rate of non-saline, non-DRC treated seeds was either significantly lower or did not differ significantly from that of seeds treated with 100 NaCl plus any of the DRCs. For the few seeds germinated in 200 mM NaCl, germination rate of seeds treated with fusicoccin and GA_3 did not differ significantly from that of non-saline, non-DRC treated seeds, but was significantly higher than that of seeds treated with thiourea (Table 2).

Effects on *Lasiurus scindicus*

In the non-saline treated seeds of *L. scindicus*, final germination of non-DRC treated seeds did not differ significantly from that of seeds treated with any of the five DRCs ($P < 0.001$), except thiourea (Table 4). However, all DRCs significantly enhanced germination speed of *L. scindicus* seeds (Table 5).

Both NaCl concentration and DRC had significant effects on both final germination and germination rate index of *L. scindicus* seeds ($P < 0.001$, Table 3). Overall final germination and germination rate did not differ significantly between seeds treated with 0, 50 and 100 mM NaCl and all attained significantly greater values than that of seeds treated with 150 and 200 mM NaCl. Final germination was significantly greater in 150 mM NaCl than in 200 mM NaCl, but germination rate did not differ significantly between these two salinities (Tables 4 and 5).

Table 4 Effects of dormancy regulating chemicals (DRC) and NaCl concentration on final germination percentage (mean ± standard error) of *Lasiurus scindicus* seeds

DRC	NaCl concentration (mM)					
	0	50	100	150	200	Overall
Control	76.3 ± 4.3	58.8 ± 5.2	47.5 ± 3.2	25.0 ± 2.0	8.8 ± 2.4	43.3 ± 5.7
Fusicoccin	70.0 ± 2.0	66.3*$^{+}$ ± 2.4	65.0*$^{+}$ ± 4.6	48.8* ± 2.4	43.8* ± 4.3	58.7 ± 2.7
GA_3	65.0 ± 2.9	72.5*$^{+}$ ± 4.8	68.8*$^{+}$ ± 3.8	47.5* ± 1.4	17.5* ± 1.4	54.3 ± 4.8
Kinetin	68.8 ± 2.4	68.8^{+} ± 3.8	52.5 ± 1.4	41.3* ± 1.3	38.8* ± 3.8	54.0 ± 3.2
Nitrate	68.8 ± 2.4	61.3 ± 2.4	66.3*$^{+}$ ± 3.7	36.3* ± 3.1	10.0 ± 2.0	48.5 ± 5.3
Thiourea	62.5 ± 3.2	59.0 ± 2.9	65.0*$^{+}$ ± 5.0	53.8* ± 2.4	42.5* ± 4.3	55.8 ± 2.3
Overall	62.5 ± 3.1	57.8 ± 3.6	53.7 ± 3.8	36.4 ± 3.2	23.6 ± 3.3	

Values with asterisk in the same salinity treatment significantly differ from the control of that treatment

$^{+}$ Not differ or significantly greater than non-saline non-treated seeds

Table 5 Effects of dormancy regulating chemicals (DRC) and NaCl on germination rate index (mean ± standard error) of *Lasiurus scindicus* seeds

DRC	NaCl concentration (mM)					
	0	50	100	150	200	Overall
Control	44.5 ± 1.0	42.6^{+} ± 0.9	34.4 ± 1.8	34.4 ± 2.2	31.5 ± 2.5	37.5 ± 1.4
Fusicoccin	49.7* ± 0.3	49.2*$^{+}$ ± 0.3	47.5*$^{+}$ ± 1.1	44.4*$^{+}$ ± 1.7	40.9*$^{+}$ ± 0.8	46.3 ± 0.9
GA_3	47.7* ± 0.8	43.4^{+} ± 1.3	41.6*$^{+}$ ± 1.3	38.6^{+} ± 1.8	28.9 ± 1.7	40.0 ± 1.6
Kinetin	49.7* ± 0.1	49.7*$^{+}$ ± 0.1	48.3*$^{+}$ ± 0.3	48.2*$^{+}$ ± 0.8	44.4*$^{+}$ ± 1.3	48.1 ± 0.5
Nitrate	49.6* ± 0.3	47.5^{+} ± 0.5	43.5*$^{+}$ ± 0.9	38.3^{+} ± 2.5	35.4 ± 3.4	42.9 ± 1.5
Thiourea	49.4* ± 0.5	49.7*$^{+}$ ± 0.3	49.2*$^{+}$ ± 0.6	41.3^{+} ± 2.8	40.5^{+} ± 2.3	46.0 ± 1.2
Overall	48.6 ± 0.4	47.3 ± 0.6	44.4 ± 1.0	37.8 ± 2.3	36.3 ± 1.9	

Values with asterisk in the same salinity treatment significantly differ from the control of that treatment

$^{+}$ Not differ or significantly greater than non-saline non-treated seeds

The interaction between NaCl concentration and DRC on final germination percentage was highly significant ($P < 0.001$, Table 3). For control, there was a gradual decease in final germination with the increase in NaCl concentrations; all final germination values differed significantly from each other at the different salinities. However, there was no significant difference in final germination between 0, 50 and 100 mM NaCl for seeds treated with fusicoccin, GA_3, nitrate and thiourea, indicating that these DRCs completely alleviated salinity induced dormancy in *L. scindicus*. Final germination of seeds treated with 150 or 200 mM NaCl + the different DRCs (except nitrate in 200 mM) was significantly greater than that of the control at these salinities, but was significantly lower than that of non-saline non-DRC treated seeds, indicating these DRCs partially alleviated salinity induced dormancy at higher salinities. For seeds treated with kinetin, final germination did not differ significantly between 0 and 50 mM NaCl, and was significantly greater, compared with that of seeds treated with 100, 150 and 200 mM NaCl, indicating that the kinetin completely alleviated salinity induced dormancy in 50 mM, but partially in 100, 150 and 150 NaCl (Table 4).

The interaction between NaCl concentration and DRC was also significant for germination rate index of *L. scindicus* ($P < 0.01$, Table 3). In non-treated seeds, germination rate was significantly reduced in 100, 150 and 200 mM NaCl, compared with 0 and 50 mM NaCl. However, germination rate was either not affected significantly or significantly increased after treating seeds with most of the used DRCs in the different salinities (Table 5).

Discussion

None of the DRCs used succeeded in improving germination of non-saline treated seeds of both *L. scindicus* and *P. turgidum*, compared to the control, except thiourea in the former species. In addition, a negative impact on the germination was observed for kinetin on seeds of *P. turgidum* and for thiourea on seeds of *L.* scindicus. In a number of subtropical and Great Basin halophytes,

DRCs like proline, betaine, GA_3, kinetin, fusicoccin, ethephon, thiourea and nitrate had either no effect or a negative effect on germination of non-saline treated seeds of several species, such as *Aeluropus lagopoides, Halopyrum mucronatum, Limonium stocksii, Salsola imbricata, Sporobolous ioclados*, and *Urochondra setulosa* (Khan and Gul 2006). In addition, little effect has been recorded for DRCs on germination of *Arthrocnemum macrostachyum*, *Haloxylon stocksii* and *Sporobolous arabicus* (Khan and Gul 2006). In the present study, other factors, such as light during seed incubation, would be more important than DRCs in improving germination of non-saline treated seeds of both *L. scindicus* and *P. turgidum*. At the same temperatures of incubation used in the present study, germination of *L. scindicus* and *P. turgidum* in darkness was 83.8% and 85%, respectively (Al-Shamsi 2009; El-Keblawy et al. 2010), which is greater than that of seeds treated with any of the used DRCs in the present study.

Endogenous hormone level is affected by many environmental stresses, such as salinity (Kabar 1987). According to the growth regulator theory, the control of dormancy has been attributed to various growth regulators—inhibitors, such as ABA, and promoters, such as gibberellins, cytokinins and ethylene. Consequently, dormancy is maintained (or induced) by inhibitors such as ABA, and it can be released only when the inhibitors are removed or when promoters overcome it (Bewley and Black 1994). In the present study, salinity-induced germination inhibition was alleviated, partially or completely, in 100 mM NaCl, by the application of GA_3, fusicoccin, kinetin and thiourea in *P. turgidum*. In *L. scindicus*, salinity-induced germination inhibition was alleviated in 200 mM NaCl by the application of fusicoccin, kinetin and thiourea. Germination under saline conditions was stimulated by applying dormancy-relieving compounds, which would counteract the negative change in growth regulator balance in seeds when they are exposed to salt stress (Khan and Gul 2006).

Germination failure in saline soils has been attributed to both osmotic and toxic effects. Osmotic effects are usually attributed to a declining soil solute potential and toxicity effects are due to uptake and/or accumulation of some ions, such as sodium and chloride, in the seeds (Khan et al. 2001; Poljakoff-Mayber et al. 1994; Tobe et al. 2001). Based on the ability of seeds to recover their germination after transfer from saline solution to distilled water and the ability of the seeds to germinate in different concentrations of PEG 6000, El-Keblawy et al. (2010) reported that germination failure in saline solutions is caused by the osmotic effect in *P. turgidum*, but caused by toxicity effect in *L. scindicus*. The results of the present study indicate that the role of DRCs in alleviating germination inhibition induced by higher salinities was greater in *L. scindicus*, compared to *P. turgidum*. Salinity-induced germination inhibition was completely alleviated by the application of GA_3 in *P. turgidum*, but by fusicoccin, GA_3, nitrate and thiourea in *L. scindicus*. These results suggest greater role for DRCs in alleviation of salinity induced germination inhibition when toxicity effects are responsible for germination failure in saline solutions, compared to their effect when osmotic effect is responsible for the inhibition. A similar conclusion has been reported for *Cyperus conglomeratus*, another glycophytic sedge of the UAE desert. In this species, most of the DRCs used alleviated the salinity-induced germination inhibition and germination failure in saline solutions was attributed to toxicity of the salts, rather than osmotic stress (El-Keblawy et al. 2009). Further studies of the response of germination levels in saline solution to different DRCs for other desert glycophytic plants, with osmotic and toxicity causes, are needed to test this hypothesis.

Nitrogenous compounds, such as thiourea and nitrate, are known to counteract the inhibitory effect of ABA and the decline in cytokinin concentration associated with salinity stress, and consequently alleviates salinity induced inhibition of germination (Esashi et al. 1979). Several studies have shown the ability of Nitrogenous compounds to alleviate salinity induced dormancy in many species. Nitrate and thiourea were able to counteract the inhibition produced by salinity treatments in *Allenrolfea occidentalis*, although they were relatively less effective, compared to other chemicals such as fusicoccin and ethephon (Gul and Weber 1998). Thiourea was effective in alleviating salinity induced dormancy in saltgrass (Shahba et al. 2008), *Triglochin maritime* (Khan and Ungar 2001c), *Sporobolus arabicus* (Khan and Ungar 2001b), *Aeluropus lagopoides* (Gulzar and Khan 2002) and *Prosopis juliflora* (El-Keblawy et al. 2005). In our study, thiourea successfully alleviated germination inhibition in the two species, but nitrate not. In the review of Khan and Gul (2006) on the effect of different DRCs on salinity induced dormancy, nitrate alleviated the germination inhibition in *Zygophyllum simplex* and *Sporobolus arabicus* out of 12 examined species of the subtropical halophytes and in *Halogeton glomeratus* and *Suaeda moquinii* out of 10 examined species of the Great Basin halophytes (Khan and Gul 2006).

In many species of saline habitats, germination occurs when salt content of the habitat reaches its lowest level, e.g., toward the end of or after the rainy period (Ismail 1990; Khan and Ungar 1996). However, high evaporation rate in the subtropical deserts would return back the high salinity level shortly after the rainy period. This is further support of the importance of the germination stage as the most critical stage in the life cycle of the plants. In most cases, plants are able to establish themselves once they pass this stage. In our study, germination inhibition in salty

solutions was alleviated, partially or completely, by fusicoccin, kinetin and thiourea in both *L. scindicus* and by fusicoccin, kinetin and thiourea and GA_3 in *P. turgidum*. This result indicates that seeds of the two species could germinate and hence establish themselves in salt affected soils when they pre-treated with these DRCs. It has been reported that salinity tolerance is greater in mature plants, than at the germination stage of development (Mayer and Poljakoff-Mayber 1975).

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References

Al-Khateeb SA (2006) Effect of salinity and temperature on germination, growth and ion relations of *Panicum turgidum* Forssk. Bioresour Technol 97:292–298

Al-Shamsi N (2009) Germination ecology of two indigenous range grasses *Lasiurus scindicus* and *Panicum turgidum*. M Sc thesis, UAE University, Al-Ain

Badger KS, Ungar IA (1989) The effects of salinity and temperature on the germination of the inland halophyte *Hordeum jubatum*. Can J Bot 67:1420–1425

Baskin JM, Baskin CC (2004) A classification system for seed dormancy. Seed Sci Res 14:1–16

Bewley JD, Black M (1994) Seeds: physiology of development and germination. Plenum Press, New York

Breen CM, Everson C, Rogers K (1997) Ecological studies on *Sporobolus virginicus* (L.) Kunth with particular reference to salinity and inundation. Hydrobiologia 54:135–140

Debez A, Chaibi W, Bouzid S (2001) Effect of NaCl and growth regulators on germination of *Atriplex halimus* L. Cah Agri 10: 135–138

El-Keblawy A (2004) Salinity effects on seed germination of the common desert range grass, *Panicum turgidum*. Seed Sci Technol 32:873–878

El-Keblawy A (2006) Overcoming innate dormancy and determination of germination requirements of economic salt tolerant native plants of the UAE. In: The proceeding of the 7th annual conference for research funded by UAE University. United Arab Emirates, Al-Ain, pp SCI 97–107

El-Keblawy A, Al-Ansari F, Al-Rawai A (2005) Effects of dormancy regulating chemicals on innate and salinity induced dormancy in the invasive multipurpose *Prosopis juliflora* (Sw.) DC. Shrub. Plant Growth Regul 46:161–168

El-Keblawy A, Rao MV, Al-Marzouqi A, Al Neyadi SS (2009) Germination ecology of indigenous *Cyprus conglomeratus* seeds: A sand dune binder. In: The proceeding of the tenth annual conference for research funded by UAE University, United Arab Emirates, Al-Ain, pp 111–120

El-Keblawy A, Al-Ansari F, Al-Shamsi N (2010) Effects of Temperature and Light on Salinity Tolerance during Germination of the two Desert Glycophytic Grasses *Lasiurus scindicus* and *Panicum turgidum*. Under publication, Forage and Grass Science

Esashi Y, Ohara Y, Okazaki M, Hishinuma K (1979) Control of cocklebur seed germination by nitrogenous compounds: Nitrite, nitrate, hydroxylamine, thiourea, azide, and cyanide. Plant Cell Physiol 20:349–361

Gul B, Weber DJ (1998) Role of dormancy relieving compounds and salinity on the seed germination of Allenrolfea occidentalis. Ann Bot 82:555–562

Gulzar S, Khan MA (2002) Alleviation of salinity-induced dormancy in perennial grasses. Biol Plantarum 45:617–619

Hester MW, Mendelssohn IA, McKee KL (1998) Intraspecific variation in salt tolerance and morphology in *Panicum hemitomon* and *Spartina alterniflora* (Poaceae). Int J Plant Sci 159:127–139

Ismail AMA (1990) Germination ecophysiology in populations of *Zygophyllum qatarense* Hadidi from contrasting habitats: effect of temperature, salinity and growth regulators with special reference to fusicoccin. J Arid Environ 18:185–194

Kabar K (1987) Alleviation of salinity stress by plant growth regulators on seed germination (*Hordeum distichum*). J Plant Physiol 128:179–183

Kabar K, Baltepe S (1989) Effect of kinetin and gibberellic acid in overcoming high temperat ure and salinity (NaCl) stresses on the germination of barely and lettuce seeds. Phyton 30:65–74

Khan AA (1977) Seed dormancy: changing concepts and theories. In: Khan AA (ed) The physiology and biochemistry of seed dormancy and germination. Elsevier, North-Holland Biomedical Press, Amsterdam, pp 29–50

Khan A, Gul B (2006) Halophyte seed germination. In: Khan MA, Weber DJ (eds) Ecophysiology of high salinity tolerant plants. Springer, Netherlands, pp 11–30

Khan MA, Gulzar S (2003) Germination responses of Sporobolus ioclados: a potential forage grass. J Arid Environ 53:387–394

Khan MA, Ungar IA (1984) The effect of salinity and temperature on the germination of polymorphic seeds and growth of *Atriplex triangularis* Willd. Am J Bot 71:481–489

Khan MA, Ungar IA (1996) Effects of light, salinity and thermoperiod on the seed germination of halophytes. Can J Bot 75: 835–841

Khan MA, Ungar IA (2001a) Alleviation of salinity stress and the response to temperature in two seed morphs of *Halopyrum mucronatum* (Poaceae). Aust J Bot 49:777–783

Khan MA, Ungar IA (2001b) Effect of germination promoting compounds on the release of primary and salt-enforced seed dormancy in the halophyte *Sporobolus arabicus* Boiss. Seed Sci Technol 29:299–306

Khan MA, Ungar IA (2001c) Seed germination of *Triglochin maritima* as influenced by salinity and dormancy relieving compounds. Biol Plantarum 44:301–303

Khan MA, Gul B, Weber DJ (2001) Seed germination characteristics of *Halogeton glomeratus*. Can J Bot 79:1189–1194

Kucera B, Cohn MA, Leubner-Metzger G (2005) Plant hormone interactions during seed dormancy release and germination. Seed Sci Res 15:281–307

Lombardi T, Fochetti T, Onnis A (1998) Germination of *Briza maxima* L. seeds: effects of temperature, light, salinity and seed harvesting time. Seed Sci Technol 26:463–470

Mayer AM, Poljakoff-Mayber A (1975) The germination of seeds. Pergamon Press, The Macmillan Co, New York

Mohammad N (1989) Rangeland management in Pakistan. Senior Fellowship Series, Kathmandu, Nepal

Noor M, Khan MA (1995) Factors affecting germination of summer and winter seeds of *Halopyrum mucronatum* under salt stress. In: Khan MA, Ungar IA (eds) Biology of salt tolerant plants. Karachi Department of Botany, University of Karachi, Karachi, pp 51–58

Peacock JM, Ferguson ME, Alhadrami GA, McCann IR, Al Hajoj A, Saleh A, Karnik R (2003) Conservation through utilization: a case study of the indigenous forage grasses of the Arabian Peninsula. J Arid Environ 54:15–28

Perez T, Moreno C, Seffino LG, Grunber A, Bravo Z (1998) Salinity effects on the early development stages of *Panicum coloratum*: Cultivar differences. Grass Forage Sci 53:270–278

Poljakoff-Mayber A, Somers GF, Werker E, Gallagher A (1994) Seeds of *Kosteletzkyz virginica* (Malvaceae): their structure, germination and salt tolerance. Am J Bot 81:54–59

Shahba MA, Qian YL, Lair KD (2008) Improving Seed Germination of Saltgrass under Saline Conditions. Crop Sci 48:756–762

Tobe K, Zhang LP, Qiu GYY, Shimizu H, Omasa K (2001) Characteristics of seed germination in five non-halophytic Chinese desert shrub species. J Arid Environ 47:191–201

Ungar IA (1978) The effect of salinity and hormonal treatments on growth and ion uptake of *Salicornia europaea*. Societe Botanique de France, Actualities Botaniques 125:95–104

Yadav MS (1997) Pasture establishment techniques. In: Yadav MS, Singh M, Sharma SK, Tewari JC, Burman U (eds) Silvipastoral systems in arid and semi-arid ecosystems. Jodhpur, pp 193–206

Yadav MS, Rajora MP (1999) Technology for seed production. In: Faroda AS, Joshi NL, Kathju S, Kar A (eds) Management of arid ecosystem. Arid Zone Research Association of India and Scientific Publishers, Jodhpur, pp 333–338