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Original article

Investigation on germination and seedling growth of three Salicornia species in response to different levels of salinity stress originated from sodium chloride using Gompertz function

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Extended abstract

Introduction

Salicornia is one of the most important industrial plants of the Chenopodiaceae family, which is grown as oilseed, fodder, or vegetable crop around the world. All Salicornia species produce succulent shoots suitable for leafy vegetable production, but they differ in germination charactristics, seedling growth and physiological parameters. Germination and seedling emergence depend on the specific genotype requirements of each species and the environmental factors such as salinity stress. Salinity stress is one of the major abiotic stresses which negatively limit crop productivity. The aim of the present study was to test biochemical and physiological responses of Salicornia species to salinity stress.

Materials and methods

In order to investigate the seed germination and seedling growth properties of Salicornia, two separate factorial experiments were conducted based on a completely randomized design with four replications and four destructive examples for each replication during 2019. The first experiment (seed investigation) was carried on in the petri dish culture and second experiment (seedling investigation) was conducted using pots in the green house condition. Experimental treatments were six levels of salinity stresses (control, 10, 20, 30, 40 and 50 dS/m) arranged as the fist factor and in the second factor was three Salicornia species *S. persica* Golestan, *S. biglovii* and *S. europaea*.

Results and Discussion

Results of analysis of variance revealed that there was significant effect of salinity stress, genotype and interaction effects of both treatment on all measured germination and seedling growth characteristics ($p<0.01$). In all studied Salicornia species, the maximum value of traits obtain at control condition and the minimum value was observed in 50 dS/m salinity except for germination uniformity, seedling water content and total phenol content. The highest seedling water content (89.44%) was obtained from *S. persica* at 40 dS/m. The maximum flavonoid (0.156 mg/g.fw) and total phenol content (0.031 mg/g.fw) was observed in S. persica at 20 dS/m. Based on the output of Gompertz function ($R^2adj \geq 0.95$ and RMSE≤3.25), salinity increase from 0 to 50 dS/m, the time to reach 50% of total seed germination was increased from 5.73 to 16.20 days in *S. percia*, 4.42 to 17.07 days in *S.biglovii* and 5.75 to 11.95 days, respectively.

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Conclusions

Seed germination traits and seedling growth of Salicornia genotypes exhibited some level of sensitivity to salinity stress. All Salicornia species were germinated successfully at a salinity of 10 dS/m while seed germination was inhibited at 50 dS/m of salinity stress. It was revealed that the Salicornia sp. originated from Iran (*S. persica*) exhibited higher salinity tolerance than the species originated from Europe (i.e., *S. biglovii* and *S. europaea*). In conclusion, all Salicornia spp. exhibited reasonable salinity tolerance in the range of (10 to 30 dS/m) without compromising the high quality of the final yield. Therefore, it could be a promising alternative crop in saline-prone areas of Iran. Now, after understanding the behavior of different Salicoenia species above 10 dS/m salinity and increae of seed germination from 0 to 10 dS/m in, scrutiny of plants reaction between 0 to 10 dS/m in, it is possible to use this finding for a better breeding program of Salicornia species.

***Keywords*:** Flavonoid, Halophyte plants, Sigmoid function, Seedling water content, Total Phenol

Table 1. Germination time course of each species and each salinity level

Species	EC (dS/m)					
	Control	**10**	**20**	**30**	**40**	**50**
***S. persica* Gorgan ecotype**	12	12	14	20	20	20
S. biglovii	11	12	19	20	20	20
S. europaea	14	16	20	19	20	16

Table 2. Indicators of stress tolerance in the seedling growth test.

Indicators of stress tolerance	Mathematical relations	References
Stress tolerance (Tol)	Tol = Yp - Ys	(Rosielle and Hamblin, 1981)
Medium productivity (MP)	MP = (Yp + Ys) / 2	(Rosielle and Hamblin, 1981)
Geometric medium productivity (GMP)	GMP = $\sqrt{(Ys)(Yp)}$	(Fernandez, 1992)
Harmonic (Harm)	Harm = [2(Yp × Ys) / (Yp + Ys)]	(Fisher and Maurer, 1978)

Yp: potential yield (seedling dry weight) in each species under a non-stress and Ys: potential yield (seedling dry weight) in each species under a salinity stress condition.

Table 3. Analysis of variance (mean squares) for the effects of Salinity on some germination and seedling traits in Salicornia species (S. biglovii, S. europaea and S. persica Golestan ecotype).

		Germination test					
S.O.V	**df**	**RL**	**HL**	**FGP**	**GR**	**CVG**	**SVI**
Salinity (S)	5	499.22**	83.58**	13957.46**	0.00003607**	32631.22**	1787.42**
Species (Sp)	2	294.10**	45.72**	935.16**	0.00001316**	8914.81**	424.81**
S × Sp	10	59.76**	3.74**	228.43**	0.00000118**	7751.32**	88.96**
Error	54	13.40	1.06	19.54	0.00000032	395.78	7.83
CV (%)		*22.22*	*18.32*	*8.08*	*10.78*	*12.62*	*19.07*
		Seedling test					
S.O.V	**df**	**SDW**	**SFW**	**SH**	**WC**	**TP**	**Fl**
Salinity (S)	5	0.13137**	4.5046**	89.53**	6741.96**	0.00695**	0.0006385**
Species (Sp)	2	0.01850**	2.2272**	12.09**	1798.05**	0.044925**	0.0006528**
S × Sp	10	0.01454**	0.8040**	2.03**	1536.18**	0.002391**	0.0000512**
Error	54	0.00041	0.0182	0.31	8.96	0.0000098	0.0000097
CV (%)		*13.90*	*14.45*	*13.84*	*3.92*	*7.10*	*20.56*

** Significant at the 0.01 probability level

RL: Radical length; HL: Hypocotyl length; FGP: Final germination percentage; GR: Germination rate; CVG: Coefficient of Uniformity of Germination; SVI: Seed vigor index; SDW: Seedling dry weight; SFW: Seedling fresh weight; WC: Water content; SH: Seedling height; TP: Total phenols; Fl: Flavonoid

Table 4. Species × salinity levels interaction on some germination and seedling traits in Salicornia seed (sliced by the each species levels)

Germination test						
Treatments		RL (mm)	HL (mm)	GR (no of seeds per day)	CVG (%)	SVI
Species	Salinity	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
S. persica Gorgan ecotype	Control	16.3^{a}±1.39	5.9^{a}±0.56	0.0065^{a}±0.0004	115.1^{c}±9.5	20.5^{a}±2.56
	10	16.1^{a}±3.51	5.4^{a}±0.66	0.0065^{a}±0.0002	115.3^{c}±8.5	17.9^{a}±3.39
	20	12.6^{b}±1.66	5.1^{a}±0.67	0.006^{ab}±0.0001	95.8^{c}±13.5	13.0^{b}±1.83
	30	11.6^{b}±1.73	3.4^{b}±0.35	0.0053^{b}±0.0005	157.5^{b}±49.1	8.0^{c}±0.76
	40	10.3^{b}±1.18	2.9^{b}±0.09	0.0039^{c}±0.0002	219.8^{a}±14.9	4.9^{d}±0.15
	50	10.1^{b}±1.48	1.6^{c}±0.79	0.0033^{c}±0.0014	154.8^{b}±30.3	0.6^{e}±0.34
LSD (0.05)		*2.94*	*0.85*	*0.0009*	*37.8*	*2.8*
S. bigelovii	Control	32.6^{a}±5.73	10.8^{a}±2.91	0.008^{a}±0.00004	110.5^{c}±4.2	41.0^{a}±3.54
	10	26.5^{b}±4.46	8.6^{b}±0.41	0.008^{ab}±0.0002	109.6^{c}±13.7	30.4^{b}±4.58
	20	24.3^{bc}±5.24	8.1^{b}±1.47	0.0070^{b}±0.00004	165.4^{b}±2.5	23.7^{c}±3.76
	30	18.3^{c}±3.68	5.6^{c}±0.12	0.0053^{c}±0.0004	253.9^{a}±8.8	14.6^{d}±1.93
	40	11.6^{d}±1.41	4.9^{c}±0.24	0.0040^{d}±0.0001	251.4^{a}±3.8	4.6^{e}±0.8
	50	5.6^{d}±2.05	2.1^{d}±0.09	0.0028^{e}±0.0015	186.0^{b}±41.5	0.7^{e}±0.19
LSD (0.05)		*6.06*	*1.99*	*0.0010*	*27.3*	*4.4*
S. europaea	Control	24.7^{a}±4.95	9.5^{a}±2.45	0.0065^{a}±0.0001	148.5^{b}±3.1	31.6^{a}±3.02
	10	24.3^{a}±7.68	9.4^{a}±0.06	0.0054^{b}±0.0001	126.0^{c}±1.7	30.5^{a}±7.33
	20	17.5^{b}±0.63	7.1^{b}±0.09	0.0050^{b}±0.0002	137.9^{bc}±9.3	12.4^{b}±1.45
	30	14.6^{b}±3.58	5.7^{b}±0.21	0.0045^{c}±0.0004	239.7^{a}±9.3	7.0^{c}±1.12
	40	12.1^{bc}±4.43	3.3^{c}±0.41	0.0035^{d}±0.0006	223.7^{a}±13.3	2.3^{cd}±0.87
	50	7.3^{c}±1.14	1.6^{d}±0.12	0.0017^{e}±0.0002	26.1^{d}±29.1	0.2^{d}±0.05
LSD (0.05)		*6.58*	*1.51*	*0.0005*	*36.1*	*4.96*

Seedling test							
Treatments		SDW (g per pot)	SFW (g per pot)	SH (cm)	WC (%)	TP (mg/g fresh weight)	Fl (mg/g fresh weight)
Species	Salinity	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
S. persica Gorgan ecotype	Control	0.21^{a}±0.002	1.4^{a}±0.069	8.53^{a}±0.50	85.4^{bc}±0.51	0.123^{b}±0.0034	0.027^{a}±0.0034
	10	0.13^{b}±0.019	1.2^{b}±0.051	6.65^{b}±0.30	89.07^{a}±0.66	0.113^{c}±0.0072	0.028^{a}±0.0081
	20	0.15^{b}±0.016	1.3^{ab}±0.06	5.38^{c}±0.38	88.8^{ab}±0.29	0.156^{a}±0.0034	0.031^{a}±0.0012
	30	0.10^{c}±0.007	0.75^{c}±0.20	3.83^{d}±0.25	85.8^{a-c}±5.05	0.105^{d}±0.0046	0.019^{b}±0.0022
	40	0.09^{c}±0.010	0.6^{d}±0.089	3.58^{d}±0.34	84.69^{c}±2.21	0.052^{e}±0.0009	0.014^{b}±0.0016
	50	0.05^{d}±0.003	0.3^{e}±0.007	0.70^{e}±0.16	83.72^{c}±0.48	0.014^{f}±0.0023	0.004^{c}±0.0018
LSD(0.05)		*0.016*	*0.15*	*0.50*	*3.40*	*3.40*	*0.0057*
S. bigelovii	Control	0.22^{b}±0.001	1.8^{a}±0.184	6.55^{b}±0.44	87.66^{a}±0.98	0.027^{b}±0.0017	0.022^{a}±0.0018
	10	0.33^{a}±0.012	1.9^{a}±0.788	7.73^{a}±0.53	82.9^{ab}±0.95	0.031^{a}±0.002	0.02^{ab}±0.0012
	20	0.14^{c}±0.001	0.78^{b}±0.08	3.90^{c}±0.38	81.50^{b}±4.82	0.022^{c}±0.0049	0.014^{c}±0.0063
	30	0.08^{d}±0.008	0.65^{b}±0.21	3.50^{c}±0.32	85.9^{ab}±7.61	0.017^{d}±0.0011	0.016^{bc}±0.001
	40	0.04^{e}±0.016	0.3^{bc}±0.05	2.05^{d}±0.57	85.9^{ab}±3.68	0.011^{e}±0.0008	0.014^{bc}±0.001
	50	0.0001^{f}±0.0	0.0001^{d}±0.0	0.0001^{e}±0.0	0.0001^{c}±0.0	0.0001^{f}±0.0012	0.0001^{d}±0.0008
LSD(0.05)		*0.013*	*0.51*	*0.62*	*5.95*	*5.95*	*0.0042*
S. europaea	Control	0.318^{b}±0.03	2.11^{b}±0.16	5.85^{b}±0.83	84.89^{b}±1.62	0.031^{a}±0.0032	0.014^{ab}±0.002
	10	0.372^{a}±0.04	2.42^{a}±0.29	7.18^{a}±1.48	84.50^{b}±1.99	0.030^{a}±0.0003	0.015^{a}±0.0003
	20	0.18^{c}±0.008	1.43^{c}±0.04	4.05^{c}±0.84	87.34^{ab}±3.60	0.024^{b}±0.0014	0.012^{ab}±0.002
	30	0.14^{c}±0.027	1.03^{d}±0.16	2.08^{d}±0.39	85.51^{b}±2.32	0.020^{b}±0.0039	0.01^{ab}±0.0044
	40	0.045^{d}±0.051	0.43^{e}±0.18	1.03^{de}±0.38	89.44^{a}±2.90	0.015^{c}±0.0037	0.011^{b}±0.0025
	50	0.0001^{d}±0.0	0.0001^{f}±0.	0.0001^{e}±0.0	0.0001^{c}±0.0	0.0001^{d}±0.0016	0.0001^{c}±0.001
LSD(0.05		*0.047*	*0.25*	*1.19*	*3.50*	*3.50*	*0.0037*

Means within each column and each species followed by the same letter are not significantly different ($P \leq 0.05$)
RL: Radical length; HL: Hypocotyl length; GR: Germination rate; CVG: Coefficient of uniformity of germination; SVI: Seed vigor index; SDW: Seedling dry weight; SFW: Seedling fresh weight; WC: Water content; SH: Seedling height; TP: Total phenols; Fl: Flavonoid

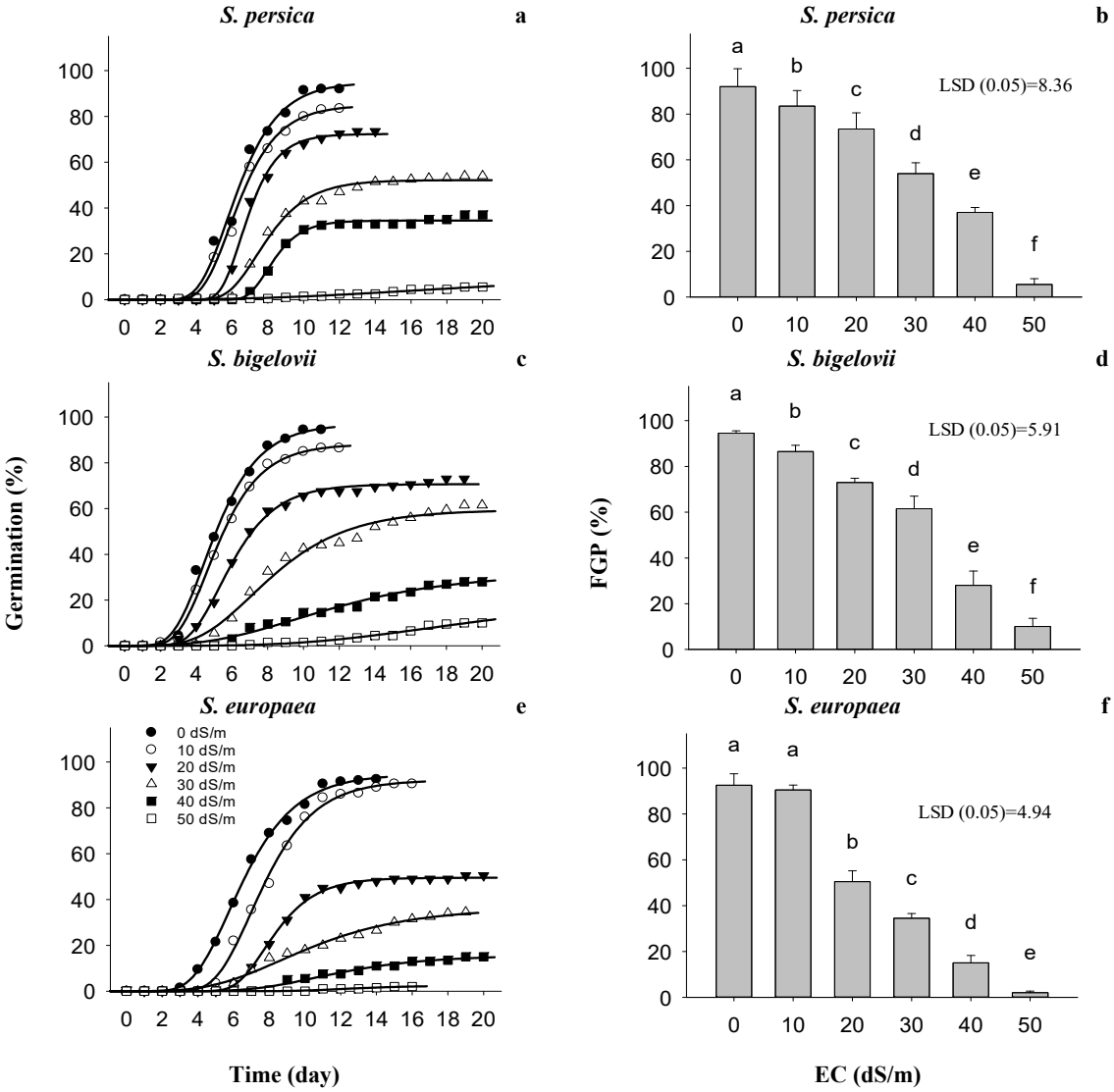

Fig. 1. Final germination percentage (b, d and f) and germination time course (a, c and e) of three Salicornia species. Cumulative germination data is represented using symbols and germination time course is represented using lines fitted through a three-parameter sigmoidal function (Gompertz).

Table 5. Model parameter from fitted sigmoid model (Gompertz) on seed germination of three Salicornia species under salinity levels at time

Treatment		Gompertz 3P				
Species	**Salinity**	**a (%CV)**	**b (%CV)**	**X_0 (%CV)**	**R^2_{Adj}**	**RMSE**
***S. persica* Gorgan ecotype**	**Control**	95.03(3.25)	1.58(11.75)	5.73(2.11)	0.991	3.249
	10	84.90(2.55)	1.49((9.57)	5.84(1.60)	0.994	2.355
	20	72.35(1.28)	1.11(7.16)	6.48(0.89)	0.997	1.625
	30	52.20(1.31)	1.59(8.01)	7.37(1.31)	0.994	1.690
	40	34.53(1.12)	1.05(8.64)	7.95(0.91)	0.995	1.048
	50	10.88(27.42)	8.67(22.47)	16.20(15.51)	0.978	0.263
S. biglovii	**Control**	96.95(2.55)	1.70(9.02)	4.42(2.25)	0.995	2.562
	10	88.14(1.44)	1.66(5.71)	4.60(1.37)	0.997	1.601
	20	70.65(0.75)	1.71(4.58)	5.32(1.11)	0.997	1.350
	30	59.44(2.47)	2.96(9.40)	7.08(2.59)	0.988	2.435
	40	31.70(6.14)	4.91(12.07)	9.60(4.41)	0.985	1.196
	50	21.17(30.95)	7.27(24.98)	17.07(13.86)	0.978	0.505
S. europaea	**Control**	94.73(1.21)	2.03(4.40)	5.75(1.01)	0.998	1.410
	10	92.13(1.40)	1.97(5.65)	6.96(1.07)	0.997	1.883
	20	49.53(0.66)	1.58(3.99)	7.72(0.62)	0.998	0.794
	30	36.26(4.60)	3.91(11.12)	8.61(3.31)	0.987	1.389
	40	15.63(5.30)	3.49(13.16)	10.51(2.84)	0.984	0.689
	50	2.47(21.38)	2.54(34.83)	11.95(5.93)	0.951	0.151

Table 6. Mean comparison of the various indicators of salinity tolerance in Salicornia species

Species	Yp	Ys	Tol	MP	GMP	Harm
	----------g----------					
***S.persica* Gorgan ecotype**	0.214b	0.1046c	0.1094b	0.1600c	0.1472b	0.1368b
S.bigelovii	0.226b	0.1196b	0.1064b	0.1747b	0.1378b	0.1265b
S. europaea	0.318a	0.1482a	0.1698a	0.2535a	0.1860a	0.1675a
LSD (0.05)	0.032	0.0139	0.0201	0.0082	0.0112	0.0150

Means within each column followed by the same letter are not significantly different ($P \leq 0.05$).