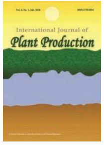

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Evaluation of grain sorghum (*Sorghum bicolor* L.) lines/cultivars under salinity stress using tolerance indices

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Abstract

Selecting and cultivating the crops/varieties that can tolerate water salinity is potentially an important strategy to save fresh water resources and maximize the crop yield in salt affected areas. To evaluate the responses of 36 sorghum lines and cultivars to salinity stress, two field experiments were conducted in non-stress (EC=2 dS/m) and salinity stress conditions (EC=12 dS/m) using randomized complete block design with three replications. The field experiments were carried out at research station of Agricultural Research Center and Natural Resources of Yazd, Iran in 2014 and 2015 growing seasons. Under salinity stress conditions, grains/panicle, panicle length, 1000 grain weight, grain yield, biological yield and harvest index were decreased 36%, 15%, 42%, 64%, 40% and 39%, respectively. The highest grain yield under non-stress conditions was produced by KDFGS2 (8182.6 kg/ha) while the highest grain yield under salinity stress conditions was achieved by KDFGS6 (3310 kg/ha). Correlation coefficients between grain yield (for both conditions) and tolerance indices showed that geometric mean productivity (GMP), stress tolerance index (STI) and harmonic mean (HAM) indices were appropriate for screening high-yielding genotypes. Principal component analysis validated the results of screening methods and introduced lines number 1, 7 and 9 as superior genotypes under both conditions. Lines number 2, 8, 15, 19, 29 and cultivars Ghalami-Herat, Sepideh and Kimia showed greater sensitivity to salinity stress. Since lines number 4, 6, 10 and 24 had greater yield stability, it appears that they may worth further explorations in future breeding projects.

Keywords: Principal component analysis; Sorghum; Tolerance indices.

Introduction

Salinity is one of the major abiotic stress factors that affects plant growth and productivity, especially in arid and semi-arid areas (Hafsi et al., 2010). In fact, in arid and semi-arid regions (e.g. Iran) due to intensity of evaporation and insufficient amount of rainfall for substantial leaching, saline soils are abundant (Dai et al., 2011). In these areas, scarcity of good-quality fresh water, particularly where agricultural systems are dependent on supplemental irrigation, limits crop production, so, using saline irrigation water to increase crop yield is becoming more common (Letey and Feng, 2007; Yarami and Sepaskhah, 2015). Recently, increasing soil salinity and water salinity has deceased crop production in arid and semi-arid countries (Jahanzad et al., 2013). Selecting alternative crops such as sorghum [*Sorghum bicolor* (L.) Moench] which can tolerate different kinds of environmental stresses is a viable option to cope with declining water quality (Marsalis et al., 2010). Grain sorghum after rice and wheat is the third important food grain for many poor people in semi-arid tropical regions (Pola et al., 2008). It is reported that in comparison to corn, sorghum has lower transpiration rate and lower irrigation requirement (Lamm et al., 2007), lower evapotranspiration (ET) (Howell et al., 2008), 25% more productive ability at the same amount of irrigation water (Bean and McCollum, 2006) and may deplete less water from soil than corn (Merrill et al., 2007). In addition, it is indicated that sorghum is more salt tolerant than corn (Mass, 1985) and has the potential for cultivation in saline soils (Igartua et al., 1994). Generally, it has been considered that large genotypic differences exist among cultivars for salinity tolerance in wheat (Munns and James, 2003), alfalfa (Noble et al., 1984), oat (Verma and Yadava, 1986) and sorghum (Lacerda et al., 2005; Krishnamurthy et al., 2007). Screening tolerant cultivars by using final yield as the main criterion, could not be recommended due to complexity in grain yield heritability (Poustini and Siosemardeh, 2004). As an alternative, researchers have employed some selection crieria such as tolerance index (TOL), Mean Productivity (MP) (Rosielle and Hamblin, 1981), stress susceptibility index (SSI) (Fischer and Maurer, 1978), stress tolerance index (STI), geometric mean productivity (GMP), harmonic mean (HAM) (Fernandez, 1992), yield stability index (YSI) (Bouslama and Schapaugh, 1984) and yield index (YI) (Gavuzzi et al., 1997) for judging the relative tolerance of genotypes to stress conditions. Ali et al. (2013) found that STI was directly correlated with rice yield in normal and salinity stress conditions. Amini et al. (2015) concluded that GMP, MP as well as STI were suitable indicators for distinguishing tolerant wheat genotypes under salinity conditions.

Recently, there has been no report on screening grain sorghum genotypes under salinity stress conditions in Iran. Therefore, the aim of this study was to identify the most suitable indices for screening lines/cultivars of grain sorghum. Additionally, yield and yield components of 36 genotypes were compared in normal and saline conditions.

Materials and Methods

Site description and plant materials

Two field experiments were conducted during 2014 and 2015 at the experimental farm of Agricultural Research Center and Natural Resources of Yazd, Iran, located in Ardakan (32°/ 20’ N and 53°/48’E and 1220 m s.l.). Mean temperature, relative humidity and precipitation are presented in Table 1. 30 lines, which have been bred under different agro-climatic conditions in Iran and have been introduced in 2013, as well as 6 cultivars, which are commercially cultivating by sorghum growers have been examined (Table 2).

Table 1. Meteorological data for the field site during sorghum growth in 2014 and 2015.

Months	Mean temperature (^{0}C)		Relative humidity (%)		Precipitation (mm)	
	2014	2015	2014	2015	2014	2015
June	32.5	33	9	9.4	0	0
July	34.1	34.5	10	9.8	0	0
August	32.1	32.4	11	10.4	0	0
September	29.3	29.7	14	12.9	0	0
October	21.2	21.6	32	31	3.3	3

Experimental design and treatments

This study was composed of two separate experiments based on randomized complete block design with three replications. Thirty lines and 6 cultivars were compared under saline and non-saline conditions in each year. Experimental plots were irrigated either with saline water (EC=12 dS m^{-1}) or normal (EC=2 dS m^{-1}) irrigation water. Plants were subjected to salinity treatments from sowing to harvesting time, which represented irrigation of sorghum fields by farmers in the region. Chemical properties of the used saline water are shown in Table 3. Tillage operation included of moldboard plowing disturbing the soil to a 30-cm depth followed by two rounds of vertical tillage with harrow disking. Each experimental unit was a plot of 4×5 m. Uniform sorghum seeds were hand-seeded at 4 rows with density of 16.7 plants m^{-2} at depth of 3 cm. Seeding rate was 10% higher than the target density.

Table 2. Sorghum cultivars/lines used in present experiment.

Code	Name	Code	Name
1	KDFGS1	19	KDFGS19
2	KDFGS2	20	KDFGS20
3	KDFGS3	21	KDFGS21
4	KDFGS4	22	KDFGS22
5	KDFGS5	23	KDFGS23
6	KDFGS6	24	KDFGS24
7	KDFGS7	25	KDFGS25
8	KDFGS8	26	KDFGS26
9	KDFGS9	27	KDFGS27
10	KDFGS10	28	KDFGS28
11	KDFGS11	29	KDFGS29
12	KDFGS12	30	KDFGS30
13	KDFGS13	31	Sistan
14	KDFGS14	32	Ghalami-Herat
15	KDFGS15	33	Sepideh
16	KDFGS16	34	Broom corn
17	KDFGS17	35	Sweet sorghum
18	KDFGS18	36	Kimia

Rows were 60 cm apart in each plot. 100 kg ammonium phosphate ha^{-1} and 180 kg N ha^{-1} as urea were applied to all plots. Hand weeding was performed during the growing seasons. Urea fertilizer based on the soil analysis (Table 4) was equally splitted and applied at planting, 30 and 60 days after planting. Before planting, the field was heavily irrigated twice to reduce soil profile salinity level. During the growing seasons, all plots were irrigated based on the crop water requirement by considering soil field capacity (FC, %) at the depth of 0-90 cm according to the rooting depth. Before each irrigation, 10 soil samples were taken randomly from each experimental block to measure the water content of the soil.

Table 3. Chemical analysis of irrigation water applied in the experiment.

Salinity (dS m^{-1})	pH	Cations and anions in water sample (meq L^{-1})						
		HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+
2	8.25	1.69	15.2	7.41	3.95	7.75	12.76	0.17
12	7.71	3.23	92.35	26.43	9.05	28.36	84.7	0.51

Table 4. Soil physic-chemical characteristics before planting.

Texture	Clay (%)	Silt (%)	Sand (%)	P $\mu g.g^{-1}$	Total N %	O.C† %	pH	EC_e‡	Soil depth (cm)
S.C.L	23	26	51	15.05	0.03	0.351	7.43	5.24	0-30
S.C.L	22.4	24.6	53	9.26	0.027	0.312	7.54	4.75	30-60

† Organic carbon, ‡ Electrical conductivity of soil saturation extract (dS/m).

Before each irrigation, soil samples were taken to determine their gravimetric water contents (Pw, %). Depth of net irrigation water (d_n, cm) was calculated as follows:

$$d_n = \frac{[\theta_{FC} - (P_w \times \rho_b)] \times R_d}{100} \tag{1}$$

where θ_{FC} is the volumetric soil water content (%) at field capacity, ρ_b is the averaged bulk density in the soil profile in root depth and R_d is the root depth varied during the growing season and was calculated as follows (Borg and Grimes, 1986):

$$\mathrm{R}_d = R_{dmax}\,[0.5 + 0.5 \sin(3.03 \frac{D_{ag}}{D_{tm}} - 1.47)] \tag{2}$$

where $R_{d\,max}$ is the maximum root depth, D_{ag} is the number of days after germination, D_{tm} is the number of days from germination to maximum effective root depth and the sine function is in radians. To consider depth of seed planting (P_d) in calculation, Eq. (2) was converted as follows:

$$\mathrm{R}_d = P_d + R_{dmax}\,[0.5 + 0.5 \sin(3.03 \frac{D_{ag}}{D_{tm}} - 1.47)] \tag{3}$$

The application efficiency (E_a) of all irrigations (basin) was assumed as 70 percent (or 30% deep percolation). Therefore, the volume of water applied to each plot was calculated as follows:

$$V_g = \frac{\mathrm{d}_n}{\mathrm{E}_a} \times P_a \tag{4}$$

where V_g is the volume of water applied to each plot with the plot area of P_a. The total water applied were 8981 and 6491 in 2014 m^3 and 8832 and 6373 m^3 in 2015 for non-saline and saline conditions, respectively. It is notable that an extra 20% water was added at each irrigation as leaching fraction to prevent excessive build-up of salts in the root zone. Also, salinity of soil were monitored during experiment by measuring electrical conductivity of soil saturated extract (EC_e).

Table 5. Soil cations and anions at research field before planting.

SAR[ℓ]	HCO_3^- Meq. L^{-1}	Cl^- Meq. L^{-1}	SO_4^{--} Meq. L^{-1}	Ca^{++} Meq. L^{-1}	Mg^{++} Meq. L^{-1}	Na^+ Meq. L^{-1}	K^+ $\mu g.g^{-1}$	Soil depth
14.3	3	105.5	16.71	23.6	26.8	71.44	134	0-30
7.8	1.2	42.75	14.59	14.6	12	28.1	121	30-60

ℓ Sodium absorption ratio.

Measurement of yield and yield components

At physiological maturity, two middle rows of each experimental plot, an area of 2.4 m^2 were harvested and the grain yield and its components were determined. Panicle length, biological yield, grain number per panicle and thousand grain weight used for yield estimation were assessed after 24 hours in 100 °C. Harvest index was calculated as:

$$HI = \frac{\mathrm{GY}}{\mathrm{BY}} \times 100 \quad (5)$$

where HI, GY and BY are the harvest index (%), the grain yield (kg ha^{-1}) and the biological yield (kg ha^{-1}), respectively.

Screening Methods

Tolerance indices were calculated using following equations:

$$SSI = (1 - (\mathrm{Ys}/\mathrm{Yp}))/(1 - (\bar{\mathrm{Y}}\mathrm{s}/\bar{\mathrm{Y}}\mathrm{p}))$$ (Fisher and Maurer, 1978) (6)

$$TOL = \mathrm{Yp} - \mathrm{Ys}$$ (Rosielle and Hamblin, 1981) (7)

$$MP = (\mathrm{Yp} + \mathrm{Ys})/2$$ (Rosielle and Hamblin, 1981) (8)

$$STI = (\mathrm{Yp} \times \mathrm{Ys})/(\bar{\mathrm{Y}}\mathrm{p})^2$$ (Fernandez, 1992) (9)

$$GMP = \sqrt{(Yp \times Ys)}$$ (Fernandez, 1992) (10)

$$HAM = (2(\mathrm{Yp} \times \mathrm{Ys}))/(\mathrm{Yp} + \mathrm{Ys})$$ (Fernandez, 1992) (11)

$$YSI = \mathrm{Ys}/\mathrm{Yp}$$ (Bouslama and Schapaugh, 1984) (12)

$$YI = \mathrm{Ys}/\bar{\mathrm{Y}}s$$ (Gavuzzi et al., 1997) (13)

In all above equations, Ys and Yp are stress and normal (potential) yield of a given genotype, respectively. $\bar{Y}_S$ and $\bar{Y}p$ are average yield of all genotypes under stress and normal conditions, respectively.

Statistical analysis

Analysis of variance was carried out using SAS (SAS release 9.2, 2002) and a Bartlett (Bartlett, 1937) test was performed for error square homogeneity whose outcome showed error square homogeneity in all parameters; therefore, the means of both years are presented. The means were compared using the least significant difference (LSD) test. Principal component (PC) analysis by using MINITAB 17 was employed to classify the genotypes. Clustering of the genotypes was carried out using Ward's method.

Results and Discussion

Soil salinity and applied water

The higher values of soil EC_e were found in top layers of soil (0-30 and 30-60 cm) in both years (Figure 1). Also, the results showed that the soil water content was greater at 12 dS/m salinity treatment in both years (Figure 2). Since soil water content usually increases with increased salinity of the irrigation water (Min et al., 2014, Azizian and Sepaskhah, 2014), in our research it was also found that total water used for saline treatments was much lower than for non-saline treatment (See Materials and Methods). As a result, salt accumulation was greater in the top soil layer at higher salinity level, so, EC_e for 12 dS/m treatment was found to be higher at 0-30 and 30-60 cm depths. This could explain why the gradual accumulation of salts in the soil, resulted to a higher EC_e in second year (2015) compared to the first year for the irrigation water of 12 dS/m salinity level (Figure 1).

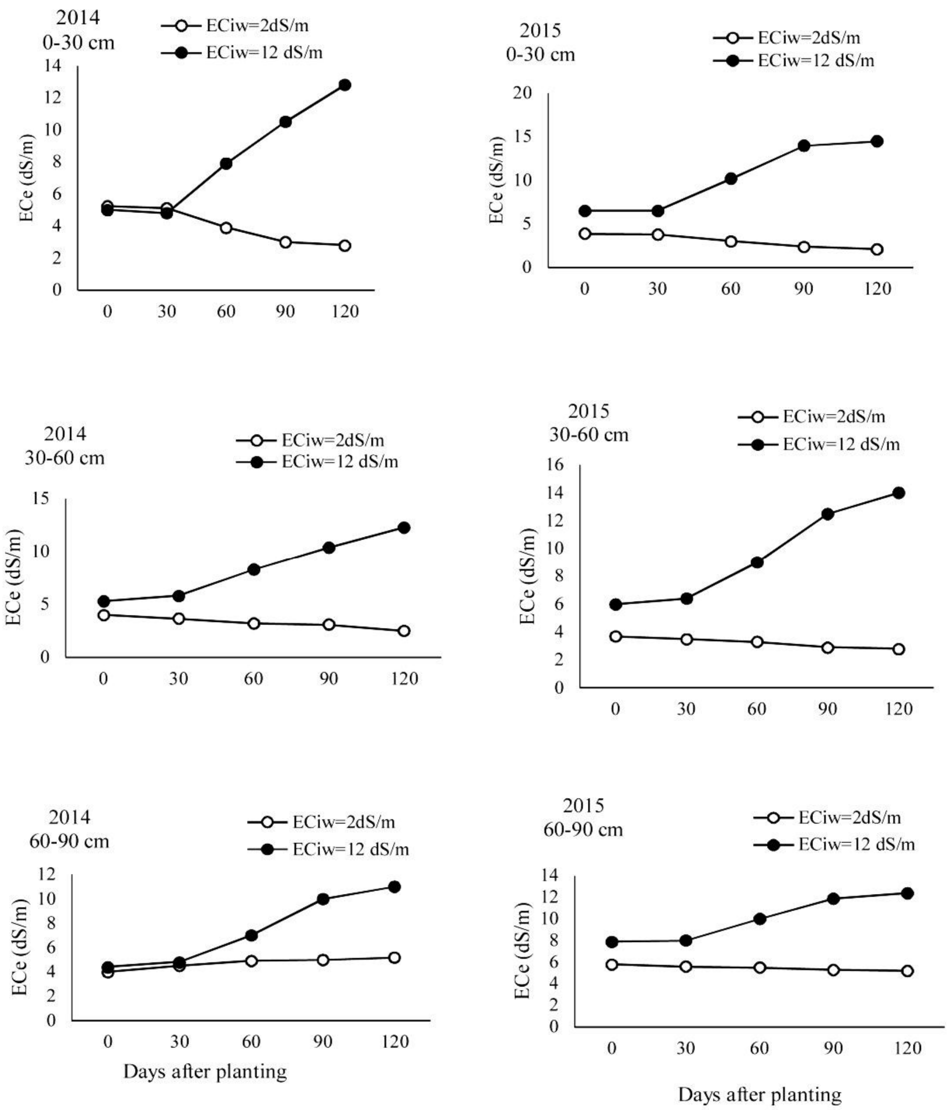

Figure 1. Electrical conductivity of soil saturated extract (EC_e) of three different soil depths (0-30, 30-60 and 60-90 cm) during growing seasons. ECiw = Electrical conductivity of irrigation water.

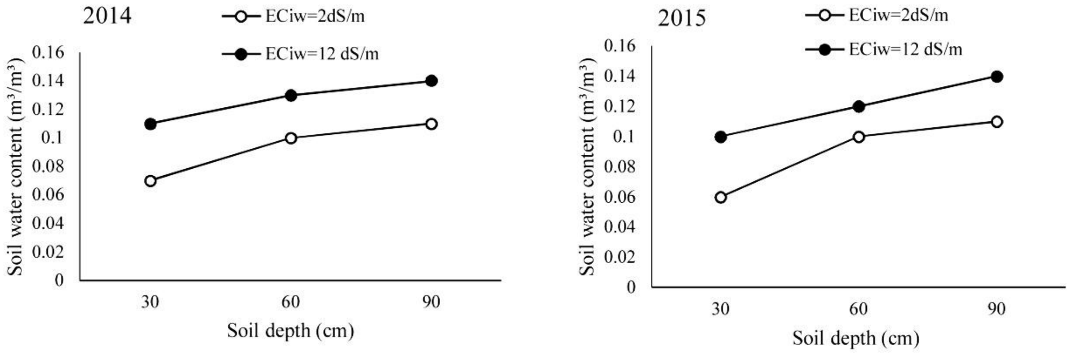

Figure 2. Mean of soil water content of three different soil depths (0-30, 30-60 and 60-90 cm) during growing seasons. ECiw = Electrical conductivity of irrigation water.

Effect of salinity stress on yield and yield components

There were significant differences among genotypes in respect to all parameters in both conditions (Tables 6 and 7). The higher grain yield was obtained by KDFGS2 line and Sepideh cultivar in non-stress conditions. Also, these genotypes had higher panicle length and 1000 grain weight (Table 6). Kimia, Ghalami-Herat and KDFGS15 line had higher grain yield after KDFGS2 and Sepideh. The higher biological yield was observed in KDFGS23, KDFGS15, KDFGS26 lines and Ghalami-Herat cultivar (Table 7). KDFGS2 line and Sepideh and Kimia cultivars had higher harvest indices (Table 7). Igartua et al. (1995), Krishnamurthy et al. (2007) and Tari et al. (2013) have reported these differences under non-stress conditions could be explained by the genetic potential capability of each genotype.

All measured traits remarkably declined under salinity stress conditions (Tables 6 and 7). Ranjbar et al. (2015) concluded that salinity stress markedly reduced grain yield of sorghum. Response of lines/cultivars to salinity stress was highly different indicating high diversity among genotypes (Tables 6 and 7). The lines KDFGS6 and KDFGS10 had higher grains per panicle, 1000 grain weight, grain yield and harvest index under salinity conditions (Tables 6 and 7). Higher panicle length was observed in KDFGS9 and KDFGS30 (Table 6). The decrease in panicle length is a well-known response of grain sorghum to water stress (Igartua et al., 1995), therefore, in present experiment, the reduced panicle length may be indicative of a salinity-induced stress. On average, 1000 grain weight was the most affected trait (42% reduction, Table 6) in comparison to other traits. Mass et al. (1986) and Igartua et al. (1995) have reported grains per panicle was the most affected trait of salt stressed sorghum plants. In general, negative effect of salinity on mean grain weight was strongly dependent on the timing of stress occurrence (Igartua et al., 1995). In the present investigation, salinity stress was imposed throughout the growing season and this is why the main yield component which has responded to salinity stress has been the grain weight. Other investigators who have reported little effect of salinity stress on mean grain weight have imposed salinity stress at late grain filling stage (Mass et al., 1986). Under saline conditions, the reduced growth of crops has been mainly attributed to mineral toxicity and lower water uptake (Elgharably, 2011). During grain filling period, three processes including photosynthesis, translocation of produced assimilates to grains and grain growth are happening. Salinity stress can accelerate grain growth period and hence inhibit each of these processes that finally could result into the grain dry weight reduction (Akbar et al., 1986). Indeed, desiccation accelerates the grain-filling period through source reduction during late grain development (Westgate, 1994; Gambin and Borras, 2007).

Table 6. Mean comparison for yield components in Sorghum lines/cultivars under non-stress and stress conditions.

Line/Cultivar[#]	Grains/Panicle			Panicle length (cm)			1000 grain weight (g)		
	N	S	C	N	S	C	N	S	C
1	1437.94	1102.6	-23	22.07	20.89	-5	21.66	13.13	-39
2	1621.7	868.15	-46	26.25	18.73	-29	30.69	12.03	-61
3	1117.53	663.4	-41	20.07	12.59	-37	19.86	11	-45
4	949.7	891.05	-6	18.96	18.75	-1	14.93	12.99	-13
5	940.97	794	-16	18.78	17.96	-4	17.03	11.53	-32
6	1457.05	1214.08	-17	21.43	21.31	-1	19.78	14.27	-28
7	1469.57	1047.3	-29	22.12	20.83	-6	22.88	13.05	-43
8	1527.55	892.3	-42	23.03	18.83	-18	23.51	12.27	-48
9	1484.35	1173.5	-21	22.56	22.12	-2	23.13	13.66	-41
10	1340.46	1313.6	-2	22.05	21.32	-3	21.61	14.04	-35
11	1141.1	941.05	-18	20.33	19.53	-4	20.38	12.91	-37
12	1091.04	585.75	-46	19.73	16.15	-18	19.34	10.83	-44
13	1110.49	928.95	-16	19.9	19.16	-4	19.04	12.87	-32
14	904.4	670.65	-26	18.54	16.69	-10	16.11	11.06	-31
15	1540.23	721.5	-53	23.5	17.06	-27	25.28	11.13	-56
16	1137.51	788.6	-31	20.46	17.9	-13	20.31	11.35	-44
17	1207.19	638.6	-47	21	14.29	-32	20.48	10.86	-47
18	1045.73	762.25	-27	19.42	17.36	-11	17.48	11.2	-36
19	1557.68	762.45	-51	25.16	17.73	-30	23.98	11.23	-53
20	1232.92	519.7	-58	21.4	14.33	-33	20.88	10.71	-49
21	919.13	826.6	-10	18.65	17.99	-4	15.89	11.09	-30
22	1034.95	571.4	-45	19.34	16.22	-16	18.73	10.73	-43
23	953.12	417.1	-56	19	12.5	-34	17.06	10.2	-40
24	841.45	772.05	-8	17.83	17.77	-0.3	11.3	11.13	-2
25	1285.44	516.65	-60	21.76	16.47	-24	21.19	10.53	-50
26	1366.46	435.6	-68	21.74	16.55	-24	21.68	11.51	-47
27	1051.15	846.75	-19	19.55	18.18	-7	17.88	11.77	-34
28	992.05	715.8	-28	19.12	16.72	-13	15.91	11.11	-30
29	1510.9	949.45	-37	22.65	20.66	-9	23.48	13.02	-45
30	1153.35	1117.55	-3	23.63	20.86	-12	20.54	13.4	-35
31	1313.19	647	-51	14.92	11.24	-25	21.38	10.93	-49
32	1737.15	913.55	-47	11.82	10.46	-12	23.61	12.29	-48
33	1661.83	847.05	-49	25.3	18.69	-26	29.51	11.89	-60
34	1351.41	350.15	-74	14.59	9.59	-34	12.75	9.82	-23
35	1353.38	497.55	-63	16.73	13.56	-19	14.81	10.5	-29
36	1566.315	729.45	-53	24.78	17.13	-31	26.45	11.16	-58
Mean	1252.91	798.18	-36	20.21	17.25	-15	20.28	11.76	-42
LSD (0.05)	249.65	159.29	-	3.65	2.16	-	3.16	1.1	-

N: Normal conditions, S: Salinity conditions, C: Percentage of changes upon salinity stress (%).
[#] Name of lines and cultivars are listed in Table 2.

Screening methods and correlation analysis

The mean values for tolerance indices are presented in Table 8. The lines 2, 6, 9, 10 and Sepideh cultivar had higher values of GMP, HAM and STI indices (Table 8). Furthermore, highly significant correlations were found between GMP, STI and HAM

(Table 9). Indeed, these indices (GMP, STI and HAM) were equal in identifying genotypes possessing better performance under both stress as well as normal conditions. Our finding is confirmed by the results of Jafari et al. (2009) who reported similar indices for maize. The higher value of MP was found in line 2 followed by Sepideh, Ghalami-Herat and Kimia cultivars (Table 8).

Table 7. Mean comparison for gain yield, biological yield and harvest index in Sorghum lines/cultivars under non-stress and stress conditions.

Line/Cultivar[#]	Grain yield (kg/ha)			Biological yield (kg/ha)			Harvest Index (%)		
	N	S	C	N	S	C	N	S	C
1	5040.3	2299.8	-54	22003.5	16347.5	-26	25.94	14.12	-46
2	8182.6	1638.1	-80	20938	13022	-38	39.37	12.6	-68
3	3653	1181.7	-68	21065	11752.5	-44	17.38	10.06	-42
4	2090.6	1989.1	-5	14088	13132	-7	17.01	14.17	-17
5	2349.8	1486.2	-37	15160	12471.5	-18	15.9	11.95	-25
6	3922.4	3310	-16	16165.5	10659	-34	24.58	31.11	27
7	5525.7	2226.6	-60	21323	13626.5	-36	27.01	16.37	-39
8	5898.9	1716.3	-71	22647	10799.5	-52	27.43	15.91	-42
9	5583.8	2551.6	-54	19923	12374.5	-38	29.62	20.67	-30
10	4750.2	3012.5	-37	16533	9234	-44	30.21	32.71	8
11	3782.2	1967.7	-48	14443.5	9359.5	-35	27.87	21.1	-24
12	3454.3	1028.6	-70	17859.5	12209.5	-32	19.4	8.45	-56
13	3458.4	1942.3	-44	19113	10775.5	-44	18.09	18.02	-0.3
14	2367.9	1215	-49	16820.5	11024	-34	14.86	11.05	-26
15	6380.4	1267.4	-80	27753	15179.5	-45	22.95	8.36	-64
16	3670.7	1452.8	-60	17545	12146.5	-31	20.99	11.98	-43
17	4039.7	1112.9	-72	19067	8871.5	-53	21.44	12.56	-41
18	2958.4	1338.9	-55	17574.5	10032	-43	16.87	13.38	-21
19	6078.1	1383.5	-77	23200	13403	-42	26.24	10.35	-61
20	4199.3	881.6	-79	19717	10752.5	-45	21.3	8.25	-61
21	2396	1391.5	-42	17750	10889.5	-39	13.84	12.78	-8
22	3171.6	968.4	-69	17542	12895	-26	18.46	7.52	-59
23	2616.2	664.2	-75	28713.5	9671.5	-66	9.15	6.85	-25
24	1506.2	1356.8	-10	13789.5	9366.5	-32	12.15	14.52	20
25	4495.2	860.2	-81	17931.5	12717.5	-29	25.17	6.78	-73
26	4866	766.7	-84	27023.5	11803.5	-56	17.87	6.43	-64
27	3010.6	1571.8	-48	19373	8186.5	-58	16.28	19.27	18
28	2514.2	1257.8	-50	19456.5	11727.5	-40	13.63	10.76	-21
29	5801.8	1985.9	-66	23771.5	12971	-45	24.77	15.36	-38
30	3856.1	2406.7	-38	16502	10024	-39	23.93	24.1	1
31	4565.4	1135.4	-75	22283	15838	-29	20.73	7.81	-62
32	6772.4	1840.1	-73	25620.5	15764	-38	26.51	11.9	-55
33	8049.1	1619.2	-80	16540.5	8307	-50	48.8	20.02	-59
34	2768.8	554.7	-80	10992.1	7133	-35	26.12	7.77	-70
35	3199.4	815.5	-75	22223.5	15129	-32	14.6	5.49	-62
36	6853.8	1320.7	-81	16936.5	8587.5	-49	40.76	15.61	-62
Mean	4273.04	1542.17	-64	19400.8	11642.76	-40	22.7	13.78	-39
LSD (0.05)	1035.9	347.54	-	3611.9	1314.5	-	6.54	3.52	-

N: Normal conditions, S: Salinity conditions, C: Percentage of changes upon salinity stress (%).
[#] Name of lines and cultivars are listed in Table 2.

Interestingly, line 2, Sepideh, Ghalami-Herat and Kimia cultivars also had higher TOL (Table 8). Indeed, higher value of MP in this study, was found to be related to higher yield potential for the above genotypes. It appeared that, MP could only introduce genotypes with higher yield potential and it is not appropriate for recognition of high yielding genotypes under stress conditions. In accordance to our findings, Hossain et al. (1990) and Mohammadi et al. (2010) also found that MP index favored those genotypes which had low difference between Y_p and Y_s. Regarding to strong positive and significant correlation between TOL and yield potential (Table 9), this index also appears to promote selecting genotypes with higher yield under normal conditions. The lower values for SSI and higher for YSI was found in lines 4, 24, 6 and 10 which had low salinity susceptibility. The lines 2, 15, 19, Sepideh, Ghalami-Herat and Kimia cultivars which had higher potential grain yield, with SSI values higher than unit and lower values of YSI might be considered as highly sensitive to salinity with poor yield stability genotypes. Stress susceptibility index (SSI) refers to those genotypes which show minimum reduction under stress, compared to control (Fischer and Maurer, 1978).

Table 8. Stress tolerant indices in Sorghum lines and cultivars based on grain yield.

Line/Cultivar[#]	Yp	Ys	GMP	HAM	MP	SSI	STI	TOL	YI	YSI
1	5040.3	2299.8	3404.66	3158.45	3670.05	0.85	0.63	2740.5	1.49	0.46
2	8182.6	1638.1	3661.14	2729.73	4910.35	1.25	0.73	6544.5	1.06	0.20
3	3653	1181.7	2077.68	1785.74	2417.35	1.06	0.24	2471.3	0.77	0.32
4	2090.6	1989.1	2039.22	2038.59	2039.85	0.08	0.23	101.5	1.29	0.95
5	2349.8	1486.2	1868.76	1820.79	1918.00	0.58	0.19	863.6	0.96	0.63
6	3922.4	3310	3603.21	3590.27	3616.20	0.24	0.71	612.4	2.15	0.84
7	5525.7	2226.6	3507.64	3174.16	3876.15	0.93	0.67	3299.1	1.44	0.40
8	5898.9	1716.3	3181.87	2658.97	3807.60	1.11	0.55	4182.6	1.11	0.29
9	5583.8	2551.6	3774.60	3502.62	4067.70	0.85	0.78	3032.2	1.65	0.46
10	4750.2	3012.5	3782.85	3686.86	3881.35	0.57	0.78	1737.7	1.95	0.63
11	3782.2	1967.7	2728.05	2588.65	2874.95	0.75	0.41	1814.5	1.28	0.52
12	3454.3	1028.6	1884.96	1585.18	2241.45	1.10	0.19	2425.7	0.67	0.30
13	3458.4	1942.3	2591.77	2487.55	2700.35	0.69	0.37	1516.1	1.26	0.56
14	2367.9	1215	1696.17	1605.96	1791.45	0.76	0.16	1152.9	0.79	0.51
15	6380.4	1267.4	2843.68	2114.73	3823.90	1.25	0.44	5113	0.82	0.20
16	3670.7	1452.8	2309.28	2081.70	2561.75	0.95	0.29	2217.9	0.94	0.40
17	4039.7	1112.9	2120.33	1745.05	2576.30	1.13	0.25	2926.8	0.72	0.28
18	2958.4	1338.9	1990.23	1843.48	2148.65	0.86	0.22	1619.5	0.87	0.45
19	6078.1	1383.5	2899.84	2253.95	3730.80	1.21	0.46	4694.6	0.90	0.23
20	4199.3	881.6	1924.08	1457.26	2540.45	1.24	0.20	3317.7	0.57	0.21
21	2396	1391.5	1825.93	1760.55	1893.75	0.66	0.18	1004.5	0.90	0.58
22	3171.6	968.4	1752.53	1483.76	2070.00	1.09	0.17	2203.2	0.63	0.31
23	2616.2	664.2	1318.21	1059.43	1640.20	1.17	0.10	1952	0.43	0.25
24	1506.2	1356.8	1429.55	1427.60	1431.50	0.16	0.11	149.4	0.88	0.90
25	4495.2	860.2	1966.41	1444.06	2677.70	1.27	0.21	3635	0.56	0.19
26	4866	766.7	1931.52	1324.68	2816.35	1.32	0.20	4099.3	0.50	0.16
27	3010.6	1571.8	2175.33	2065.32	2291.20	0.75	0.26	1438.8	1.02	0.52
28	2514.2	1257.8	1778.30	1676.76	1886.00	0.78	0.17	1256.4	0.82	0.50
29	5801.8	1985.9	3394.38	2958.97	3893.85	1.03	0.63	3815.9	1.29	0.34
30	3856.1	2406.7	3046.39	2963.68	3131.40	0.59	0.51	1449.4	1.56	0.62
31	4565.4	1135.4	2276.74	1818.54	2850.40	1.18	0.28	3430	0.74	0.25
32	6772.4	1840.1	3530.14	2893.91	4306.25	1.14	0.68	4932.3	1.19	0.27
33	8049.1	1619.2	3610.14	2696.05	4834.15	1.25	0.71	6429.9	1.05	0.20
34	2768.8	554.7	1239.30	924.24	1661.75	1.25	0.08	2214.1	0.36	0.20
35	3199.4	815.5	1615.27	1299.71	2007.45	1.17	0.14	2383.9	0.53	0.25
36	6853.8	1320.7	3008.62	2214.65	4087.25	1.26	0.50	5533.1	0.86	0.19

Yp: Yield in non-stress conditions; Ys: Yield in stress conditions; GMP: Geometric mean productivity; HAM: Harmonic mean; MP: Mean productivity; SSI: Stress susceptibility index; STI: Stress tolerance index; TOL: Tolerance index; YI: Yield Index; YSI: Yield stability index; SI= 0.32. [#] Name of lines and cultivars are listed in table 2.

Therefore, it can select stress tolerant genotypes with low yield potential (Fernandez, 1993). Higher values of YI index was observed for line 6 followed by lines 10, 9 and 30 (Table 8). Since YI index only takes into consideration the yield capacity under stress conditions, so selection only based on this index, is not suitable for screening tolerant genotypes. Correlation between yield potential (Y_p) and stress yield (Y_s) was 0.22 (Table 9). Fernandez (1993) have concluded that the degree of linear association between Ys and Yp decreases with the increase in stress intensity. Although, Fernandez (1993) found absolute correlation (r = -0.84) between SSI and STI under severe stress conditions, no relationship was found between SSI and STI in this investigation. Similar results have been reported by Ali et al. (2013). They studied the response of rice genotypes to salinity stress and found that despite the weak correlation between yield potential and stress yield (r=0.22), there was no correlation between SSI and STI.

Table 9. Correlation coefficients between grain yield and tolerance indices in stress and non-stress conditions.

	Yp	Ys	GMP	HAM	MP	SSI	STI	TOL	YI	YSI
Yp	1									
Ys	0.22^{ns}	1								
GMP	0.78**	0.78**	1							
HAM	0.53**	0.93**	0.94**	1						
MP	0.94**	0.52**	0.93**	0.77**	1					
SSI	0.55**	-0.58**	0.007^{ns}	-0.28^{ns}	0.29^{ns}	1				
STI	0.76**	0.78**	0.99**	0.94**	0.92**	-0.08^{ns}	1			
TOL	0.92**	-0.15^{ns}	0.49**	0.18^{ns}	0.75**	0.78**	0.47**	1		
YI	0.22^{ns}	0.99**	0.78**	0.93**	0.52**	-0.58**	0.78**	-0.15^{ns}	1	
YSI	-0.55**	0.58**	-0.07^{ns}	0.28^{ns}	-0.29^{ns}	-0.99**	0.08^{ns}	-0.78**	0.58**	1

*,** Significant at 5% and 1% probability levels, respectively; ns, non-significant.
Yp: Yield in non-stress conditions; Ys: Yield in stress conditions; GMP: Geometric mean productivity; HAM: Harmonic mean; MP: Mean productivity; SSI: Stress susceptibility index; STI: Stress tolerance index; TOL: Tolerance index; YI: Yield index; YSI: Yield stability index.

Principal component analysis

Since GMP, HAM, MP, SSI, STI and YSI indices had significant correlations with the grain yield under both conditions, principal component analysis (PCA) was performed using these indices. Principal component analysis revealed that the first component (PC_1) explained 62.3% of total variation. This component had positive correlation with the grain yield under both conditions, GMP, HAM, MP and STI. The second component (PC_2) explained 35.8% of variations. Positive correlation was observed between PC_2 with Yp and SSI index, whereas this index had negative correlation with Y_s and YSI index (Table 10). Therefore, the second component could be named as salinity susceptible component. This indicates that selecting genotypes with high PC_2 might be suitable for non-stress conditions (Figure 3). Thus, lines 2, 8, 15, 19, 29, Ghalami-Herat, Sepideh and Kimia cultivars were considered as high-yielding genotypes in non-stress conditions and had poor yield stability in stress environments. Lines 1, 6, 7, 9 and 10 due to high PC_1 and low PC_2 were found to be the most salinity tolerant genotypes. Although lines 4 and 24 had low grain yield in both conditions, due to low yield reduction under salinity conditions, had greater yield stability and could be suggested for future breeding programs.

Table 10. Principal components analysis based on grain yield and six tolerance indices.

PC	EV	V (%)	Yp	Ys	GMP	HAM	MP	SSI	STI	YSI
PC1	4.98	62.3	0.34	0.35	0.44	0.42	0.42	-0.008	0.44	0.005
PC2	2.86	35.8	0.35	-0.35	0.006	-0.17	0.19	0.58	-0.001	-0.58

PC_1: First principal components, PC_2: Second principal component, EV: Eigen value, V: Variance, Yp: Yield in non-stress condition; Ys: Yield in stress condition; GMP: Geometric mean productivity; HAM: Harmonic mean; MP: Mean productivity; SSI: Stress susceptibility index; STI: Stress tolerance index; YSI: Yield stability index.

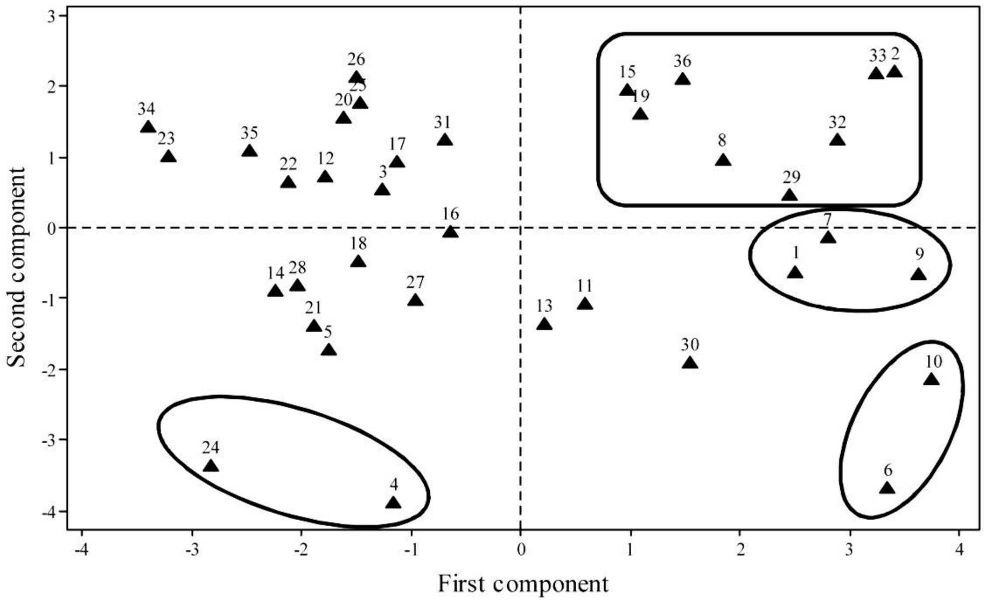

Figure 3. Biplot display using tolerance indices in 36 sorghum lines and cultivars based on first two components. Name of lines and cultivars are listed in table 2.

Cluster analysis

In this study the cluster method was also used to classify different genotypic groups. The genotypes were classified into four groups (Figure 4). The first group included lines 1, 6, 7, 9 and 10. According to principal component analysis, these lines were introduced as the most tolerant lines. Lines 2, 8, 15, 19, 29 and Ghalami-Herat, Sepideh and Kimia cultivars located in the second group which had high yield potential and were sensitive to salinity conditions. The third group consisted of lines 3, 12, 17, 25 and 26 which were introduced as sensitive lines by principal component analysis. Lines 4 and 24 have been located in fourth group which based on principal component analysis had greater stability in salinity stress conditions.

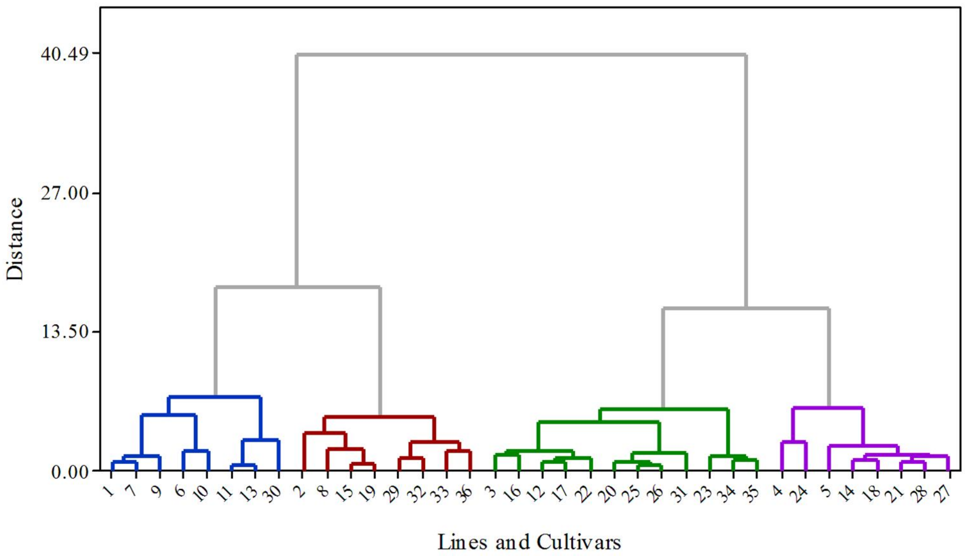

Figure 4. Dendrogram resulted from cluster analysis of sorghum lines and cultivars based on tolerance indices using Ward's method. Name of lines and cultivars are listed in table 1.

Conclusion

Increased salinity of irrigation water had strongly negative impact on yield and yield components of sorghum lines/cultivars. It was also concluded that large genotypic variation was observed among genotypes. GMP, HAM, STI as well as SSI were found to be effective selection indices, whereas MP index only favored the genotypes with higher yield potential. All commonly grain sorghum cultivars including Sepideh, Ghalami-Herat and Kimia were found sensitive to saline conditions. Lines 1, 7 and 9 could be suggested as superior genotypes where the salinity stress is main environmental constraint to grain sorghum production. It was also found that total water used for saline treatments was much lower than for non-saline treatment.

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