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Research Article

Identification of salinity tolerance indices in sugar beet genotypes

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Abstract

To evaluate the salinity tolerance of sugar beet genotypes using tolerance indices and also to identify the best tolerance indices, full-sib families along with control cultivars were studied in separate experiments at Miandoab Agricultural and Natural Resources Research Station, West Azerbaijan, under salinity and control conditions. Analysis of variance showed that salinity stress reduced root and sugar yield. Weak correlations in root and sugar yield were observed under both normal and stress conditions. GMP, MP, and STI indices had a significant positive correlation with both root yield and sugar yield under both normal and saline stress conditions. The principal component analysis applied to both yield traits displayed that the first component had a high positive relationship with Ys and RSI, YI, YSI, and SI and a high negative relationship with Y_P, SSI, TOL, ATI, and SSPI. The second component showed a positive relationship with Yp, Ys, MP, GMP, YI, ATI, SSPI, and SNPI for both traits. The plot of components showed that genotypes 14, 6, 5, 4, 3, and 11 were the best ones for root yield, while genotypes 1, 3, 6, and 14 were the best ones for sugar yield, respectively. It seems that the MP, GMP, and STI indices can better distinguish the group A genotypes from the others. Also, for both yield traits, full sibs 1, 3, and 6 showed higher yield in both normal and saline environments.

Keywords: Full-sib, Indices, Salinity, Sugar yield

Abbreviation: Yp: Yield in normal condition, Ys: Yield in saline stress condition, SSI: Stress sensitivity index, RSI: Relative saline index, TOL: Tolerance index, MP: Mean productivity index, GMP: Geometric mean productivity index, STI: Stress tolerance index, YI: Yield index, YSI: Yield stability index, SI: Saline resistance index, ATI: Abiotic tolerance index, SSPI: Stress sensitivity percentage index, SNPI: Non-stress and stress environmental product index.

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Introduction

High concentration of salt in water and soil is one of the major factors limiting the growth and production of plants all over the world (Arzani, 2008) and is a global environmental challenge affecting crop production over 800 million hectares, or 25 to 33 percent of the world’s total arable land (Rengasamy, 2006). Depending on the plant species, yield reduction in the face of environmental stress, especially drought and salinity, has been reported between 50 and 80 percent (Fita *et al.*, 2015). Among the primary effects of salinity stress, can mention water scarcity and ion imbalance, and its secondary effects include reduced growth, reduced photosynthesis, production of active oxygen species, disruption of membranes, reduced enzyme activity, and cell metabolic activity. Osmotic stress occurs rapidly in

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the initial phase of stress, and ionic stress occurs slowly in the second phase of stress, which causes the death of plant cells at high levels of salinity stress (Horie *et al*., 2012; Munns and Tester, 2008). Salinity can limit plant growth due to low water potential, toxicity, and ionic imbalance (Munns *et al.*, 2006). The effect of each of these factors is different in relation to genotype and environmental conditions. Many efforts have been made to develop salinity-tolerant genotypes through methods of breeding and gene transfer from wild salinity tolerant genotypes to different crops (Shannon, 1984).

Salinity tolerance is certainly affected by a number of morphological, physiological, biochemical, and molecular attributes in plants (Arzani and Ashraf, 2016). Although root yield is the most reliable trait for selecting salinity tolerance in sugar beet, its implication has been hindered by two factors. First, the repeatability and efficiency of such selection criteria are adversely influenced by the genotype × environment interactions (Arzani, 2008). Second, sugar beet is a biennial crop species with a 2-year life cycle, which leads to a longer generation time in the breeding programs.

Drought and salinity stress occur simultaneously in many regions, and due to the increasing trend of drying up of rivers and salinization of agricultural lands, it is necessary to identify genotypes tolerant to these two stresses. In recent years, significant genetic diversity in sugar beet (*Beta vulgaris* L.) germplasm has been obtained in drought tolerance and water use efficiency during periodic selections (Taleghani, 2016). So far, a limited number of salinity-tolerant cultivars have been introduced in tuberous plants such as sugar beets because salt stress management is a multidimensional management in the field of breeding tolerant plants, crop management, and the use of plant protection materials (Chourasia *et al*., 2022). Sugar beet has a high capacity for osmotic adjustment due to its long vegetative period, without a delicate flowering stage, and having a deep root system, and it tolerates drought and soil salinity conditions (Dunham, 1993). Sugar beet with a tolerance threshold of 7 dS m^{-1} is on the list of salt-tolerant plants. In areas where, because of the salinity of water and soil, it is not possible to grow other plants, sugar beet can be cultivated (Lauchli and Epstein, 1990). Due to reduced sugar beet yield under salinity stress conditions, economic production in saline conditions is one of the major goals of breeding programs (Ober and Rajabi, 2010). One of the important problems in improving salinity tolerance is the complexity of salinity tolerance and lack of effective criteria and methods for selection of tolerant genotypes.

The selection of salinity-tolerant genotypes in sugar beet has been reported by several researchers (Abbasi *et al*., 2018; Anagholi *et al*., 2018; Khayamim and Noshad, 2012; Khayamim *et al*., 2021, 2014). Achieving a genetic increase in yield under stress conditions has been identified to be an important challenge for breeders, while advances in yield have been higher in desirable environments (Richards *et al.*, 2002). The indices that provide a measure of stress based on yield loss under stress conditions in comparison to normal conditions have been used for screening stress tolerant genotypes (Mitra, 2001). These criteria are either based on stress tolerance or sensitivity of genotypes (Fernandez, 1992). Different quantitative indices have been suggested for the selection of genotypes based on their yield in stress and normal conditions. Based on the mentioned indices, genotypes are compared in normal and stress conditions (Taghian and Abo-Elwafa, 2003).

Different strategies have been proposed for the selection of relative stress tolerance and resistance; so, some researchers have proposed selection under non-stress conditions (Richards, 1996; Rajaram and Van Ginkle, 2001; Betran *et al.,* 2003), others have suggested selection in the target stress conditions (Ceccarelli and Grando, 2000; Rathjen, 1994), while several of them have chosen the middle way and believe in selection under both non-stress and stress conditions (Fischer and Maurer, 1978; Clarke *et al*., 1992; Fernandez, 1992; Byrne *et al*., 1995; Rajaram and Van Ginkle, 2001). Therefore, identifying genotypes that are adaptable in any stress and non-stress environment and produce acceptable yields are useful for breeding purposes and are of particular importance.

The aim of this study was to evaluate the tolerance of sugar beet genotypes to saline conditions using tolerance indices and also to identify the best stress tolerance indices to evaluate the susceptibility and tolerance of sugar beet genotypes. Then, the relationship between these indices for use in breeding programs was studied**.**

Material and methods

In both saline and control conditions, two series of full-sib families (obtained from a multigerm, open-pollinated population named) along with control cultivars were studied in separate experiments at Miandoab Agricultural and Natural Resources Research Station, West Azerbaijan, Iran (Table 1). Table 2 presents some of the physical and chemical properties of the field soil. The experiment was conducted in a randomized complete block design with 3 replications. Each experimental plot consisted of three rows with a length of 7 m and a distance of 50 cm. In both normal and saline conditions, soil preparation operations, including tillage, fertilizer application, irrigation, weed and pest control, etc. were carried out as usual. Finally, the sugar beet root yield (RY) and sugar yield (SY) were determined after harvest.

Before analyzing the variance, normality of data was assessed. Combined analysis of variance was then performed (environment and genotype as test factors) with three replications.

Several quantitative indices have been used for the selection of genotypes based on their performance in

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Table 1. Full-sib families examined in drought and normal experiments

No	Genotype	No	Genotype	No	Genotype	No	Genotype	No	Genotype
1	S-P.1	6	S-P.7	11	S-P.14	16	SD.21	21	IR7(Drought control)
2	S-P.2	7	S-P.8	12	S-P.15	17	SD.10	22	MSC2 (salt tol.)
3	S-P.3	8	S-P.9	13	S-P.17	18	191 (Drought control)	23	MS261 (salt suscept.)
4	S-P.5	9	S-P.10	14	SD.44	19	MSCT×7233-P.29	24	8001(salt tol.)
5	S-P.6	10	S-P.11	15	SD.7	20	Gazal	25	Jolge

Table 2. Physical and chemical properties of field soil

Conditions	K (ppm)	P (ppm)	Ca (ppm)	NH_4 (ppm)	NO2 (ppm)	Mg (ppm)	Electrical conductivity Ds/m	Neutralizing substances %	Organic carbon %	Soil texture
Normal	417	13.16	5.33	13.42	20.67	3.6	1.2	7.9	0.18	Silty loam
Saline	250	8.3	14	7.42	12.51	16	18.84	8.5	0.21	Silty loam

saline and normal conditions. Since the effect of stress on root and sugar yield has been established, the quantitative saline tolerance indices were calculated using these two traits on the basis of the following equations.

Stress Sensitivity Index (SSI)=$(1–Ys_i/Yp_i)/SI$, SI =$1–(\bar{Y}s/\bar{Y}p)$ (Fischer and Maurer, 1978)

Stress Tolerance Index (STI)=$(Yp_i)\ (Ys_i)/(\bar{Y}p)^2$ (Fernandez, 1992)

Mean Productivity Index (MP)=$(Ys_i+Yp_i)/2$ (Fernandez, 1992)

Abiotic Tolerance Index (ATI)=$(Yp_i/Ys_i)/\ (\bar{Y}p/\bar{Y}s)\times(\sqrt{Yp_i}\times\sqrt{Ys_i})$ (Moosavi *et al.*, 2008)

Geometric Mean Productivity Index (GMP)=$\sqrt{Ys_i}\times Yp_i$ (Fernandez, 1992)

Tolerance Index (TOL)=$Yp_i - Ys_i$ (Rosielle and Hamblin, 1981)

Yield Stability Index (YSI)=Ys_i/Yp_i (Bouslama and Schapaugh, 1984)

Relative Saline Index (RSI)=$(Ys_i/Yp_i)/\ (\bar{Y}s/\bar{Y}p)$ (Fischer and Wood 1979)

Yield Index (YI)= $Ys_i/\bar{Y}s$ (Gavuzzi *et al.*, 1997)

Saline Resistance Index (SI)= $(Ys_i(Ys_i/Yp_i))/\bar{Y}s$ Lan (1998)

Stress non-stress production index (SNPI)=$[(\sqrt{Yp_i}+\sqrt{Ys_i})/(\sqrt{Yp_i}-\sqrt{Ys_i})]\times[\sqrt{Yp_i}\times\sqrt{Ys_i}\times\sqrt{Ys_i}]$ (Moosavi *et al.*, 2008)

Stress Susceptibility Percentage Index (SSPI) =$(Yp_i-Ys_i)/(2\times\bar{Y}p\times100)$ (Moosavi *et al.*, 2008)

Ys_i =Mean value of genotype i in saline stress conditions

Yp_i =Mean value of genotype i in normal conditions

$\bar{Y}s$ =Average yield of all genotypes in saline stress condition

$\bar{Y}p$ =Average yield of all genotypes in normal condition

Correlation analysis among the investigated saline tolerance indices with the root and sugar yield was performed to determine the best indices. Principal component analysis (PCA) was performed based on the indices. Correlation analysis and principal component analysis, based on the correlation matrix, were performed by SPSS v. 20.2.

Result and discussion

Analysis of variance: Analysis of variance showed that the difference between the two environments for root and sugar yield was significant at the 1% probability level, and saline stress reduced root and sugar yields (Table 3). Yield, as a complex quantitative trait, is widely influenced by stress environments, especially salinity and drought stresses, and in almost all studies comparing yield under stress and non-stress conditions, yield was less than optimal under stress conditions. This is because, under salinity stress, the plant consumes part of the metabolic energy produced to regulate its osmotic potential. In addition, the decrease in photosynthetic material production due to the closure of the stomata under saline conditions, as well as the restriction of their transport to the root, slows cell division and elongates the root cells, thereby reducing root weight under stress. One of the important effects of salinity on the plant is the reduction of root volume, which decreases water uptake (Mass and Hoffman, 1977). Reduction in root and sugar yields of sugar beet genotypes under saline stress compared to normal moisture conditions has also been reported by other researchers (Ebrahimian *et al.*, 2008; Winter, 1989; Dunham and Clark, 1992).

Considering the significant genotype × environment interaction and separate analysis of variance for each environment, it was found that in a normal environment, there were significant differences between full-sibs at the 1% probability level, but the difference between full-sibs was not significant under salinity stress. Root yield variations in a normal environment showed that full-sibs 16, 1, 2, 4, 7, 9, 10, 13, 18, and control cultivars 23, 24, and 25 had the highest, whereas the full-sibs 11 and 12 had the lowest root yield (Figure 1) .

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Table 3 -Combined variance of analysis and mean comparison of sugar beet full-sibs in two conditions

S. O. V	df	Mean Squares	
		Root Yield	Sugar Yield
Condition	1	735^{**}	89.1^{**}
Ea	4	1.54	0.195
Genotype	24	3.83^{**}	0.67^{**}
Condition×Genotype	24	4.27^{**}	0.72^{**}
Eb	96	1.18	0.215
CV%		17.74	18.4
Mean comparison of conditions			
Saline stress		17.96^{b}	3.4^{b}
Normal		74.4^{a}	11.3^{a}

****, * significant at 1 and 5 percent respectively**

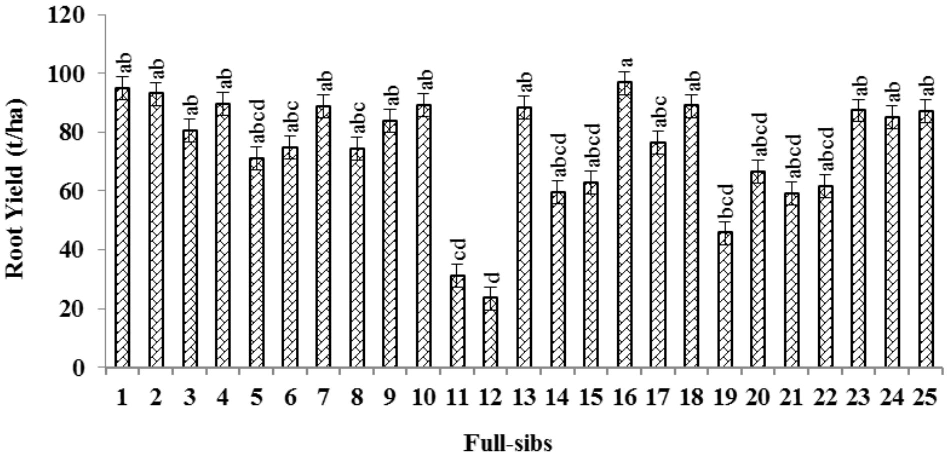

Figure 1. Root yield mean of full-sib families in normal environment

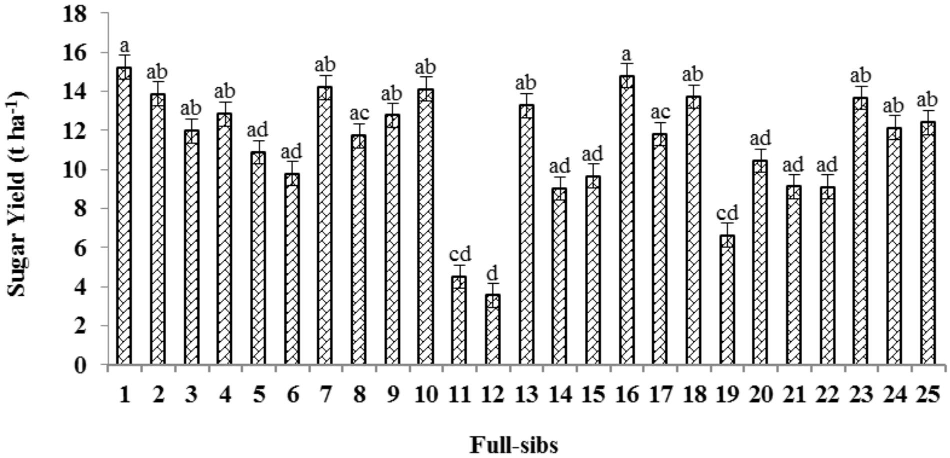

Figure 2. Sugar yield means of full-sib families in a normal environment

It was found that there were significant differences between full-sibs for sugar yield in a normal environment (Figure 2). In studying the response of sugar beet genotypes to salinity at different stages of root growth, Jahad Akbar *et al*. (2012) observed the highest root yield and white sugar yield in the treatment that received the lowest saline water and stated that increasing salinity decreased root yield and white sugar yield in genotypes.

Ober *et al*. (2005) reported a statistically significant difference between different genotypes and cultivars of sugar beet in terms of white sugar content and stated that economically and environmentally, high quality crops are obtained when the susceptibility of new cultivars to biotic and abiotic stresses is reduced.

Tolerance indices: In general, stress tolerance is a polygenic and complex trait influenced by various factors (Hasthanasombut *et al*., 2010). So, the high values of indices for a genotype are not suitable for planting under stress conditions because there are genotypes that are less susceptible to stress but have low yield.

Using the MP index, whose high numerical values indicate relative stress tolerance, often leads to the selection of high-yielding varieties in stress-free and stress conditions (Rosielle and Hamblin, 1981). Evaluation of full-sibs based on root yield using this index showed that the full-sibs 1, 2, 3, 4, 6, 7, 10, 13, and 16 were the most tolerant, whereas the full-sibs 11, 12, 15, 19, and control 22 were the most sensitive (Table 4). In terms of sugar yield, the full-sibs 1, 2, 3, 4, 6, 7, 10, 13, 16, and 17 were the most tolerant, and the full-sibs 11 and 12 were the most sensitive (Table 5).

A high GMP index indicates plant tolerance to stress. We should know that the GMP index is less sensitive to very different Ys and Yp values, while the MP index is based on the arithmetic mean. When there is a large relative difference between Ys and Yp, it will have an upward bias. Therefore, the GMP index, in comparison with the MP index, has much power in separating Group A from other groups (Fernandez, 1992). Evaluation of full-sibs based on root yield showed that the full-sibs 1, 3, 6, and control 21 were the most tolerant, whereas full-sibs 11, 12, 8, 15, 16, and control 23 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 1, 2, 3, 6, and 7 were the most tolerant, and the full-sibs 11, 12, 8, 15, 16, and controls 23 and 25 were the most susceptible (Table 5).

Various tolerance indices have been used in many studies to evaluate sugar beet genotypes under drought and salinity conditions, and in most of these studies, STI is recognized as the superior index. Ahmadi *et al*. (2011) used different indices to identify drought tolerant S1 lines and finally selected STI as the most appropriate index for grouping sugar beet lines. Sadeghian *et al*. (2000) reported STI as an effective index in the diagnosis of drought tolerant sugar beet breeding lines. Ebrahimian *et al*. (2008) studied different genotypes of sugar beet in a greenhouse and field under saline stress conditions and identified five breeding lines as salt-tolerant lines using STI. High STI values indicate high stress tolerance and high yield potential .The stress tolerance index selects genotypes with high yield under both conditions. Evaluation of full-sibs based on root yield showed that the full-sibs 1, 3, and 6 were the most tolerant, and the full-sibs 11, 12, 15, and control 23 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 1, 3, and 6 were the most tolerant, and full-sibs 11, 12, and control 23 were the most susceptible (Table 5).

High SSI values indicate plant sensitivity to stress. This index is based on the ratio of yield of each cultivar under stress to non-stress conditions in comparison to this ratio in all cultivars, so that two cultivars with high or low yield in two environments can have the same specific value. So, choosing based on this index may mislead the breeders. Selection based on SSI causes selection of low-yield genotypes under normal conditions and high-yield genotypes under stress conditions. The major disadvantage of this index is that it is not able to identify group A from group C (Fernandez, 1992). Evaluation of full-sibs based on root yield showed that the full-sibs 1, 6, 11, 12, 14, and controls 19 and 21 were the most tolerant, whereas the full-sibs 2, 4, 7, 8, 9, 10, 13, 15, 16, 17, 18, and controls 23, 24, and 25 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 6, 11, and 12 and controls 19 and 21 were the most tolerant, and the full-sibs 8, 15, 16, and 17 and controls 23 and 25 were the most susceptible (Table 5).

A high TOL index indicates susceptibility of the plant to stress. Evaluation of full-sibs based on root yield showed that the full-sibs 6, 11, 12, 14, and controls 19 and 21 were the most tolerant, while the full-sibs 2, 4, 10, 16, and controls 18, 23, and 25 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 6, 11, 12, 14, and controls 19 and 21 were the most tolerant, and the full-sib 16 and controls 18, 23, and 25 were the most susceptible (Table 5).

YI, proposed by Gavuzzi *et al*. (1997), was significantly correlated with stress yield. This index ranks genotypes only on the basis of their yield under stress conditions, so it does not discriminate genotypes of group A. Therefore, it does not recognize high-yielding genotypes under both stress and non-stress conditions (Sio-Se Marde *et al*., 2006). Evaluation of full-sibs based on root yield showed that the full-sibs 1, 3, 6, and control 21 were the most tolerant, whereas the full-sibs 8, 12, 15, 16, and controls 18, 23, and 25 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 1, 3, 6 and controls 19 and 21 were the most tolerant, and the full-sibs 8, 15, 16 and controls 23 and 25 were the most susceptible (Table 5).

Relative Saline Index (RSI) values higher than one indicate that the genotype of interest is partially resistant, whereas values lower than one show that the genotype is susceptible. Evaluation of full-sibs based on root yield showed that the full-sibs 1, 3, 6, 11, 12 and controls 19, 21 were the most tolerant, and the full-sibs 8, 13, 14, 15, 16, 17 controls 18, 23, 24, 25 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 1, 3, 6, 11, 12 and controls 19, 21 were the most tolerant, and the full-sibs 8, 15, 16, and controls 23, 25 were the most susceptible (Table 5).

Yield Stability Index (YSI) was presented by Bouslama and Schapagh (1984). Higher YSI genotypes are expected to have high yield under stress conditions. Evaluation of full-sibs based on root yield showed that the full-sibs 6, 11, 12 and control 21 were the most tolerant, and the full-sibs 2, 8, 10, 15, 16, 17 and controls 23, 24, 25 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 1, 3, 6, 11, 12, 14 and controls 19, 21 were the most tolerant, and the full-sibs 8, 15, 16 and controls 18, 23, 25 were the most susceptible (Table 5).

Saline Resistance Index (SI) identifies genotypes that are adapted to stress and non-stress conditions. Evaluation of full-sibs based on root yield showed that the full-sibs 1, 6 and control 21 were the most tolerant, whereas the full-sibs 2, 4, 5, 8, 10, 13, 15, 16, 17, and controls 18, 20, 23, 24, 25 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 1, 3, 6,

Table 4. Quantities of Yp, Ys and investigated indices for root yield in the studied genotypes

Ge.	Yp	Ys	SSI	RSI	TOL	MP	STI	GMP	YI	YSI	SI	ATI	SSPI	SNPI
1	94.8	36.2	0.88	1.29	58.6	65.5	0.62	58.6	1.65	0.38	0.63	2297.4	0.57	65.3
2	93.1	17.9	1.15	0.65	75.2	55.5	0.3	40.8	0.81	0.19	0.16	2049.8	0.73	35.3
3	80. 6	27.1	0.94	1.14	53.5	53.8	0.39	46.7	1.23	0.34	0.41	1670.2	0.52	49.2
4	89.6	17.7	1.14	0.67	71.9	53. 7	0.29	39.9	0.81	0.2	0.16	1915.6	0.69	34.8
5	71	16.3	1.09	0.78	54. 7	43. 7	0.21	34.1	0.74	0.23	0.17	1245.2	0.53	31.2
6	74.6	37.4	0.71	1.7	37.2	56	0.5	52.8	1.7	0.5	0.85	1314.9	0.36	68.0
7	88.8	19.1	1.11	0.73	69.7	53.9	0.31	41.2	0.87	0.21	0.19	1917.4	0.67	36.8
8	74.4	11.2	1.21	0.51	63.2	42.8	0.15	28.8	0.51	0.15	0.08	1219.4	0.61	23.3
9	83.9	17.5	1.12	0.7	66. 5	50.7	0.27	38.3	0.8	0.21	0.17	1702.2	0.64	34.0
10	89.2	17.1	1.15	0.65	72.2	53	0.28	39	0.78	0.19	0.15	1882.7	0.7	33.7
11	31.1	16.9	0.65	1.84	14.1	24	0.09	22.9	0.77	0.54	0.42	216.7	0.14	31.1
12	23.5	12.9	0.64	1.87	10.5	18.2	0.05	17.4	0.59	0.55	0.32	122.5	0.1	23.9
13	88.4	16	1.16	0.61	72.4	52.2	0.26	37.6	0.73	0.18	0.13	1820.3	0.7	32.0
14	59.4	24.8	0.83	0.41	34.6	42.1	0.27	38.4	1.13	0.42	0.47	888.8	0.33	44.7
15	62.8	9.8	1.2	0.53	53	36.3	0.11	24.8	0.45	0.16	0.07	880.9	0.51	20.3
16	96.7	7.2	1.31	0.25	89.5	52	0.13	26.4	0.33	0.07	0.02	1581.3	0.86	18.0
17	76.4	14	1.16	0.62	62.4	45.2	0.19	32.7	0.64	0.18	0.12	1365.7	0.6	27.9
18	88.9	12	1.23	0.46	76.9	50.5	0.19	32.7	0.55	0.14	0.07	1682.9	0.74	25.7
19	45.7	21.4	0.75	1.59	24.3	33.6	0.18	31.3	0.98	0.47	0.46	507.9	0.23	38.8
20	66.6	15.9	1.08	0.81	50.7	41.2	0.19	32.5	0.72	0.24	0.17	1102.2	0.49	30.1
21	59.2	32.2	0.65	1.84	26.9	45.7	0.34	43.7	1.47	0.54	0.8	787.2	0.26	59.3
22	61.7	15.9	1.05	0.87	54.8	38.8	0.18	31.3	0.72	0.26	0.19	957.8	0.44	29.7
23	87.3	4.5	1.35	0.18	82.8	45.9	0.07	19.9	0.21	0.05	0.01	1101	0.8	12.6
24	85.2	16.4	1.15	0.65	68.8	50.8	0.25	37.3	0.75	0.19	0.14	1717.7	0.66	32.3
25	87.2	11.4	1.23	0.44	75.7	49.3	0.18	31.6	0.52	0.13	0.07	1599	0.73	24.6

Yp: Yield in normal condition, Ys: Yield in saline stress condition, SSI: Stress sensitivity index, RSI: Relative saline index, TOL: Tolerance index, MP: Mean productivity index, GMP: Geometric mean productivity index, STI: Stress tolerance index, YI: Yield index, YSI: Yield stability index, SI: Saline resistance index, ATI: Abiotic tolerance index, SSPI: Stress sensitivity percentage index, SNPI: Non-stress and stress environmental product index.

****, * significant at 1 and 5 percent probability levels, respectively.**

Table 5. Quantities of Yp, Ys and investigated indices for sugar yield in the studied genotypes

Ge.	Yp	Ys	SSI	RSI	TOL	MP	STI	GMP	YI	YSI	SI	ATI	SSPI	SNPI
1	94.8	36.2	0.88	1.29	58.6	65.5	0.62	58.6	1.65	0.38	0.63	2297.4	0.57	65.3
2	93.1	17.9	1.15	0.65	75.2	55.5	0.3	40.8	0.81	0.19	0.16	2049.8	0.73	35.3
3	80. 6	27.1	0.94	1.14	53.5	53.8	0.39	46.7	1.23	0.34	0.41	1670.2	0.52	49.2
4	89.6	17.7	1.14	0.67	71.9	53. 7	0.29	39.9	0.81	0.2	0.16	1915.6	0.69	34.8
5	71	16.3	1.09	0.78	54. 7	43. 7	0.21	34.1	0.74	0.23	0.17	1245.2	0.53	31.2
6	74.6	37.4	0.71	1.7	37.2	56	0.5	52.8	1.7	0.5	0.85	1314.9	0.36	68.0
7	88.8	19.1	1.11	0.73	69.7	53.9	0.31	41.2	0.87	0.21	0.19	1917.4	0.67	36.8
8	74.4	11.2	1.21	0.51	63.2	42.8	0.15	28.8	0.51	0.15	0.08	1219.4	0.61	23.3
9	83.9	17.5	1.12	0.7	66. 5	50.7	0.27	38.3	0.8	0.21	0.17	1702.2	0.64	34.0
10	89.2	17.1	1.15	0.65	72.2	53	0.28	39	0.78	0.19	0.15	1882.7	0.7	33.7
11	31.1	16.9	0.65	1.84	14.1	24	0.09	22.9	0.77	0.54	0.42	216.7	0.14	31.1
12	23.5	12.9	0.64	1.87	10.5	18.2	0.05	17.4	0.59	0.55	0.32	122.5	0.1	23.9
13	88.4	16	1.16	0.61	72.4	52.2	0.26	37.6	0.73	0.18	0.13	1820.3	0.7	32.0
14	59.4	24.8	0.83	0.41	34.6	42.1	0.27	38.4	1.13	0.42	0.47	888.8	0.33	44.7
15	62.8	9.8	1.2	0.53	53	36.3	0.11	24.8	0.45	0.16	0.07	880.9	0.51	20.3
16	96.7	7.2	1.31	0.25	89.5	52	0.13	26.4	0.33	0.07	0.02	1581.3	0.86	18.0
17	76.4	14	1.16	0.62	62.4	45.2	0.19	32.7	0.64	0.18	0.12	1365.7	0.6	27.9
18	88.9	12	1.23	0.46	76.9	50.5	0.19	32.7	0.55	0.14	0.07	1682.9	0.74	25.7
19	45.7	21.4	0.75	1.59	24.3	33.6	0.18	31.3	0.98	0.47	0.46	507.9	0.23	38.8
20	66.6	15.9	1.08	0.81	50.7	41.2	0.19	32.5	0.72	0.24	0.17	1102.2	0.49	30.1
21	59.2	32.2	0.65	1.84	26.9	45.7	0.34	43.7	1.47	0.54	0.8	787.2	0.26	59.3
22	61.7	15.9	1.05	0.87	54.8	38.8	0.18	31.3	0.72	0.26	0.19	957.8	0.44	29.7
23	87.3	4.5	1.35	0.18	82.8	45.9	0.07	19.9	0.21	0.05	0.01	1101	0.8	12.6
24	85.2	16.4	1.15	0.65	68.8	50.8	0.25	37.3	0.75	0.19	0.14	1717.7	0.66	32.3
25	87.2	11.4	1.23	0.44	75.7	49.3	0.18	31.6	0.52	0.13	0.07	1599	0.73	24.6

Yp: Yield in normal condition, Ys: Yield in saline stress condition, SSI: Stress sensitivity index, RSI: Relative saline index, TOL: Tolerance index, MP: Mean productivity index, GMP: Geometric mean productivity index, STI: Stress tolerance index, YI: Yield index, YSI: Yield stability index, SI: Saline resistance index, ATI: Abiotic tolerance index, SSPI: Stress sensitivity percentage index, SNPI: Non-stress and stress environmental product index.

****, * significant at 1 and 5 percent probability levels, respectively.**

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11 and controls 11, 21 were the most tolerant, and the full-sibs 8, 13, 15, 16, 17 and controls 18, 23, 25 showed the highest susceptibility (Table 5).

The Abiotic Tolerance Index (ATI) is used to identify high-yielding genotypes under stress and non-stress conditions and can separate B and C groups from each other. This index takes into account stress intensity and yield values in two environments and can distinguish group A genotypes from other genotypes and is, therefore, an appropriate index for the selection of stress-tolerant genotypes. This index is a suitable criterion for the selection of drought-tolerant genotypes because it selects genotypes that perform well in both stress and non-stress environments. The high value of this index for the genotype indicates more drought tolerance and higher potential yield of the genotype (Fernandez, 1992). Evaluation of full-sibs based on root yield showed that the full-sibs 1, 2, 4, 6 were the most tolerant, whereas the full-sibs 11, 12, 14, 15 and the controls 19, 21, 21 were the most susceptible (Table 4). In terms of sugar yield, the full-sibs 1, 2, 7, and 10 were the most tolerant, and controls 6, 11, 12, 19, and 21 were the most susceptible (Table 5).

The indicators mentioned have been used in many studies, but most of them have disadvantages ,especially because they cannot easily separate the Fernandez groups (Moosavi *et al*., 2008). In this regard, Moosavi *et al*. (2008) introduced two new, better-performing indices: The "Stress Sensitivity Percentage Index" (SSPI), which is capable of separating relatively tolerant genotypes from non-tolerant genotypes, is better than the previous ones, and the Non-stress and Stress Environmental Product Index (SNPI), which is capable of isolating Group A genotypes and emphasizes high and stable yield in both environments. According to the SSPI index, despite calculating the difference between the two environments compared to non-stress environments, the results are similar to those of the abiotic tolerance index and would be more reliable for screening genotypes of both environments. Evaluation of full-sibs based on root yield showed that full-sibs 2, 4, 7, 8, 9, 10, 13, 16, and controls 18, 23, 24, 25 were the most tolerant, and full-sibs 11, 12, 14 and controls 19, 21 were the most susceptible (Table 4). In terms of sugar yield, full-sibs 2, 7, 10, 13, 16 and controls 18, 23, 25 were the most tolerant, and the full-sibs 6, 11, 12 and controls 19, 21, and 25 were the most susceptible (Table 5).

In the SNPI Index, the ratio of stress to non-stress environment was used to identify tolerant and susceptible genotypes, and the genotypes with less variation in both environments, regardless of the quantity of each environment, had the highest rank. However, SSPI, SNPI and ATI indices have been introduced for screening drought-tolerant genotypes under both stress and non-stress conditions (Moosavi *et al*., 2008). The SNPI index separates genotypes based on their two traits, having relatively acceptable yield under stress and non-stress conditions and also yield stability (with more emphasis on yield in stress condition than in non-stress condition). The strong and significant correlation of this index with yield under stress condition shows the importance of this index to the amount of yield of stress conditions while paying attention to the yield under non-stress conditions (Jalalifar *et al.,* 2012). Evaluation of full-sibs based on root yield showed that the full-sibs 1, 3, 6 and control 21 were the most tolerant whereas the full-sib 15, 16 and control 23 displayed the highest susceptibility (Table 4). In terms of sugar yield, the full-sibs 1, 3, 6 and control 21 were the most tolerant and the full-sibs 8, 15, 16 control 23 were the most susceptible (Table 5).

Correlation analysis: Positive correlation between the two selection indices means that selection based on one index for stress tolerance can be related to selection based on the second index. In other words, the performance of the two indicators is similar. Now, if several indicators have positive and significant correlations, in some cases, one of them can be used instead of the others. Now, if several indices have a significant negative correlation, this indicates that one of them can still be used instead of the other.

In calculating the correlation between indices, the full-sibs root and sugar yield were used. Weak correlations between root and sugar yield were observed under normal and saline conditions. This correlation indicates a weak relation between yields in the two conditions. Due to this weak relation, breeding for these traits under the two conditions cannot be performed simultaneously. In this case, high-yielding genotypes under normal conditions may not be successful in saline stress conditions (Fernandez, 1992).

The MP, STI, and GMP indices had significant positive correlation with both root yield and sugar yield under both normal and stress conditions (Table 6). Given the high correlations, these indices appear to be suitable criteria for the selection of superior genotypes. According to Fernandez (1992), the most appropriate criterion for stress tolerance should be able to distinguish group A genotypes from the other groups. According to the point mentioned and the fact that the best indices are those that are highly correlated with yield under both stress and non-stress conditions, it is observed that GMP, MP, and STI indices have this property. Therefore, genotypes with high levels of these indices are recognized as tolerant ones.

The SSI, TOL, and SSPI indices had positive correlation under normal conditions and negative correlation under stress conditions with root and sugar yield (Table 6), so genotypes with lower values of these indices should be selected as tolerant genotypes. Genotypes selected based on high values of these indices have high yield under normal conditions, but their yield is low under saline stress, so selection on the basis of these indices is not recommended.

The RSI and YSI indices had positive correlation under saline stress and negative correlation under normal conditions with root and sugar yield (Table 6),

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Table 6. Simple correlation coefficients for Yp, Ys and investigated indices

		YP	YS	SSI	RSI	TOL	MP	STI	GMP	YSI	SI	ATI	SSPI	SNPI
YP	RY	1												
	SY	1												
YS	RY	-0.05	1											
	SY	-0.01	1											
SSI	RY	0.73**	-0.68**	1										
	SY	0.72**	-0.67**	1										
RSI	RY	-0.67**	0.61**	-0.93**	1									
	SY	-0.72**	0.67**	-1**	1									
TOL	RY	0.92**	-0.43*	0.93**	-0.85**	1								
	SY	0.89**	-0.46*	0.94**	-0.94**	1								
MP	RY	0.92**	0.42*	0.42*	-0.39	0.69**	1							
	SY	0.89**	0.45*	0.39	-0.34	0.59**	1							
STI	RY	0.42*	0.87**	-0.26	0.24	0.04	0.74**	1						
	SY	0.45*	0.86**	-0.24	0.24	0.02	0.8**	1						
GMP	RY	0.46*	0.85**	-0.21	0.18	0.09	0.77**	0.99**	1					
	SY	0.49*	0.85**	-0.19	0.19	0.05	0.83**	0.98**	1					
YI	RY	-0.05	1**	-0.68*	0.61**	-0.43*	0.35	0.87**	0.85**	1				
	SY	-0.01	1**	-0.66**	0.67**	-0.46*	0.45*	0.86**	0.85**	1				
YSI	RY	-0.73**	0.68**	-1**	0.92**	-0.93**	-0.42*	0.26	0.21	0.68**	1			
	SY	-0.72**	0.67**	-1**	1**	-0.94**	-0.34	0.24	0.19	0.67**	1			
SI	RY	-0.36	0.91**	-0.87**	0.8**	-0.68**	0.03	0.63**	0.58**	0.92**	0.87**	1		
	SY	-0.36	0.89**	-0.87**	0.87**	-0.72**	0.09	0.57**	0.53**	0.897**	0.87**	1		
ATI	RY	0.94**	0.13	0.57**	-0.5*	0.79**	0.93**	0.59**	0.63**	0.13	-0.57**	-0.54	1	
	SY	0.94**	0.08	0.62**	-0.61**	0.08**	0.88**	0.55**	0.58**	0.08	-0.61**	-0.34	1	
SSPI	RY	0.93**	-0.43*	0.92**	-0.84**	1**	0.7**	0.05	0.09	-0.43*	-0.92**	-0.67**	0.8**	1
	SY	0.89**	-0.46*	0.94**	-0.94**	1**	0.59**	0.01	0.05	-0.46*	-0.94**	-0.72**	0.8**	1
SNPI	RY	0.01	1**	-0.64**	0.58**	-0.38	0.41*	0.89**	0.87**	1**	0.64**	0.9**	0.18	-0.37
	SY	-0.03	1**	-0.69**	-0.69**	-0.47*	0.43*	0.84**	0.82**	1**	0.69**	0.92**	0.04	-0.48*

RY: Root Yield, SY: Sugar Yield

Yp: Yield in normal condition, Ys: Yield in stress condition, SSI: Stress sensitivity index, RDI: Relative drought index, TOL: Tolerance index, MP: Mean productivity index, GMP: Geometric mean productivity index, STI: Stress tolerance index, YI: Yield index, YSI: Yield stability index, SI: Saline resistance index, ATI: Abiotic tolerance index, SSPI: Stress sensitivity percentage index, SNPI: Stress non-stress production index.

****, * significant at 1 and 5 percent probability levels, respectively.**

so genotypes with high values of these indices should be selected as saline-tolerant genotypes.

The SIT, YI, and SNPI indices were positively and significantly correlated with root and sugar yield under stress conditions, but this correlation was not significant under normal condition genotypes. Therefore, these two indices can identify high-yielding genotypes under saline stress conditions.

The ATI index showed significant positive correlation with root and sugar yield under normal conditions, but this index did not show significant correlation with both traits under saline stress conditions (Table 6).

Principal component analysis: The principal component analysis is mostly used for grouping cultivars and genotypes and is, in fact, a complement to cluster analysis. This method is usually performed before cluster analysis to determine the relative importance of the variables involved in the grouping. Principal component analysis (PCA) showed that in root yield, the first two principal components explained 52.18% and 32.16% of variation for Yp, Ys, and investigated indices, respectively. For sugar yield, the first two principal components explained 55.67% and 42.02% of variation, respectively (Table 7).

In both yield traits, the first component had a high positive relationship with Ys, RSI, YI, YSI, and SI and had a high negative relationship with YP, SSI, TOL, ATI, and SSPI. The second component showed a positive relationship with Yp, Ys, MP, GMP, YI, ATI, SSPI, and SNPI for both traits (Table 7). Therefore, for the two traits, selection based on the first component will have genotypes with lower SSI, TOL, ATI, and SSPI and higher Ys, RSI, STI, GMP, YI, YSI, and SI indices. Also, selection based on the second component will have genotypes with higher Yp, Ys, MP, STI, GMP, YI, ATI, SSPI, and SNPI indices.

Plot of components showed that the full-sibs 1, 3, 6, 14, and control 21 were the best genotypes for root yield, whereas the full-sibs 1, 3, 6 and control 21 were the best ones for sugar yield, respectively. In general, the results of grouping the two traits seem to have many similarities (Figure 3).

Ranking method: Fernandez (1992) divided genotypes into four groups on the basis of genotypes yield in two stress and non-stress environments.

1- Genotypes that have the same expression in stress and non-stress environments (Group A).

2- Genotypes with only good performance in non-stress environment (group B).

3- High yielding genotypes in stress environment (group C).

4- Genotypes with poor expression in both environments (Group D).

According to Fernandez (1992), the most appropriate selection criterion for stress is the criterion

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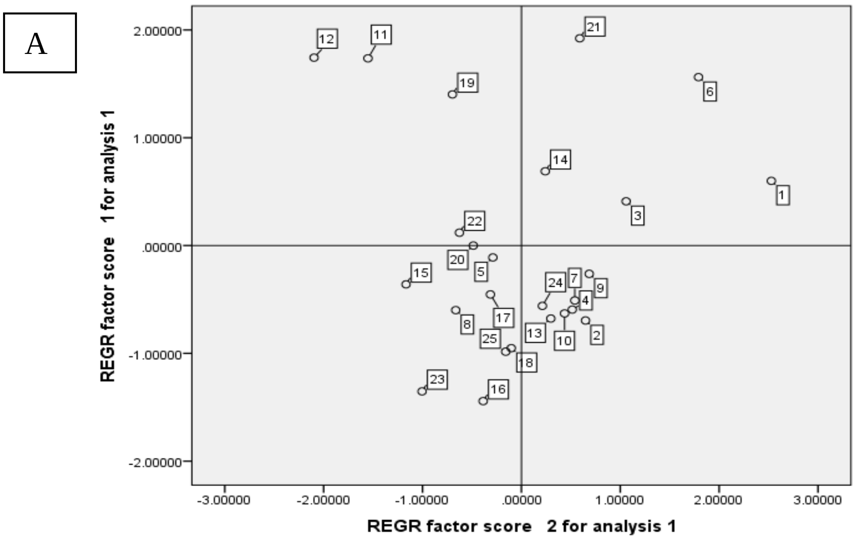
Table 7: First two component quantities for Yp, Ys and investigated indices in root and sugar yield

Trait	PC	%Var	YP	YS	SSI	RSI	TOL	MP	STI	GMP	YI	YSI	SI	ATI	SSPI	SNPI
RY	1	52.18	-0.77	0.65	-0.99	0.93	-0.95	-0.47	0.22	0.17	0.65	0.99	0.85	-0.64	-0.77	0.30
	2	39.39	0.62	0.75	-0.05	0.03	0.27	0.87	0.96	0.97	0.75	0.05	0.46	0.66	0.62	0.53
SY	1	55.67	-0.64	0.77	-0.98	0.98	-0.91	-0.22	0.36	0.32	0.77	0.98	0.93	-0.55	-0.66	0.77
	2	42.02	0.76	0.64	0.12	-0.12	0.39	0.97	0.92	0.93	0.64	-0.12	0.29	0.79	0.74	0.62

Yp: Yield in normal condition, Ys; Yield in stress condition

RY: Root yield, SY: Sugar yield, SSI: Stress sensitivity index, RSI: Relative Saline index, TOL: Tolerance index, MP: Mean productivity index, GMP: Geometric mean productivity indexes, STI: Stress tolerance index, YI: Yield index, YSI: Yield stability index, SI: Saline resistance index, ATI: Abiotic tolerance index, SSPI: Stress sensitivity percentage index, SNPI: Stress non-stress product index.

****, * significant at 1 and 5 percent probability levels, respectively.**



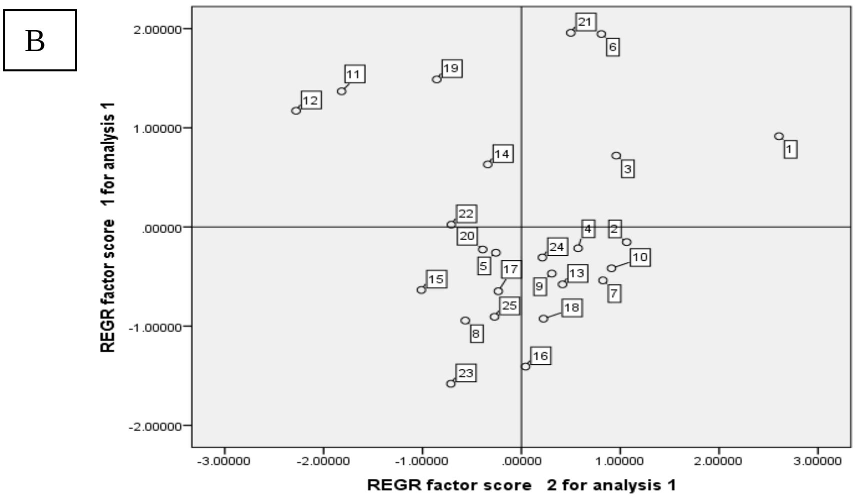


Figure 3. Principal component analysis using indices calculated in two traits of root and sugar yield. A: Principal component analysis for root yield, B: Principal component analysis for sugar yield

that can distinguish group A from the other groups.

According to Fernandez's theory of grouping genotypes and according to genotypes expression under saline and normal conditions, different genotypes for the two yield traits were categorized in Table 8. As mentioned, an appropriate index is the one that can distinguish genotypes belonging to the group A from the others. Accordingly, for both yield traits, the full-sibs 1, 3 and 6 showed higher yield in both normal and saline environments.

Conclusion

Stability of yield and its components under stress conditions are still the main indicators of stress-tolerant genotypes in many breeding programs .Yield is subject to several conditions, such as planting date, density, fertilizer amount, irrigation, growth type, and soil and water conditions. By changing these conditions, the

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Table 8. Grouping of genotypes based on Fernandez method

Group	Yield		Root Yield	Sugar Yield
	Stress	Normal		
A	High	High	1, 3, 6	1, 2, 3, 6
B	High	Low	2, 4, 5, 7, 8, 9, 10, 13, 15, 16, 17, 18, 20, 22, 23, 24, 25	4, 5, 7, 8, 9, 10, 13, 16, 17, 18, 20, 23, 24, 25
C	Low	High	14, 19, 21	14, 19, 21
D	Low	Low	11, 12	11, 12, 15, 22

yield of these genotypes will change, but there is no difficulty in identifying tolerant and susceptible genotypes through indices, because the basis of calculation of indices is the ratio of yield under stress and normal conditions. So, if these conditions cause a change in yield, this change applies equally to both stress and normal conditions. Therefore, these indices are used as suitable criteria for the identification of tolerant genotypes. These indices include crop yield in stress and non-stress environments.

According to the results of the study of different indices based on the yields of genotypes under stress and normal conditions, it seems that the MP, GMP, and STI indices can better distinguish the A group genotypes from the others. Therefore, these indices can be used to select superior sugar beet genotypes in saline conditions. On the other hand, for both yield traits, the full-sibs 1, 3, and 6 showed higher yield in both normal and saline environments. Therefore, these genotypes can be used for subsequent crossing with single-cross female parents towards the development of salt-tolerant hybrid varieties.

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