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Evaluation of grain yield stability of irrigated barley (*Hordeum vulgare* L.) promising lines in salinity affected regions of moderate climate of Iran

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ABSTRACT

Salinity stress represents a significant abiotic factor that adversely impacts crop production. Although barley is recognized as a salinity-resistant species, all stages of its growth are susceptible to the detrimental effects of salinity stress. The present study aimed to identify promising irrigated barley lines exhibiting high grain performance and stability under conditions of salinity stress. Eighteen promising barley lines, along with two local checks (the Golshan cultivar and MBS-98-10), were evaluated across three saline regions (Yazd, Isfahan, and Birjand) during the 2021-22 and 2022-23 cropping seasons. The results of the combined analysis of variance for grain yield indicated no significant effects for year, genotype×location, and genotype×year interactions; however, significant effects were observed for location, genotype, year×location, and genotype×year×location interactions. Mean comparison results revealed that genotypes G8, G4, G11, G13, and G14 exhibited the highest grain yields relative to the other genotypes. To assess yield stability, both non-parametric parameters ($S^{(1)}$, $S^{(2)}$, $S^{(3)}$, and $S^{(6)}$) and parametric parameters (coefficient of variance, Shukla's stability variance, Wricke's Ecovalence, and Kang's rank-sum) were employed. The findings identified genotypes G4, G13, and G14 as lines with desirable and stable yields, which may not only serve as new cultivars in salinity-affected regions but also contribute to future breeding programs aimed at developing new salt-tolerant barley lines.

Key words: Non-parametric stability, Parametric stability, Salinity stress.

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INTRODUCTION

Barley (*Hordeum vulgare* L.) is a cereal crop that is extensively cultivated across diverse environmental conditions due to its superior tolerance to abiotic stresses compared to other cereal crops. It ranks as the fourth most important cereal globally, while in Iran, it is the second most cultivated crop in terms of area. The total area under barley cultivation in Iran, encompassing cold, moderate, and warm regions, is estimated to be 1,439,778 ha, yielding a production of 2,478,886 t (Anonymous, 2022). Barley exhibits a high level of adaptability and resilience to various biotic and abiotic stresses, including salinity stress, which enhances its suitability for production in different regions. The grain of barley is nutritionally valuable, containing essential minerals such as phosphorus and calcium, moderate amounts of protein, small quantities of vitamins—particularly B vitamins—and dietary fiber, making it widely utilized in both the feed and food industries (Pour-Aboughadareh *et al.,* 2023). Salinity represents a significant challenge to agriculture worldwide, leading to considerable reductions in crop yields both globally and within Iran. Currently, approximately one billion ha of the Earth's surface (7%) are affected by salinity stress; however, the extent to which this land is utilized for crop production remains unclear (Hopmans *et al.,* 2021). Iran is recognized as one of the countries most severely impacted by salinity stress, with an estimated 6.8 million hectares of saline land (Moameni, 2010). Factors contributing to soil salinization include inappropriate irrigation practices and excessive application of nutrients and chemical fertilizers. The presence of salts in saline soils inhibits plants' ability to absorb water and nutrients, leading to water deficiency and dehydration. Salinity stress adversely affects both physiological and morphological traits of plants. Additionally, it disrupts ion homeostasis by altering the concentrations of sodium (Na+) and potassium (K+) ions (Khalily and Naghavi, 2020).

Abiotic stress, specifically salinity, induces two distinct types of stress in plants. The first type occurs when salt accumulates around the roots, leading to a decrease in water availability and the onset of osmotic stress. This condition reduces the transfer of water from the soil to the roots, ultimately resulting in diminished shoot growth. The second type of stress, known as ionic stress, arises when the concentrations of cytosolic sodium and chloride increase in developing leaves (Munns *et al.,* 1995). In the context of salinity stress, ionic homeostasis is one of the tolerance mechanisms that becomes disrupted. Plants employ various protective strategies to maintain ion homeostasis, including the exclusion of Na+ (Munns and Tester, 2008). One such strategy involves establishing a balance between the concentrations of Na+ and K+ in different plant tissues.

The utilization of genetic diversity in crops and pastures to identify cultivars that exhibit tolerance to salinity stress represents an effective approach for managing this environmental challenge (Ranjbar and Pirasteh-Anosheh, 2015; Shahmoradi *et al.,* 2018). One of the most efficient strategies for mitigating the adverse effects of salinity is the cultivation of salinity-tolerant cultivars. Barley, recognized as one of the most salinity-tolerant crops, is extensively cultivated in areas affected by salinity; however, salinity stress impacts all growth stages of this crop, leading to a reduction in yield. Among the various barley cultivars, significant variation exists in salinity stress tolerance, which can be leveraged to introduce more resilient cultivars (Kharub *et al.,* 2013). Currently, three salinity-tolerant barley cultivars—Khatam (Ghazvini *et al.,* 2016), Mehr (Nikkhah *et al.,* 2018), and Golshan (Barati *et al.,* 2020)—are being cultivated in Iran, having been selected from the national barley breeding program.

Genotypic performance is influenced by the main effects of genotype (G), environment (E), and the interaction between genotype and environment (GEI). The presence of GEI can hinder genetic advancement in plant breeding programs and complicate the selection of genotypes suitable for diverse environmental conditions (Perkins and Jinks, 1968; Falconer, 1981). Therefore, it is essential to investigate the effects of GEI prior to the introduction of new high-yielding varieties. One approach to mitigate the impact of GEI is to select genotypes that are widely adapted and stable across various environments, while another strategy involves selecting the most suitable genotypes for specific target environments (Ceccarelli, 1989). Given the challenges associated with providing adapted cultivars for every possible environment, efforts should focus on developing cultivars that can be recommended for a broad range of conditions. In crop improvement programs, the ultimate objective for breeders is to identify genotypes that can perform well across diverse environments (Ahmadi *et al.,* 2012). Various statistical methods have been proposed to analyze GEI and assess yield stability. Huhn (1990) and Nassar and Huhn (1987) introduced four non-parametric statistics: (1) $S^{(1)}$, the mean of the absolute rank differences of a genotype over all tested environments, (2) $S^{(2)}$, the variance among the ranks over all tested environments, (3) $S^{(3)}$, the sum of the absolute deviations for each genotype relative to the mean of ranks, and (4) $S^{(6)}$, the sum of squares of rank for each genotype relative to the mean of ranks. Wricke (1962) proposed the concept of ecovalence as the contribution of each genotype to the GE interaction sum of squares. The ecovalence (Wi) of the ith genotype is its interaction with the environments, squared and summed across environments. Thus, genotypes with low values have smaller deviations from the mean across environments and are more stable. Shukla (1972) suggested stability variance, which is modified form of Wrick's stability criterion. In this method the stability variance of genotype i is considered as its variance among environments after removing the main effects of environmental factors. According to this statistic, genotypes with minimum values are intended to be more stable. Kang's rank-sum (Kang, 1988) uses both yield and Shukla's stability variance ($\sigma^2 i$) as selection criteria. The ranks of yield and stability variance ($\sigma^2 i$) are added for each genotype and the genotypes with the lowest rank-sum are the most desirable. The rank of genotype with the highest yield and lowest $\sigma^2 i$ is one. The primary aim of this research was to identify barley genotypes with high and stable yields in salinity-affected, moderate climate regions of Iran.

MATERIALS AND METHODS

A total of 18 promising barley lines, including a local cultivar (cv. Golshan) and a pure line (MBS-98-10) serving as two experimental controls, were evaluated using a randomized complete block design with three replications. The study was conducted in three regions affected by salinity: Yazd (EC_{water}: 10 dS. m^{-1}, EC_{soil}: 10 - 12 dS. m^{-1}), Isfahan (EC_{water}: 14 dS. m^{-1}, EC_{soil}: 10 dS. m^{-1}), and Birjand (EC_{water}: 10 dS. m^{-1}, EC_{soil}: 14 dS. m^{-1}) during the 2021-22 and 2022-23 cropping seasons (Tables 1-3).

Each genotype was cultivated in six rows, each measuring 6 meters in length, with a spacing of 20 cm between rows. The seed density for each plot was established at 450 seeds. m^{-2}. Planting occurred in November across all research stations. During the tillering stage, Granstar and Pumasuper herbicides were applied to manage broadleaf and grass weeds,

Table 1. Pedigree of promising barley lines evaluated under salinity stress conditions during the 2021-2023 cropping seasons.

Genotypes	Pedigree
G1	Golshan (CH-1)
G2	Rojo/3/LB.IRAN/Una8271//Gloria"S"/Com"S"/4/Nik
G3	PINON/3/QUINN/ALOE//CARDO/4/CIRU/5/Rhn-03//L.527/NK1272
G4	Legia//Rhn/Lignee 527/3/Yousef
G5	Legia//Rhn/Lignee 527/3/Nik
G6	Rojo/3/LB.IRAN/Una8271//Gloria"S"/Com"S"/4/ Rojo/3/LB.IRAN/Una8271//Gloria"S"…
G7	Beecher/4/Rihane-03/3/As46/Aths*2//Aths/Lignee686
G8	Lignee 527/Chn-01//Gustoe/4/Rhn-08/3/Deir Alla 106//Dl71/Strain 205/5/Rihane-03…
G9	Rojo/3/LB.IRAN/Una8271//Gloria"S"/Com"S"/4/Rihane-03
G10	Bgs/Dajia//L.1242/3/(L.B.IRAN/Una8271//Gloria'S'/3/Alm/Una80//....)/4/Nosrat/5/Rhn-
G11	Triton/Yazd-5//Nik/3/Rhn03
G12	(D-16)Bda/Rhn-03//ICB-107766/3/Nosrat/4/Nik/5/Yousef
G13	Legia//Rhn/Lignee 527/3/Yousef
G14	Sahra/4/ Rojo/3/LB.IRAN/Una8271//Gloria"S"/Com"S"
G15	Triton/Yazd-5//Nik/3/Rhn03
G16	CIRU/TOCTE
G17	PENCO/CHEVRON-BAR/6/P.STO/3/LBIRAN/UNA80//LIGNEE640/4/BLLU/5/PETUNIA 1
G18	MSEL/LOGAN-BAR
G19	LBIRAN/UNA80//LIGNEE640/3/PUNGSANCHAPSSALBORI
G20	Bda/Rhn-03//ICB-107766/3/Nosrat/4/Nik (MBS-98-10, CH-2)

Table 2. Geographical locations of the test environments.

Station	Latitude	Longitude	Altitude (m)
Isfahan	32°30'N	51o16'E	1541
Yazd	31°54'N	54°16'E	1237
Birjand	32°52'N	58°59'E	1491

respectively. Following seed planting, irrigation was conducted once in the autumn (during planting) and four times in the spring (during the tillering, stemming, flowering, and grain filling stages). The traits examined included Days to 50% Heading (DHE), Plant Height (PH), Days to Physiological Maturity (DMA), Grain Yield, and Thousand Kernel Weight (TKW). The duration from DHE to DMA was designated as the Grain Filling Period (GFP). At harvest, border effects were mitigated by excluding 0.5 meters from each side of the plots, resulting in a harvesting area of 5 m^2. The grain yield of the evaluated genotypes was calculated and presented as t. ha^{-1}. Following the collection of experimental data, a combined analysis of variance was performed using SAS version 9.1 software. The Least Significant Difference (LSD) method was employed for mean comparisons. To assess the stability of grain yield, both non-parametric statistics, as proposed by Huhn (1990) and Nassar and Huhn (1987), including Si1, Si2, Si3, and Si6, as well as parametric parameters such as the Coefficient of Variation (Francis and Kannenberg, 1987), Shukla's Stability Variance (Shukla, 1972), Wricke's Ecovalence (Wrick, 1962), and Kang's Rank-Sum (Kang, 1988), were utilized.

RESULTS AND DISCUSSIONS

The results of the combined analysis of variance indicated that the simple effects of location, genotype, and the interaction effect of genotype×location×year were statistically significant. Conversely, the effects of year, year×location, genotype×year, and genotype×location were not significant (Table 4). The significant effect of genotype suggests that the various genotypes exhibited notable differences in grain yield. The genotypes examined in this study were selected superior lines from previous stages of barley breeding programs specifically designed for salinity stress conditions. The non-significant interaction effect of genotype×location implies that the studied genotypes responded similarly across different environments, with their average grain yield remaining relatively stable across these settings. Consequently, it can be concluded that it is not feasible to introduce lines with specific adaptability to the locations under investigation. Additionally, the non-significant interaction effect of genotype×year indicates that different genotypes performed similarly across various years. However, the significant triple interaction effect of genotype×year×location revealed that the genotypes exhibited varying performances across different years and locations. This finding underscores the necessity to identify lines that demonstrate

Table 3. Monthly meteorological data for the cropping seasons of 2021-2022 and 2022-2023 in the test environments.

Environment			Cropping year 2020-2021									Cropping year 2021-2022								
			Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
Yazd	Rainfall (mm)		0	22.4	2.7	6.3	0.4	3.2	0	6.5	0	0	6.7	8.5	31.2	6.4	6.6	1.4	0.6	0.5
	Temp. (°C)	Min	13	5	2.4	-0.5	-1.6	7.8	10.9	15.8	20.7	15.9	9.1	3.1	-0.1	5.1	10.9	14.8	20.2	26.1
		Max	32.6	21.5	19.5	16.3	18.2	24.2	30.6	33.3	38.6	30.7	21.2	13.5	10.1	16.5	24.2	27.5	33.8	39.7
		Mean	22.8	13.3	10.9	7.9	8.3	16	20.7	24.5	29.7	23.3	15.1	8.3	5	10.8	17.6	21.2	27	32.9
Isfahan	Rainfall		0	9.2	5.9	6.5	7.2	6.3	0.6	2.5	0	0	13.2	9.5	30.8	52	4.2	8.3	10.8	8.1
	Temp. (°C)	Min	10.3	3.1	0.3	-3.3	-3.3	4.6	7.2	11.2	16.1	9.7	3.2	-1.5	-2.9	-0.3	4.5	7.9	12.3	18
		Max	29.8	18.6	15.4	11.9	13.4	19	25.9	28.5	34.9	28.4	18.5	12.4	7.7	13.9	21.2	25.8	31.3	38.1
		Mean	20	10.9	7.9	4.3	5	11.8	16.5	19.9	25.5	18.9	10.9	5.4	2.4	6.8	12.9	16.8	21.8	28
Birjand	Rainfall		0	14.2	7.37	48	24.9	0.51	1.78	8.37	0	0	2.2	6.5	27	38	6.6	15.9	1.9	0.1
	Temp. (°C)	Min.	5.2	0.8	-2	-1.7	0.1	6.9	10.8	12.7	18.1	8.2	5.8	-0.2	-3.8	0.4	5.5	8.1	12.6	17.7
		Max.	27.4	19.4	16.3	12.9	16.6	24	29.7	31.4	35.9	30.5	22.8	16.8	11.4	12.6	21.8	23.6	30.6	36.2
		Mean	16.6	9.9	6.8	5.3	8.3	16.2	1.3	23.2	28.1	19.4	14.3	8.3	3.8	6.5	13.6	15.9	21.6	26.9

Table 4. Combined ANOVA for grain yield data of promising barley genotypes in saline regions of Iran during the 2021-2022 and 2022-2023 cropping seasons.

Source of variation	df	Mean of square	Variability explained (%)
Year (Y)	1	54.230^{ns}	11.57
Location (L)	2	389.72*	83.14
Y×L	2	15.90**	3.39
Replication (Y×L)	12	0.51	
Genotype (G)	19	3.99**	0.85
G×L	38	1.67ns	0.36
G×Y	19	1.07ns	0.23
G×Y×L	38	1.08**	0.23
E_2	228	0.59	

* and ** denote statistical significance at the 5% and 1% probability levels, respectively, whereas n.s. indicates non-significance.

Table 5. The mean grain yield for each test environment, along with a comparison of total means and yield stability parameters for the evaluated promising barley genotypes in salinity-affected regions of Iran during the 2021-22 and 2022-23 cropping seasons.

Genotype	Grain yield (t. ha-1)							Stability parameters							
	Isfahan		Birjand		Yazd		Grand mean	Non-parametric statistics				Parametric			
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23		$S^{(1)}$	$S^{(2)}$	$S^{(3)}$	$S^{(6)}$	W_i^2	σ^2_i	CVi	*K*R
G1	6.705	5.507	5.153	7.722	3.114	2.116	5.053	7.1	38.3	22.1	3.0	5.1	1.1	41.9	31
G2	6.667	5.471	5.333	5.431	3.746	2.091	4.790	3.1	6.8	4.9	1.4	0.2	0.0	33.8	17
G3	5.666	6.360	5.931	5.153	3.689	2.244	4.840	4.9	18.6	10.5	2.2	1.4	0.3	32.5	22
G4	6.995	6.038	6.667	5.750	4.926	3.143	5.586	4.7	15.0	5.3	1.2	1.3	0.3	25.0	8
G5	6.673	5.776	5.833	5.139	3.469	2.138	4.838	2.2	3.4	2.1	1.1	0.2	0.0	35.2	17
G6	7.333	6.455	6.194	5.597	4.750	2.469	5.466	3.9	9.9	3.4	1.0	0.7	0.1	31.2	12
G7	7.232	6.450	5.264	6.694	3.943	2.056	5.273	6.1	25.9	11.1	2.1	1.4	0.3	37.3	15
G8	7.014	5.586	6.903	7.306	4.971	3.171	5.825	6.1	33.4	10.3	1.5	2.7	0.6	27.3	16
G9	6.667	7.157	6.777	5.819	3.474	2.947	5.474	6.5	27.8	10.0	2.0	1.8	0.4	33.1	17
G10	6.557	6.479	6.736	6.486	2.873	2.479	5.268	6.4	34.8	14.5	2.5	2.3	0.5	38.2	22
G11	6.349	5.902	6.806	7.569	4.567	2.248	5.574	7.3	35.4	13.8	2.3	3.6	0.8	34.3	20
G12	6.985	4.562	6.056	6.097	4.104	2.578	5.064	5.7	30.3	13.0	1.8	2.6	0.5	32.0	24
G13	7.238	6.040	6.861	6.444	4.118	2.477	5.530	3.6	9.2	3.1	0.8	0.7	0.1	33.4	8
G14	7.450	6.243	6.736	6.083	4.124	2.329	5.494	3.2	8.3	2.8	0.8	0.5	0.1	34.7	8
G15	7.238	6.481	5.181	4.847	3.434	2.107	4.881	6.7	35.1	18.5	3.2	1.6	0.3	38.9	22
G16	6.916	6.612	4.681	5.069	2.944	2.109	4.722	6.9	34.0	21.3	3.3	2.1	0.4	40.7	29
G17	6.367	5.848	3.403	4.417	2.663	1.279	3.996	2.8	6.0	10.0	4.0	3.1	0.7	48.4	36
G18	6.302	6.231	5.361	4.500	2.440	1.783	4.436	4.3	14.6	15.1	3.9	1.7	0.3	43.5	28
G19	6.263	6.729	5.167	3.528	2.973	1.934	4.432	6.6	43.8	37.5	4.5	4.4	1.0	43.2	37
G20	6.917	4.767	5.417	5.486	5.330	1.538	4.909	8.0	45.6	25.3	3.1	4.6	1.0	36.6	31
LSD 1%: 0.942 t. ha^{-1}, LSD 5%: 0.703 t. ha^{-1}.															

$S^{(1)}$, $S^{(2)}$, $S^{(3)}$, $S^{(6)}$: Huhn's and Nassar and Huhn's non-parametric statistics; W_i^2: Wricke's Ecovalence; σ^2_i: Shukla's stability variance; CVi: Coefficient of variations; *K*R: Kang's rank-sum.

general adaptability to the studied areas (Table 4). Furthermore, the means comparisons revealed that genotypes G8, G4, G11, G13, and G14 exhibited the highest yields among the evaluated lines (Table 5) and can be regarded as superior genotypes. Nevertheless, due to the significance of the triple interaction effect, it is imperative to further investigate the yield stability of these genotypes.

The average grain yield of the assessed promising barley genotypes varied from 1.279 t. ha^{-1}, associated with genotype G17 at the Yazd station during the second year, to 8.722 t. ha^{-1}, linked to the Golshan cultivar (G1) at the Birjand station in the same year, across six different environments (Table 5).

STABILITY STATISTICS

Based on the four non-parametric statistics introduced by Huhn (1990) and Nasser and Huhn (1987), lines G2, G5, G13, G14, and G17 exhibited greater stability, as evidenced by their lower values across all or some of these statistics. Among the lines identified through this methodology, line G17 was recognized as the most stable according to the $S^{(1)}$ and $S^{(2)}$ parametric statistics; however, it also recorded the lowest grain yield among the genotypes examined. Utilizing Wricke's ecovalence parameter, lines G2, G5, G14, G13, and G6 were identified as genotypes demonstrating superior grain yield stability, attributable to their low parameter values. According to the methodology proposed by Shukla (1972), a lower value of this statistic signifies enhanced stability, and lines G2, G5, G14, G13, and G6, which exhibited lower values, were thus deemed more stable (see Table 5). A comparative analysis of the stability test results using Rick's and Shukla's methods revealed a high degree of similarity, indicating a congruence between these two parameters in identifying stable genotypes. The consistency of results derived from these two statistics has been corroborated in previous studies (Dehghanpour, 2006; Bakhshayeshi Qashlaq, 2012). In accordance with Kang's (1988) stability criterion, genotypes that presented lower values according to this criterion were associated with favorable yield and stability. Consequently, based on the calculated values for this criterion, lines G14, G13, G4, G6, and G7 were identified as desirable in terms of grain yield and stability (Table 5). The environmental coefficient of variation is determined by the average grain yield of each genotype across all environments; a lower value of this coefficient for each cultivar indicates reduced fluctuations in grain yield across varying environments (a combination of year and location), thereby reflecting its stability. Based on the calculated values for this coefficient, lines G4, G8, G6, G12, and G3 demonstrated high stability (Table 5).

The traits measured in the field are presented in Table 6. It is important to note that in areas impacted by salinity stress, additional factors such as heat and drought stress also play a significant role. The grain filling period is likely to cease with the onset of heat stress; therefore, genotypes that initiate the flowering phase earlier will have a competitive advantage, as they will have an extended duration for grain filling. Furthermore, thousand-grain weight is a critical component of grain yield, exhibiting a positive correlation with overall grain yield. Genotypes that demonstrate a higher thousand-grain weight tend to produce greater grain yields.

The introduction of a new cultivar in a specific region can enhance stability and ensure consistent production by promoting genetic diversity, even if the new cultivar does not outperform the control cultivar in terms of grain yield. The findings indicate that genotypes G8, G4, G11, G13, and G14 exhibited the highest yields among the evaluated lines, with respective yields of 5.825, 5.586, 5.573, 5.529, and 5.494 tons per hectare. Given the high grain yields of these five lines, it is feasible to identify and introduce lines with desirable and stable yields through an assessment of their stability. Utilizing the non-parametric statistical methods proposed by Huhn (1990) and Nasser and Huhn (1987), along with stability parameters such as Wricke's Equivalence (1962), the environmental coefficient of variation (1987), Shukla's Stability Variance (1972), and Kang's rank-sum (1988), lines G4, G13, and G14 were identified as possessing desirable and stable yields. These three lines also exhibited an earlier flowering onset (as shown in Table 6), which allowed for an extended grain-filling period, and they demonstrated a higher thousand-kernel weight compared to the average of the studied environments (refer to Table 6). These genotypes were developed through the Iran International Irrigated Barley Breeding Program, with initial crosses aimed at identifying salinity-tolerant genotypes. The pedigree of these lines is detailed in Table 1. Lines G4 and G13 are sister lines selected from Iran's national barley program, resulting from the cross between Legia//Rhn/Lignee 527 (the maternal parent) and the Yousef cultivar (the paternal parent). Legia//Rhn/Lignee 527 is currently recognized as the Armaghan cultivar, which is cultivated commercially and is characterized by high yield and thousand-kernel weight (Nikkhah *et al.,* 2019). Yousef cultivar is also a commercially cultivated variety in Iran's moderate climate, notable for its terminal drought resistance, making it suitable for regions affected by drought stress. Line G14 was developed from a cross between Sahra cultivar (the maternal parent) and Rojo/3/LB.IRAN/Una8271//Gloria"S"/Com"S" (the paternal parent), and is currently recognized as the Oksin variety. Oksin is distinguished by its high resistance to salinity and drought stresses (Ghazvini *et al.,* 2019) and is utilized

Table 6. The studied traits means of evaluated promising barley genotypes in saline regions of Iran during the 2020-2021 and 2021-2022 cropping seasons.

Genotype	Grain yield (t/h)			Days to 50% heading			Grain filling period			Plant height (cm)			Thousand kernels weight (g)		
	Birjand	Isfahan	Yazd	Birjand	Isfahan	Yazd	Birjand	Isfahan	Yazd	Birjand	Isfahan	Yazd	Birjand	Isfahan	Yazd
G1	6.438	6.106	2.615	84.5	112	105	44	29	50	79.2	83.2	73.5	45.4	38.4	33.9
G2	5.382	6.069	2.918	77.7	108	99	45	32	52	67.0	77.0	65	46.9	32.2	29.5
G3	5.542	6.013	2.966	71.5	104	96	46	33	39	75.3	79.8	66.5	41.2	39.6	29.0
G4	6.208	6.517	4.034	74.3	104	95	45	42	38	75.5	78.5	66.5	40.0	36.8	32.1
G5	5.486	6.225	2.803	76.5	106	99	43	30	39	74.8	81.7	69.5	41.6	35.6	29.0
G6	5.896	6.894	3.610	77.2	104	99	46	35	50	69.7	83.7	75	42.1	37.4	31.4
G7	5.979	6.841	3.000	75.7	106	99	46	32	43	80.5	79.8	70	41.1	38.3	31.1
G8	7.104	6.300	4.071	76.3	106	98	47	33	49	80.0	84.8	74	40.8	34.7	31.6
G9	6.298	6.912	3.211	71.2	105	99	49	33	40	71.8	73.0	74.5	41.8	34.4	29.6
G10	6.611	6.518	2.676	75.2	109	97	46	29	42	73.0	79.8	77	41.8	34.6	31.2
G11	7.188	6.126	3.408	78.5	103	99	48	37	42	77.0	82.3	75.5	46.2	37.7	33.6
G12	6.076	5.774	3.341	77.0	107	97	48	32	51	78.7	82.0	73.5	44.7	35.7	31.6
G13	6.653	6.639	3.297	75.3	103	96	47	40	48	82.2	83.8	72.5	43.1	37.6	33.0
G14	6.410	6.846	3.227	73.7	104	97	50	41	47	72.0	76.3	72	41.8	35.3	26.9
G15	5.014	6.859	2.771	76.5	107	98	43	30	50	74.7	80.0	69.5	42.0	39.2	33.6
G16	4.875	6.764	2.527	80.3	109	97	42	30	43	63.7	68.8	71.5	47.8	45.1	34.1
G17	3.910	6.107	1.971	73.5	106	95	47	31	39	74.3	83.2	74	44.1	43.1	34.1
G18	4.931	6.267	2.112	69.7	103	95	49	35	42	70.2	74.7	67	43.3	39.6	29.5
G19	4.347	6.496	2.454	76.5	106	99	44	31	39	65.3	72.0	68	44.5	41.0	30.3
G20	5.451	5.842	3.434	81.8	112	105	45	27	44	82.2	77.0	69.5	42.3	35.1	30.3

in barley breeding programs to enhance tolerance to these environmental stresses.

In light of previous GEI analyses concerning various traits, it has been established that barley exhibits sensitivity to environmental changes, similar to other crops (Ahakpaz *et al.,* 2021; Hilmarsson *et al.,* 2021; Ghazvini *et al.,* 2022; Pour-Aboughadareh *et al.,* 2023). The interaction between genotype and environment is crucial for genotype selection, cultivar release, and the identification of appropriate target production environments to optimize yield performance. Certain regions in Iran, including Isfahan, South Khorasan, Yazd, Kerman, Khuzestan, Razavi Khorasan, Alborz, Tehran, and Fars, contain lands adversely affected by salinity stress. The identification and utilization of salinity stress-tolerant crops represent effective strategies for mitigating this issue. One promising approach for identifying salt-tolerant crops is yield-based breeding conducted in saline target environments (Richards, 1992). Barati *et al.* (2020) examined a selection of elite barley lines at the Yazd, Isfahan, and Birjand research stations during 2012-2014 cropping seasons, ultimately selecting line G8, which has the pedigree "L.527/Nk1272// Jlb70-63/3/1-BC-80320," based on its optimal grain yield and general adaptability. This line has since been introduced as the Golshan cultivar, which is now cultivated in areas affected by salinity.

Identifying high-yield and stable genotypes with general adaptability across salinity-affected regions in Iran presents significant challenges due to the vastness and dispersion of these areas impacted by salinity stress. However, it appears that the identification of high-yielding genotypes with broad adaptability can be facilitated through the evaluation of salinity-tolerant lines in multi-environment experiments. Various statistical methods can be employed to assess yield stability, with each method revealing different aspects of cultivar stability. Consequently, no single method can comprehensively define the stability of a genotype across diverse environments. Stability analysis methods are categorized into univariate and multivariate groups. In univariate methods, the genotype's response to environmental conditions is assessed by calculating a stability index, which is further divided into parametric and non-parametric subgroups. Non-parametric methods rank the performance of genotypes within each environment, considering genotypes with the same rank across different environments as stable. These non-parametric methods exhibit reduced sensitivity to outlier data compared to parametric methods, and they do not require assumptions of normality, independence of data, or uniformity of variance in experimental errors. Furthermore, the interpretation of non-parametric criteria is generally more straightforward than that of parametric methods, and the addition or removal of one or a few genotypes does not significantly impact the stability index (Helms, 1993).

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