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Assessment of synthetic wheat lines for soil salinity tolerance

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Abstract

In order to determine the performance of synthetic wheat (*Triticum turgidum* × *Aegilops squarrosa*) lines under soil salinity stress conditions and to screen quantitative indices of salinity tolerance, 43 synthetic wheat lines from International Maize and Wheat Improvement Center (CIMMYT), Turkey were tested in a randomized complete block design in two replications under non-salinity (normal) and salinity stress conditions in Absheron and Ujar regions of the Republic of Azerbaijan. The results of analysis of variance (ANOVA) showed significant differences among the wheat genotypes for all quantitative morphological traits studied. Salinity stress tolerance indices, including stress sensitivity index (SSI), tolerance index (TOL), mean productivity index (MPI), stress tolerance index (STI), geometric mean productivity index (GMPI) and harmonic mean index (HMI) were calculated according to the grain yield under non-salinity and salinity stress conditions. The correlation coefficients showed that GMPI, STI, MPI and HMI were the most desirable selection criteria for high yielding and soil salinity tolerant genotypes.

The results of this experiment revealed that among the studied wheat genotypes lines Nos 16 and 27 were highly tolerant but produced low grain yield. Also, lines Nos 5, 29, 15, 28, 4, 25 and 24 had the highest tolerance to salinity stress and produced the highest grain yield in both (non-salinity and salinity stress) conditions. In conclusion, it was suggested that these wheat lines are suitable for salinity stress conditions and are appropriate for hybridization with the aim of increasing salinity tolerance.

Key words: genetic diversity, soil salinity tolerance, *Triticum turgidum* × *Aegilops squarrosa*.

Introduction

Soil salinity is one of the most crucial environmental factors limiting plant growth and productivity, particularly in arid and semi-arid regions. This is due to the reason pertaining to plants imposing a complex phenotypic and physiological phenomenon of ion imbalance (Munns, Tester, 2008). It is estimated that 20% of the irrigated land in the world is presently affected by salinity, excluding the regions classified as arid and desert lands (Yamaguchi, Blumwald, 2005). As a consequence of irrigation by low-quality water, salinization occurs in drought areas as a result of poor quality water irrigation. The excessive salinization in the soil impacts winter cereal crops and consequently cell elongation occurs which causes decreases in the leaf surface and weakening of ion accumulation in leaf cells. The negative contribution of salty soil results in premature senescence, wizened grains, many spike bearing tillers and loss of distal spikelets. Additionally, it contributes to reduction in productivity. Moreover, the number of productive stems decreased dramatically (Ogbonnaya et al., 2013).

Useful lands for agricultural purposes are around 4.8 million hectares in Azerbaijan of which around 37.4% is under soil salinity stress conditions (FAOSTAT, http://www.fao.org/faostat/en/#country/52). Azerbaijan has a slightly continental climate with relatively cold winters and hot summers; it is also arid in most of the low-lying areas, while it becomes colder and generally rainier in the mountains. During maturity stage of wheat crops, because of water insufficiency and high temperatures, the plants flourish earlier and the grains mature rapidly. In this period of year, in Azerbaijan, the elevated temperatures

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and the lack of sufficient precipitation during cereal crop and pasture growth periods lead to a major water scarcity in the soil (Sylven et al., 2008). High temperatures as well as drought stress enhances the salinity levels in soil which will result in reduction during harvest (Passioura, 2007).

Wheat is the most widely cultivated cereal in the world. Wheat constitutes the major element of the food which is consumed by 4.5 billion people from 95 developing countries (Braun et al., 2010). Scientists prognosticate that the requirement for wheat is likely to escalate from 30% to 40% by 2030. In the current situation, growth in production should expand yearly 1.2% to satisfy the demand. This figure is expected to reach 1.6%–1.8% in order to satisfy the increased necessity. According to Ogbonnaya et al. (2013), genetics and breeding are foreseen to comprise 1% of the estimated 1.6% growth.

There is limited genetic variation in elite germplasm used in breeding programs amongst the current bread wheat cultivars. Synthetic hexaploid wheat derived from crosses between durum wheat (genomes AB) and *Aegilops squarrosa* (genome D) is widely accepted as an important source of useful traits in wheat breeding (Ogbonnaya et al., 2013, Li et al., 2014). Considerable genetic variation for salinity tolerance has been found in synthetic hexaploids. Therefore, salinity-tolerant germplasm should be sought as an economically feasible alternative to methods of soil amelioration (Pritchard et al., 2002; Ogbonnaya et al., 2005). Evaluation of an elite set of synthetic hexaploid wheat from International Maize and Wheat Improvement Center (CIMMYT) resulted in several synthetic hexaploid wheat being categorized as tolerant (Pritchard et al., 2002; Jafarzadeh et al. 2016). Development of winter wheat synthetics was started at CIMMYT in 2004, when winter durum wheat germplasm from Ukraine and Romania was crossed with winter *Ae. tauschii* accessions from the Caspian Sea basin (Morgounov et al., 2017; Gadimaliyeva et al., 2018). Independent studies indicated and confirmed that synthetic hexaploid wheat possessed considerable variation for salinity tolerance based on Na exclusion (Dreccer et al., 2004).

The present research on 43 synthetic wheat lines for the first time was conducted to identify the best wheat genotypes for salinity-affected areas of Azerbaijan Republic and to group synthetic wheat according to the obtained results under non-salinity and salinity stress conditions.

Materials and methods

The material used in the study is presented in Table 1. Each of the three main groups: 1) CIMMYT synthetics, 2) CIMMYT synthetics × modern and 3) Japanese synthetic wheats, comprised 12 lines selected in Turkey from a larger set of materials. The genotypes were selected based on their agronomic performance, including disease resistance. Germplasm in groups 1 and 2 originated from single spike selections in F7 and F5, respectively. A Russian winter wheat landmark cultivar ‘Bezostaya-1’, a CIMMYT spring wheat cultivar with cold tolerance ‘Seri’ and cultivar ‘Ekinci-84’ from Azerbaijan were used as checks.

Table 1. Pedigree of synthetic lines and their derivatives, origin of *Aegilops squarrosa* (*Ae.sq*.) used in the synthetic wheat lines

Entry No.	Cultivar or line pedigree	Cross ID	*Aegilops squarrosa* origin	Average yield in Absheron region	Average yield in Ujar region
1.	Bezostya-1 (check)			3.87	2.58
2.	Seri (check)			4.36	2.94
3.	Ekinci-84 (check)			3.82	2.30
	CIMMYT winter wheat synthetics				
4–8.	Aisberg/*Ae.sg.* (369)	C04GH3	Mazandaran, Iran	4.22	3.8
9.	Aisberg/*Ae.sg.* (511)	C04GH5	unknown	2.85	1.88
10.	Ukr.-od.952.92/*Ae.sg.* (1031)	C04GH61	Zanjan, Iran	3.87	2.70
11, 12.	Ukr.-od.1530.94/*Ae.sg.* (310)	C04GH68	Gilan, Iran	2.77	2.46
13, 14.	Ukr.-od.1530.94/*Ae.sg.* (458)	C04GH74	unknown	3.22	3.60
15.	Ukr.-od.1530.94/*Ae.sg.* (629)	C04GH76	Mazandaran, Iran	4.06	3.54
16.	Soldur/*Ae.sg.* (658)	C08B97	unknown	1.82	4.33
	CIMMYT winter wheat synthetics × modern cultivars				
17, 18.	Aisberg/*Ae.sg.* (369)//Demir	TCI091254	Mazandaran, Iran	3.64	3.46
19–21.	Leuc.84693/*Ae.sg.* (310)//Adyr	TCI091259	Gilan, Iran	3.59	3.60
22.	Ukr.-od.1871.94/*Ae.sg.* (213)//Mezgit-6	TCI091264	Gorgan, Iran	3.24	3.37
23–25.	Ukr.-od.952.92/ *Ae.sg.* (409)//Sonmez	TCI091266	Dagestan, Russia	3.88	3.29
26, 27.	Ukr.-od.1530.94/ *Ae.sg.* (312)//Bagci-2002	TCI091272	Gorgan-Khush Yailaq, Iran	3.18	4.42
28, 29.	Ukr.-od.1530.94/*Ae.sg.* (446)//Katya-1	TCI091274	Gilan, Iran	3.98	3.65
	Japanese synthetic wheats				
30.	Langdon/*Ae.sg.* (AE 929)	–	Mtskheta, Georgia	2.52	2.24
31.	Langdon/*Ae.sg.* (IG 48042)	–	Jammu and Kashmir	2.46	2.70
32.	Langdon/*Ae.sg.* (IG 126387)	–	Ashkhabad, Turkmenistan	2.91	2.00
33.	Langdon/*Ae.sg.* (IG 131606)	–	Talas, Kyrgyzstan	2.74	2.36
34.	Langdon/*Ae.sg.* (KU-2080)	–	Gorgan, Iran	3.07	2.36
35.	Langdon/*Ae.sg.* (KU-2092)	–	Babulsar, Iran	2.83	3.01
36.	Langdon/*Ae.sg.* (KU-2096)	–	Babulsar, Iran	3.04	2.55
37.	Langdon/*Ae.sg.* (KU-2098)	–	Ramsar, Iran	2.98	2.28
38.	Langdon/*Ae.sg.* (KU-2159)	–	Ramsar, Iran	2.52	2.09
39.	Langdon/*Ae.sg.* (KU-2829A)	–	Tbilisi, Georgia	3.01	2.46
40.	Langdon/*Ae.sg.* (KU-20-10)	–	Ramsar, Iran	2.38	2.56
41.	Langdon/*Ae.sg.* (KU-2079)	–	Aliabad, Iran	2.94	2.56
42.	Langdon/*Ae.sg.* (KU-2093)	–	Babulsar-Chalus, Iran	3.06	1.79
43.	Langdon/*Ae.sg.* (KU-2132)	–	Van, Turkey	2.02	1.92

The experiment was conducted during 2015–2016 under irrigated conditions in a high salinity soil at two sites in Absheron (0 m a.s.l.) and Ujar (20 m a.s.l.) regions of the Republic of Azerbaijan (Fig. 1).

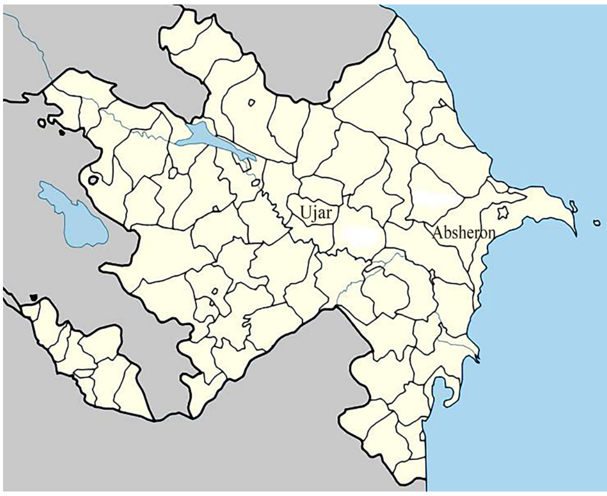


Figure 1. Geographic location of two regions (Absheron and Ujar) in Azerbaijan Republic

At both sites, experiments were managed using optimal production technologies. At all locations, each entry was planted on an area of 1 m^2 in two replications using a randomized complete block design. The following traits were recorded during the growing season: heading date (HD), plant height (PH), number of spikes per square meter (NSM), peduncle length (PL), grain number per spike (GN), grain weight per spike (GW), spike length (SL), spike weight (SW), spikelet number per spike (SpN), 1000 kernel weight (TKW), spike harvest index (SHI), grains per spikelet (GrSp), spike density (SD), spike fruiting efficiency (SFE) and reaction to stripe and stem rusts. All genotypes were evaluated using five random samples from each replication.

The weather conditions changed during the experiment. The amount of rainfall between January–June of 2015 and 2016 was 175–180 mm in Absheron region. The rainfall was 232 mm in 2016 in Ujar. The weather conditions were more favourable for wheat in 2015 due to better rainfall distribution.

The stability of different yield component parameters across soil salinity stress contrasting environments was evaluated using the stress sensitivity index (SSI) (Fischer, Maurer, 1978), tolerance index (TOL) (Rosielle, Hamblin, 1981), geometric mean productivity index (GMPI) (Fernandez, 1992), mean productivity index (MPI) (Rosielle, Hamblin, 1981), stress tolerance index (STI) (Fernandez, 1992) and harmonic mean index (HMI) (Schneider et al., 1997).

The analysis of variance (ANOVA) based on a randomized complete block design and correlation analysis was done by the software *SPSS*, version 19.0 (SPSS Inc., USA), while principal component analysis (PCA) and cluster analysis was carried out using the software packages *PAST* (Hammer et al., 2001) and *SYSTAT*, version 13 (Systat Software Inc., USA), respectively. Heritability in the broad sense was calculated as the ratio of the total genetic variance to the phenotypic variance.

Results and discussion

The results of the analysis of variance for the studied traits based on a randomized complete block design are shown in Table 2. The ANOVA results showed highly significant differences among wheat lines for all the studied traits such as heading date (HD), plant height (PH), number of spikes per square meter (NSM), peduncle length (PL), grain number per spike (GN), grain weight per spike (GW), spike length (SL), grain number per spike (GN), grains per spikelet (GrSp), spike length (SL), spike weight (SW), spikelet number per spike (SpN), 1000 kernel weight (TKW), spike harvest index (SHI), spike density (SD) and spike fruiting efficiency (SFE) traits in both (non-salinity and salinity stress) conditions. Salinity significantly affected all of the measured traits, except for the number of spikelets per spike, TKW and spike fruiting efficiency traits. The interaction between genotypes and salinity stress was significant for all studied characters, except TKW. This means that some wheat lines showed much better performance than the tolerant cultivars under soil salinity stress conditions.

Table 2 shows that the genotypic coefficient of variation ranged from 8.54% to 41.42%. The results of genotypic coefficient of variation revealed that spike fruiting efficiency and grain weight per spike exhibited

Table 2. The analysis of variance (ANOVA) and broad-sense heritability of 43 synthetic wheat lines for the studied morphological traits in non-salinity and salinity stress conditions

Trait	Replication	Condition	Genotype	G × C	Error	LSD5%	CV%	GCV%	h^2_{bs}
Df	1	1	42	42	85	–	–	–	–
HD	1.308ns	52.47**	99.57**	6.640**	0.343	1.15	0.46	9.54	0.98
PH	3.349 ns	3235.558**	737.08**	155.02**	40.95	12.54	9.07	14.08	0.94
NSM	728.58 ns	122702.5**	822.9**	909.31**	344.828	36.39	23.21	19.32	0.58
PL	0.004 ns	42.33*	96.92**	61.298**	11.125	6.54	7.59	14.92	0.88
GN	180.09**	2865.1**	281.32**	95.49**	15.53	7.72	9.38	27.44	0.94
GW	0.741**	0.741**	0.859**	0.327**	0.066	0.500	14.43	35.37	0.92
SL	4.660**	299.32**	8.990**	1.233**	0.351	1.16	4.70	16.49	0.96
SW	1.900**	3.940**	1.140**	0.606**	0.110	0.65	12.6	27.28	0.90
SpN	5.590**	0.285 ns	7.050**	2.120**	0.611	1.53	3.72	8.540	0.91
TKW	28.86	1535.8 ns	115.77	116.48 ns	13.69	7.25	8.70	16.80	0.88
SHI	10.48 ns	891.89**	226.85**	42.60*	25.47	9.89	7.55	19.02	0.89
GrSp	0.243**	7.820**	0.679**	0.243**	0.033	0.36	8.95	27.99	0.95
SD	1.800**	598.33**	12.43**	2.99**	0.717	1.65	5.04	14.40	0.94
SFE	231.63 ns	221.98 ns	1033.26**	310.83**	94.45	19.05	18.58	41.42	0.90

Df – degree of freedom; HD – heading date, PH – plant height (cm), NSM – number of spikes per square meter, PL – peduncle length, GN – grain number per spike, GW – grain weight per spike, SL – spike length, SW – spike weight, SpN – spikelet number per spike, TKW – 1000 kernel weight, SHI – spike harvest index, GrSp – grains per spikelet, SD – spike density, SFE – spike fruiting efficiency; G × C – interaction of genotypes (G) with growing conditions (C); CV – coefficient of variation for experimental design, GCV – genetic coefficient of variation, h^2_{bs} – broad sense heritability; **, * – $P < 0.01$, $P < 0.05$, ns – non-significant the highest genotypic coefficient of variation of 41.42% and 35.37%, respectively. The high genetic coefficient of variation (GCV) observed are evident from their high variability that in turn offers good scope for selection in both (non-salinity and salinity stress) conditions.

Heritability can be broadly defined as the proportion of phenotypic variability that is attributable to genetic factors. It is a measure of the extent of phenotypic variation caused by the action of genes. Heritability estimates assess the relationship in parents and progeny; therefore, crosses have been made to incorporate desirable genes in present wheat cultivars to increase the crop productivity. According to Kumar et al. (2014), heritability in the broad sense plays an important role in deciding the suitability and strategy for selection of a character. Munir et al. (2013) reported that salinity also affected the heritability of wheat genotypes. Heritability values under soil salinity stress were found to be lower as compared to those under controlled conditions during both phases of the experiment. In this experiment, high estimates of heritability (above 80%) in broad sense were recorded for all characters studied, except for the number of spikes per square meter (NSM) (58%). The highest heritability values indicate that heritability may be due to the higher contribution of a genotypic component. Kumar et al. (2017) obtained high heritability (above 80%) in all studied morphological traits. Similar findings have been reported by Jamil et al. (2017) as well.

In this study, lines No. 2, 5, 6 and 8 had a high yield in non-salinity conditions, whereas in salinity stress conditions lines No. 8, 16, 18, 19 and 27 were identified as a high performance. Line No. 5 shows that early initiation of heading occurs within 124 days under non-salinity conditions, while it is 125 days for lines Nos 2, 3, 6, 17, 21, 23 and 27. However, it is described as a late heading cultivar for line No. 35 with 137 days and it is 136 days for lines Nos 36 and 43. Wheat lines Nos 1, 5 and 6 were early heading, while Nos 32, 33, 34, 40, 42 and 43 were late heading in soil salinity stress conditions.

Correlation coefficients between the studied traits under non-salinity and salinity stress conditions are presented in Table 3.

Table 3. Coefficients of correlation between the studied morphological traits in non-salinity (above main diagonal) and salinity stress conditions (under main diagonal) of synthetic wheat lines

	PL	GN	GW	SL	SW	SpN	HD	PH	NSM	TKW	SHI	SpN	SpD	SFE
PL	1	−0.09 ns	0.02 ns	0.32*	−0.02 ns	0.01 ns	0.03 ns	0.70**	0.44**	0.33*	0.25 ns	−0.08 ns	−0.40**	0.01 ns
GN	−0.35*	1	0.89**	0.07 ns	0.83**	0.39**	−0.67**	−0.32*	0.01 ns	0.21 ns	0.74**	0.94**	0.21 ns	0.75**
GW	−0.25 ns	0.95**	1	−0.01 ns	0.95**	0.14 ns	−0.70**	−0.28*	−0.06 ns	0.61**	0.83**	0.92**	0.08 ns	0.61**
SL	0.325*	0.06 ns	0.12 ns	1	0.14 ns	0.52**	0.32*	0.46**	0.29*	−0.01 ns	−0.08 ns	−0.09 ns	−0.72**	−0.24 ns
SW	−0.13 ns	0.90**	0.97**	0.24 ns	1	0.15 ns	−0.629**	−0.28*	−0.14 ns	0.59**	0.63**	0.85**	−0.06 ns	0.37**
SpN	−0.20	0.43**	0.36**	0.41**	0.41**	1	0.14 ns	0.24 ns	0.30*	−0.31*	0.13 ns	0.06 ns	0.17 ns	0.31*
HD	0.26*	−0.69**	−0.68**	0.21 ns	−0.60**	−0.09 ns	1	0.43**	0.22 ns	−0.28*	−0.56**	−0.77**	−0.27*	−0.54**
PH	0.51**	−0.33*	−0.33*	0.29*	−0.26*	−0.14 ns	0.46**	1	0.62**	0.07 ns	−0.03 ns	−0.39**	−0.37**	−0.16 ns
NSM	−0.04 ns	0.13 ns	0.09 ns	−0.24 ns	0.06 ns	−0.06 ns	−0.41**	0.24 ns	1	0.01 ns	0.23 ns	−0.07 ns	−0.15 ns	0.22 ns
TKW	0.13 ns	0.31*	0.57**	0.16 ns	0.63**	−0.05 ns	−0.37**	−0.18	−0.06 ns	1	0.56**	0.35*	−0.31*	0.05 ns
SHI	−0.50**	0.77**	0.71**	−0.31*	0.53**	0.11 ns	−0.75**	−0.42**	0.24 ns	0.19 ns	1	0.78**	0.13 ns	0.83**
SpN	−0.33*	0.97**	0.94**	−0.03 ns	0.87**	0.21 ns	−0.72**	−0.32*	0.17 ns	0.34*	0.81**	1	0.14 ns	0.71**
SD	−0.54**	0.24 ns	0.14 ns	−0.83**	0.01 ns	0.11 ns	−0.33*	−0.43**	0.23 ns	−0.18 ns	0.49**	0.23 ns	1	0.47**
SFE	−0.65**	0.60**	0.46**	−0.51**	0.28*	0.10 ns	−0.59**	−0.47**	0.25*	−0.16 ns	0.85**	0.63**	0.71**	1

PL – peduncle length, GN – grain number per spike, GW – grain weight per spike, SL – spike length, SW – spike weight, SpN – spikelet number per spike, HD – heading date, PH – plant height, NSM – number of spikes per square meter, TKW – 1000 kernel weight, SHI – spike harvest index, SpN – spikelet number per spike, SD – spike density, SFE – spike fruiting efficiency; *, ** – significant at $P < 0.05$ and $P < 0.01$

Under non-salinity conditions the results revealed that the grain yield per plant showed highly significant and positive correlation with the number of grains per spike, spike weight, TKW, spike harvest index, number of grains per spikelet and spike fruiting efficiency traits. A highly significant and negative correlation was observed between yield with heading days and plant height in both (non-salinity and salinity stress) conditions. The significant negative correlation between grain yield and heading date confirms that earliness played a very important role in the stability of wheat yield within the dry areas, characterized by excessive temperature and hot winds during the period of grain filling. Also, the correlation analysis showed that in soil salinity stress conditions a positive significant correlation was obtained between the grain yield and the number of grain per spike, spike weight, number of spikelets per spike, TKW, spike harvest index, grains per spikelet and spike fruiting efficiency. The analysis of correlation of different traits with grain yield can help to make decision about the relative importance of these traits and their merits as selection criteria (Naghavi, Khalili, 2017).

For better evaluation of 43 synthetic wheat lines for soil salinity tolerance, six selection indices, including SSI, TOL, GMPI, STI, MPI and HMI, were used. To determine the most desirable salinity tolerance criteria, the correlation coefficient between yield under non-salinity conditions (Yn), yield under salinity stress conditions (Ys) and other quantitative indices of salinity tolerance were calculated (Table 4). Grain yield had a positive highly significant correlation with all calculated tolerance indices in non-salinity conditions, whereas, the correlation between Ys with SSI and TOL indices was negative. These results were in agreement with those reported by Sardouie-Nasab et al. (2014). Furthermore, in salinity stress conditions positive significant correlations were established between Ys and GMPI, STI, MPI and HMI. Stress susceptibility index had a positive highly significant correlation with TOL and a negative correlation with MPI.

TOL and HMI, GMPI and MPI were the better predictors of Yn and Ys than other indices under both (non-salinity and salinity stress) conditions. Therefore, selection based on HMI and MPI, GMPI and STI will help in the selection of genotypes with higher salinity tolerance and yield potential, while TOL and SSI exhibited good correlation with Yn. Several reports have introduced the HMI, GMPI, MPI and STI as the most suitable criteria for selecting the best genotypes for stress-prone areas (Sio-Se Mardeh et al., 2006). As reported by other researchers (Golabadi et al., 2006; Mohammadi et al., 2011; Sardouie-Nasab et al., 2014),

Table 4. Simple correlation coefficients between salinity tolerance and susceptibility indices of synthetic wheat lines

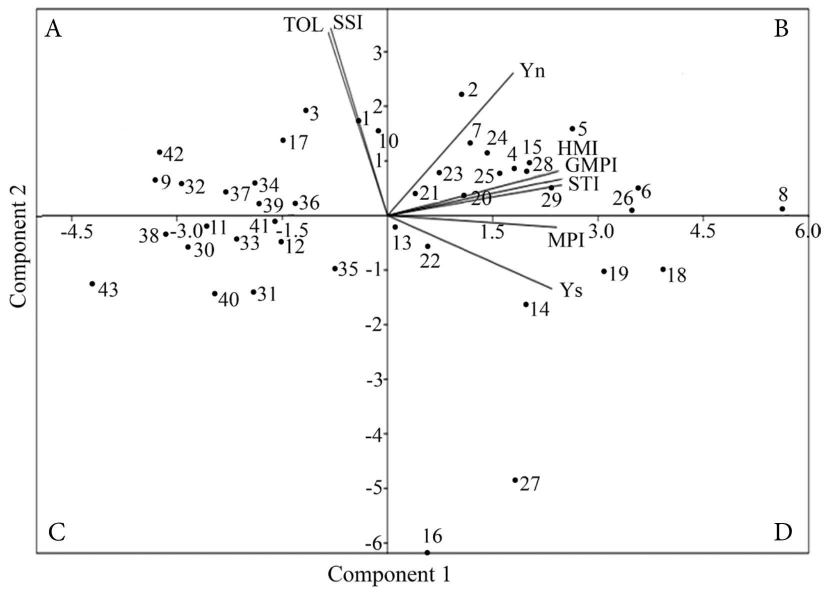
Trait	Yn	Ys	SSI	TOL	GMPI	STI	MPI	HMI
Yn	1							
Ys	0.417**	1						
SSI	0.394**	−0.634**	1					
TOL	0.404**	−0.663**	0.962**	1				
GMPI	0.823**	0.855**	−0.153	−0.183	1			
STI	0.812**	0.869**	−0.193	−0.206	0.996**	1		
MPI	0.673**	0.953**	−0.385*	−0.405**	0.970**	0.978**	1	
HMI	0.834**	0.833**	−0.107	−0.151	0.997**	0.988**	0.956**	1

Yn – yield under non-salinity conditions, Ys – yield under salinity stress conditions, SSI – stress sensitivity index, TOL – tolerance index, GMPI – geometric mean productivity index, STI – stress tolerance index, MPI – mean productivity index, HMI – harmonic mean index; *, ** – significant at $P < 0.05$ and $P < 0.01$

grain yield under Yn was positively correlated with Ys. Nevertheless, some reports showed a negative correlation between Ys and Yn (Sio-Se Mardeh et al., 2006). Kumawat and et al. (2017) did not find any correlation between grain yield under non-salinity and salinity stress conditions. The good responses shown by some cultivars under soil salinity stress conditions could be ascribed to adaptation mechanisms.

Since coefficients of correlation cannot be provided thorough information about the relations of different soil salinity tolerance indices and given the various advantages of multivariate statistical analyses for the deep understanding of data structure, principal component analysis (PCA) was used in the current study. By using PCA, the first two factors explained 99.21% of the total variation between the data (data not shown). The 1st component justified most of the variance between the studied wheat lines (68.72%). Indices that correlated with the 1st component included Yn, Ys, GMPI, STI, MPI and HMI (data not shown). Therefore, the first factor was named as yield potential and soil salinity tolerance. Thus, the selection of lines for high yield is possible on the basis of indices under the 1st principal component. The second factor accounted for 30.49% of total variation and had high correlation with TOL, SSI and Yn (data not shown). Similar findings were also reported by Mursalova et al. (2015) as well. Hence, this factor was able to distinguish high yielding wheat lines under non-salinity conditions.

Biplot diagram was depicted based on the 1st and 2nd components which accounted for 99.21% of the variation (Fig. 2). The biplot diagram was divided into four categories named A, B, C, and D on the basis of the two first principal components.



TOL – tolerance index, SSI – stress sensitivity index, Yn – yield under non-salinity conditions, HMI – harmonic mean index, GMPI – geometric mean productivity index, STI – stress tolerance index, MPI – mean productivity index, Ys – yield under salinity stress conditions

Figure 2. Biplot analysis of two first components of 43 synthetic wheat lines based on principal component analysis (PCA)

The higher scores for 1st component and lower scores for 2nd component part A from Figure 2 were in accordance with the higher rank of soil salinity tolerance. Lines with grain yield higher than tolerant checks under salinity stress conditions were identified as the most productive lines under salinity stress conditions and recommended as promising lines for salinity lands. Therefore, the lines which are placed in part A can be introduced as tolerant synthetic wheat into subsequent breeding programs for the selection of soil salinity tolerant and high-yielding lines under stress conditions. Whereas, lines located in part D are salinity-sensitive lines (low scores for 1st and 2nd components). Lines located in part C had high grain yield in non-salinity conditions (lower 1st component and higher 2nd component scores). But lines located in part B had appropriate potential under both (non-salinity and salinity stress) conditions and high production potential under non-salinity conditions (having high scores of 1st and 2nd component). Sardouie-Nasab et al. (2014) obtained similar results with bread wheat.

In this research, based on the analysis of salinity indices between studied synthetics wheat genotypes, Nos 18, 19, 4 and 27 were selected as the most salinity-tolerant lines. Lines Nos 5, 29, 15, 28, 4, 25 and 24 were stable genotypes for both conditions. Hence, these lines can be recommended to be used as donor parents for

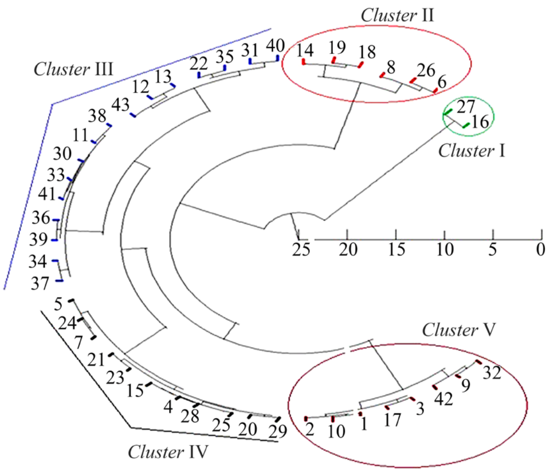


Figure 3. Dendrogram of 43 synthetic wheat lines generated by Ward's (1963) clustering method by Euclidean distance based on salinity stress indices

salinity tolerance genotypes in wheat breeding programs for salinity-affected areas of Azerbaijan Republic.

Cluster analysis based on Ward's (1963) method by using soil salinity tolerance indices and grain yield under salinity and non-salinity stress conditions classified all the studied wheat lines into five main groups (Fig. 3).

The cluster I only included lines Nos 16 and 27 that had high tolerance indices and produced low grain yield. The lines Nos 6, 26, 8, 18, 19 and 14 which are located in the cluster II contained the lines with moderate salinity stress and yield potential in both (non-salinity and salinity stress) conditions. All the lines located in the cluster III are salinity-sensitive genotypes. In the cluster IV lines Nos 29, 20, 25, 28, 4, 15, 23, 21, 7, 24 and 5 were identified as genotypes with high yield and stress tolerance potential in both (stress and non-stress) conditions and can be recommended to be used in salinity-affected and non-stress environments. In the cluster V, lines Nos 2, 10, 1, 17, 3, 42, 9 and 32 which were located in yield potential part C of biplot are considered to be most desirable genotypes for non-stress area. Cluster analysis was also used by several studies to classify genotypes according to their response to stress conditions (Nasim et al., 2014; Singh et al., 2015; Chunthaburee et al., 2016). The averages of some studied morphological traits in non-salinity and salinity stress conditions based on obtained fifth clusters are given in Table 5.

Table 5. The average of some main morphological traits of synthetic wheat lines based on salinity stress indices (cluster analysis)

Number of cluster	Line No.	Traits (average)											
		SW		GN		GW		SpN		TKW		HD	
		Ab	Uj	Ab	Uj	Ab	Uj	Ab	Uj	Ab	Uj	Ab	Uj
I	16, 27	2.67	3.32	38.13	51.22	1.38	2.50	18	20.25	31.74	48.10	128	132
II	6, 8, 14, 18, 19, 26	3.87	4.39	58.19	59.10	2.70	3.16	18.97	21.64	46.25	53.72	128.67	130.83
III	11, 12, 13, 22, 30, 31, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43	2.78	2.53	40.96	35.35	1.66	1.65	18.59	20.99	40.75	46.82	133	136.25
IV	4, 5, 7, 15, 20, 21, 23, 24, 25, 28, 29	3.93	3.40	58.89	50.31	2.66	2.52	19.01	20.64	45.67	50.30	127	130.68
V	1, 2, 3, 9, 10, 17, 32, 42	3.53	2.31	54.24	34.68	2.37	1.63	19.56	20.12	44.04	47.21	128.31	133

SW – spike weight, GN – grain number per spike, GW – grain weight per spike, SpN – spikelet number per spike, TKW – 1000 kernel weight, HD – heading date; Ab – Absheron region (non-salinity conditions), Uj – Ujar region (salinity stress conditions)

Conclusions

1. In the studied synthetic wheat lines the morphological traits, such as grain number per spike (GN), spike weight (SW), heading date (HD), plant height (PH), 1000 kernel weight (TKW), spike harvest index (SHI), spikelet number per spike (SpN) and spike fruiting efficiency (SFE) were the best criteria for improving grain yield in synthetic wheat under non-salinity and salinity stress conditions. As a result, screening for high values of these traits can bring an increase in wheat grain yield under the both (stress and non-stress) conditions.

2. Synthetic wheat lines Nos 5, 29, 15, 28, 4, 25 and 24 had the highest tolerance to soil salinity stress and produced the highest grain yield in both (non-salinity and salinity stress) conditions.

3. The selected wheat genotypes can be recommended as promising lines for salinity-affected areas. These lines can be utilized through appropriate selection as donor parents in wheat breeding programs for further improvement of wheat germplasm for soil salinity tolerance.

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Sintetinių kviečių linijų atsparumas dirvožemio druskingumo stresui

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Santrauka

Siekiant ištirti paprastojo kviečio (*Triticum aestivum* L.) linijų atsparumą dirvožemio druskingumo stresui ir nustatyti kiekybinius tolerancijos druskingumui rodiklius, buvo tirtos 43 sintetinių kviečių (*Triticum turgidum* × *Aegilops squarrosa*) linijos iš Tarptautinio kukurūzų ir kviečių selekcijos centro (Turkija) taikant atsitiktinių imčių pilno bloko bandymo schemą su dviem pakartojimais normaliomis (nedruskingomis) ir druskingumo streso sąlygomis Azerbaidžano Respublikos Absheron ir Ujar regionuose. Dispersinės analizės rezultatai parodė, kad tirti genotipai reikšmingai skyrėsi visais tirtais morfologiniais požymiais. Druskingumo streso tolerancijos rodikliai: jautrumo stresui indeksas, tolerancijos indeksas, vidutinio produktyvumo indeksas, tolerancijos stresui indeksas, geometrinis vidutinio produktyvumo indeksas ir vidutinis harmonijos indeksas, buvo apskaičiuoti pagal grūdų derlių druskingumo streso ir ne streso sąlygomis. Koreliacijos koeficientai parodė, kad tinkamiausi produktyvių ir dirvožemio druskingumui atsparių genotipų atrankos kriterijai yra geometrinis vidutinio produktyvumo, tolerancijos stresui, vidutinio produktyvumo bei vidutinis harmonijos indeksai.

Tyrimo rezultatai atskleidė, kad tirtų genotipų linijos Nr. 16 ir 27 buvo tolerantiškiausios druskingumo stresui, tačiau davė mažą grūdų derlių. Linijos Nr. 5, 29, 15, 28, 4, 25 bei 24 buvo tolerantiškos druskingumo stresui ir davė didžiausią grūdų derlių abiejuose auginimo fonuose. Nustatyta, kad šios kviečių linijos yra tinkamos auginti druskingumo streso sąlygomis ir vertingos hibridizacijos programoms, siekiant sukurti veisles, tolerantiškas druskingiems dirvožemiams.

Reikšminiai žodžiai: atsparumas dirvožemio druskingumo stresui, genetinė įvairovė, *Triticum turgidum* × *Aegilops squarrosa*.