Original scientific paper
DOI: /10.5513/JCEA01/25.1.3866
Journal of Central European Agriculture, 2024, 25(1), p.94-109

Investigation of agronomic traits, dry matter remobilization and stress indices in promising bread wheat genotypes under salinity stress

Elias ARAZMJOO[1] (✉), Ashkboos AMINI SEFIDAB[2]

[1] Horticulture Crops Research Department, South Khorasan Agricultural and Natural Resources Research and Education Centre, AREEO, Birjand, Iran

[2] Seed and Plant Improvement Institute, Agricultural Research, Education and Extension Organization, AREEO, Karaj, Iran

✉ Corresponding author: e.arazmjo@areeo.ac.ir

Received: January 23, 2023; accepted: November 24, 2023

ABSTRACT

Improving the crop yield by conventional breeding methods and selection of genetically modified genotypes are the basic approaches to produce tolerance against salinity stress. In total 20 wheat genotypes and cultivars in non-stress and salinity stress environments were evaluated during the cropping years of 2015-2016 in a randomized complete block design with three replications. The amount of dry matter during pollination and maturity stages was higher in non-stress conditions than in salinity stress. The results showed that exposure to salinity stress significantly increased dry matter remobilization and decreased current photosynthesis in wheat. The dry matter remobilization rate and its efficiency in genotypes No. 14, 16, and Arg cultivar and the dry matter remobilization ratio in genotypes No. 9, 5, and 14 were higher than others. Also, the Principal Component Analysis (PCA) showed that the first principal component (PC1) had a high positive correlation with grain yield under stress conditions (Ys) and MP, STI, GMP, HM, YI, and RSI indices, and the second principal component (PC2) had a high positive correlation with grain yield under non-stress conditions (Yp) and TOL and SSI indices. According to the biplot diagram, genotypes No. 16 and 14 with more value of PC1 and less value of PC2 identified as the most tolerant genotypes to salinity stress.

Keywords: grain filling period, grain yield, current photosynthesis, correlation

INTRODUCTION

Wheat is the most important crop that accounts for about 20% of the world's land and according to the FAO, the area under wheat cultivation in the world is more than 215 million hectares and its production is 731 million tons (Becker-Reshef et al., 2020). On the other hand, salinity is one of the major stresses in arid and semi-arid regions of the world that limits the production agricultural production. Salinity stress is a major threat to agricultural production and currently affects 20% of the world's arable land, which is constantly increasing due to climate change and human activities (Arora, 2019).

Stored carbohydrates in the stem are known as the total of unstructured carbohydrates (starch and sugars) and are different from the structural carbohydrates (cellulose, hemicelluloses) in the cell wall. The ability to store carbohydrates in the stem and the efficiency of transferring these reserves to the grain are two components that affect the estimated amount of stem reserves shared in grain yield (Ehdaie et al., 2006). In cereals including wheat, during a period of growth especially before flowering, the production of photosynthetic substances is more than the plant needs. In these cases excess photosynthetic substances

accumulate in the stems and leave pods as unstructured carbohydrates. These reserves are transferred to the grains in later stages of growth (Bahrani, 2011; Schauer and Fernie, 2006). Dry matter remobilization is very important in wheat because current photosynthesis as an important source of carbon for grain filling usually decreases after flowering due to aging and various stresses. Because of high respiration during the grain-filling period and the fact that photosynthesis of flag leaf alone is not sufficient to meet the respiratory and grain-filling requirements at the same time, so a significant amount of carbohydrate required by wheat grains comes from stem reserves before flowering (Sharbatkhari et al., 2014). In general, premature leaf aging, which serves as the main current source of grain filling, appears to limit the use of stem reserves (Blum, 1998). Researchers' results show that there is a wide genetic diversity for storage and carbohydrate remobilization between different wheat genotypes (Dabiri 2016, Piaskowski et al., 2016; Ehdaie et al., 2006; Ruuska et al., 2006). This indicates that stem water-soluble carbohydrates (WSC) levels are genetically determined and that selection for high-level WSC should be possible at the early generation stage of a breeding program (Rebetzke et al., 2008; Dong et al., 2016). The difference between the dry weight or stem-soluted carbohydrate content at the pollination and physiological maturity stages is one of the methods for estimating the transfer of stem reserves to grain (Ehdaie et al., 2006). According to Homayoun (2011), the amount of remobilization from stems under stress conditions is significantly higher than in favourable conditions. Mashi and Galeshi (2006) research on barley showed that when the plant was affected by salinity from the beginning of its growth, its grain yield decreased and in this case, the share of remobilization from stem reserves was 10% higher than the control treatment. Under environmental stress, the current photosynthetic capacity of the plant decreases, and grain filling depends on the remobilization of stem reserves, which contributes to the formation of grain yield of 22 to 66% of dry grain weight (Blum, 1998). On the other hand, due to the growing trend of salinization of arable lands in arid and semi-arid regions, the development of planting cultivars tolerant to salinity is necessary to produce economic production in these lands. To reduce the effects of salinity, there are various approaches such as drainage and cropping methods. One way to produce crops in lands with soil or water salinity is to modify and introduce genotypes that are compatible with salinity stress which has acceptable yield stability in saline conditions (Amini, 2013). Therefore, improving grain yield under stress conditions requires the identification of stress-tolerant genotypes. Several selection criteria have been proposed for the selection of genotypes based on their grain yield in stress and non-stress environments (Fischer and Maurer, 1978; Rosielle and Hamblin, 1981; Fernandez, 1992). Stress indices reflect the behaviour of the crop under stress concerning crop yield under non-stress and stress conditions. Some researchers recommend selecting in favourable environments, with the view that such cultivars are expected to retain their high yield potential in stress environments as well (Richards, 1996; Van-Ginkel et al., 1998; Betran et al., 2003). Some researchers also believe in simultaneous selection in stress and non-stress environments (Fischer and Mourer, 1978; Fernandez, 1992; Mitra, 2001; Nouri et al., 2011). Fischer and Mourer (1978) proposed the stress sensitivity index (SSI) and showed that this index is not independent of yield potential. Clarke et al. (1992) stated that SSI index did not differentiate between potentially stress resistant genotypes and those that have low overall yield potential. Rosielle and Hamblin (1981) introduced the stress tolerance index (TOL) based on the difference in yield measured under non-stress (Yp) and stress (Ys) conditions. But Fernandez (1992) stated that selection by TOL chooses genotype with low Yp but with high Ys (group C), hence, TOL deficiencies to distinguish between group C and genotype with high Yp and high Ys (group A). Rosielle and Hamblin (1981) defined the mean productivity index (MP). MP is mean yield for a genotype in two stress and non-stress conditions. MP can select genotypes with high Yp but with relatively low Ys (group B) and it fails to distinguish group A from group B. MP has an upward bias when there is a big difference between Yp and Ys. Mean geometric productivity (GMP), which is less

sensitive to very large values, is a better indicator than MP for isolating superior genotypes in both stress and non-stress environments (Rosielle and Hamblin, 1981). GMP is more powerful than MP in separating group A and has a lower susceptibility to different amounts of Ys and Yp. Fernandez (1992) has defined a new stress tolerance index (STI) that can be used to identify genotypes that produce high yields under both stress and non-stress conditions. A high STI demonstrates a high tolerance and the best advantage of STI is its ability to separate group A from others. Some researchers have suggested Principal Component Analysis (PCA) (Golabadi et al., 2006; Azizi Chakherchaman et al., 2009; Majidi et al., 2009). PCA is one of the most successful techniques for reducing the multiple dimensions of observed variables to inherently smaller dimensions than the independent variables (Johnson and Wichern, 2007). In PCA, the primary components are orthogonal linear combinations of the original variables. The first principal component is responsible for much of the variation in the original data. The second principal component tries to capture as much variance as possible in the data. Singh et al. (2015) in a study of wheat under salinity conditions reported that grain yield under stress and non-stress conditions had a positive correlation with GMP, MP, and STI indices, and these indices have been better compared to TOL, SSI, and YSI. In their study, the PC1 (the first principal component) and PC2 (the second principal component) explained 99.74% of the differences between genotypes, and the PC1 was correlated to YS, YP, MP, GMP, STI, and YI while the PC2 was correlated to YP, TOL, and SSI. The studies of Jamshidi and Javanmard (2017) on 26 barley genotypes showed that Nimroz, Kavir, Dasht and Yousef cultivars are the most sensitive and Reyhan, Makouti and Afzal cultivars are the most tolerant to salinity stress based on stress indices.

Evaluation of promising bread wheat genotypes in terms of dry matter remobilization, and determining the best index to identify salinity tolerant genotypes were the main objectives of this research.

MATERIAL AND METHODS

To evaluate the dry matter remobilization and stress indices in promising wheat genotypes under salinity stress, 17 promising genotypes obtained from wheat breeding programs of Iran temperate climate along with three check cultivars tolerant to salinity including Narin, Ofogh, and Arg were evaluated. The experiment carried out during the 2015-2016 crop year in two conditions of non-stress and salinity stress at the Agricultural and Natural Resources Research and Education Centre of South Khorasan. Non-stress and salinity stress experiments were performed separately from each other in a randomized complete block design with three replications. One field as saline conditions with irrigation water and soil-saturated extract ECs equal to 8.4 and 10.8 dS/m and one field as non-stress conditions with irrigation water and soil-saturated extract ECs equal to 3.4 and 3.9 dS/m were considered. In the salinity test, non-saline water was used for uniform emergence up to 2-3 leaf stage and complete plant establishment, and then saline water with electrical conductivity of 8.4 dS/m was used. The irrigation water for both experiments provided from well water. The names of the cultivars and pedigrees of the studied genotypes are presented in Table 1. The amount of rainfall and the average monthly temperature during the experiment are shown in Figure 1. The experimental field was not cultivated in the last year. The soil characteristics of the two sites are presented in Table 2.

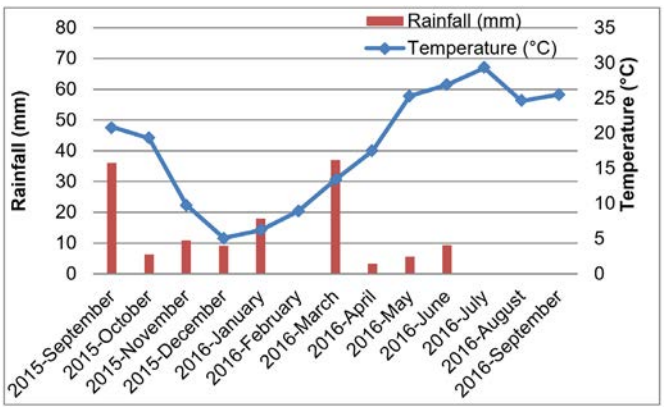

Figure 1. Monthly precipitation and average temperature during 2015-2016

Table 1. Wheat genotypes pedigree

No.	Pedigree
1	Narin
2	Ofogh
3	Arg
4	BAM/ Fiocco//KAVIR
5	BAM// Kauz/Sorkhtokhm/3/SISTAAN
6	BAM// Kauz/Sorkhtokhm/3/SISTAAN
7	BAM/WEEBILL1//KAVIR
8	BAM/WEEBILL1//Sistan
9	BAM/3/ IRENA/BABAX//PASTOR/4/SISTAAN
10	AKBARI/ WEEBILL1/3/Opata*2/Wulp//Mrn
11	SISTAAN // 1-70-28/BCN 88/3/KAVIR
12	SISTAAN/4/1-66-22//Bow"s"/Crow"s"/3/ Kavir/6/1-66-22//Bow"s"/Crow"s"/3/Kavir
13	1-66-22//Bow"s"/Crow"s"/3/Kavir/4/ IRENA/BABAX// PASTOR/5/SISTAAN
14	1-66-22//Bow"s"/Crow"s"/3/Kavir/4/ IRENA/BABAX// PASTOR/5/SISTAAN
15	Bam/webill1//Akbari
16	Bam/webill1//Akbari
17	Pishtaz/7/T.Aest/5/Ti/4/La/3/Fr/Kad//Gb/6/F13471/ Crow"
18	Pishtaz/7/T.Aest/5/Ti/4/La/3/Fr/Kad//Gb/6/F13471/ Crow"
19	Spn/Mcd//Cama/3/Nzr/4/Passarinho/5/Yaco/2*Parus/6/ Pishtaz
20	Nik.N/3/Kj1//Maya"S"/Mon"S"*2/5/Omid/4/Bb/Kal// Ald/3/Y50E/3*Kal//Emu

Cultivation was done with the Wintersteiger model seeder in 6 rows at a distance of 20 cm and a length of 2.5 meter and an area of 3 meter square. The amounts of 50, 100, and 100 kg/ha urea, triple superphosphate, and potassium sulphate fertilizers were used based on soil test and before planting, respectively. The remaining nitrogen was applied twice, each time 100 kg/ha as urea fertilizer in mid-March and April. The sowing date was in the second half of November and the amount of seed for planting was 450 seeds per square meter based on 1000-grain weight. Broadleaf weeds with 2,4-D herbicide and aphid pest with Diazinon pesticide were controlled in the tillering stage. Harvesting was done in the first half of July 2016.

The studied traits including the number of days to spike emergence, number of days to physiological maturity, grain filling period, plant height, 1000-grain weight, and grain yield were recorded and measured. To measure plant height, 5 plants were randomly selected after full maturity, and measurement was done on the main stem. To determine the grain yield, the whole plot was harvested by concerning margin effect and after threshing, the grain yield was weighed and for 1000-grain weight, three batches of 1000 grains from each genotype and cultivar were counted and their average was recorded. The relative amount of chlorophyll was read using SPAD (Minolta 502 model) in the pollination stage and 5 flag leaves (three points per leaf) of each treatment and their average was recorded. The SPAD 502 determines the relative amount of chlorophyll present by measuring the absorbance of the leaf in two wavelength (red and near-infrared) regions. Using these two absorbances, the meter calculates a numerical SPAD value which is proportional to the amount of chlorophyll present in the leaf.

Table 2. Physico-chemical traits of soil in different conditions (salt stress and none salt) of the experiment site

Experiment condition	Sand (%)	Silt (%)	Clay (%)	Soil Texture	pH	EC (dS/m)
Salinity stress	60.9	18	21.1	Sandy clay loam	8.13	10.8
non-stress	38	42	20	Loam	7.6	3.9

To measure the dry matter remobilization, 10 plants from each experimental plot at the pollination stage and 10 plants at physiological maturity were randomly removed from the soil surface. Samples were oven-dried at a temperature of 70 °C for 72 hours and the total weight of the plant, stem, and grain was measured. Then amount, efficiency, and the ratio of dry matter remobilization and the amount, efficiency, and ratio of current photosynthesis were calculated using the following equations (Papakosta and Gagianas, 1991):

Remobilization Amount (g/plant) = dry weight of vegetative parts in pollination (g/plant) - dry weight of parts in maturity (g/plant)

Remobilization Efficiency (g/g) = remobilization amount (g/plant) / dry weight of vegetative parts in pollination (g/plant)

Remobilization Ratio (%) = remobilization amount (g/plant) / grain weight per plant (g/plant) × 100

Current Photosynthesis Amount (grams per plant) = grain weight per plant (g/plant) - remobilization amount (g/plant)

Current Photosynthesis Efficiency (g/g) = current photosynthesis amount (g/plant) / dry weight of vegetative parts in pollination (g/plant)

Current Photosynthesis Ratio (%) = 100 - remobilization ratio.

Stress indices including MP, GMP, TOL, HARM, STI, YI, YSI, RSI, and SSI, their correlation with grain yield, and principal component analysis were calculated using the iPASTIC program (Pour-Aboughadareh et al., 2019). In the following equations, Yp and Ys are the average yield of all cultivars and genotypes under non-stress and stress conditions, respectively, and Ypi and Ysi are the average yields of each of them in both conditions.

1) SI = 1 − (Ys /Yp) (Fischer and Maurer, 1978)
2) SSI= (1 − (Ysi /Ypi))/ SI (Fischer and Maurer, 1978)
3) TOL = Ypi − Ysi (Rosielle and Hamblin, 1981)
4) STI = (Ypi × Ysi)/$(Yp)^2$ (Fernandez, 1992)
5) MP = (Ypi + Ysi)/2 (Rosielle and Hamblin, 1981)
6) GMP = $(Ypi \times Ysi)^{0.5}$ (Fernandez, 1992)
7) HARM= $(2\times(Y_{pi} \times Y_{si}))/(Y_{pi} + Y_{si})$ (Bidinger et al., 1987)
8) YI = Ysi / Ys (Gavuzzi et al., 1997)
9) YSI = Ysi / Ypi (Bouslama and Schapaugh, 1984)
10) RSI = (Ysi / Ypi) / (Ys + Yp) (Fischer and Wood, 1979)

Combined analysis of variance in two conditions to determine the main and interaction effects by two-way ANOVA and means comparison by Duncan's multiple range tests at 5% probability level was performed using SAS-9.0 software. The F test for the sources of variation was performed assuming the fixed effects for conditions and genotypes.

RESULTS AND DISCUSSION

Phenological traits

Analysis of variance showed that the effects of salinity stress and genotype on the number of days to spike emergence, number of days to physiological maturity and grain filling period, and also the interaction of stress × genotype on the number of days to physiological maturity were significant at 1% level (Table 3).

Based on the results, by exposing wheat to salinity stress, each of the mentioned traits was significantly reduced and the highest values were obtained in non-stress conditions. Salinity stress led to a reduction of 5.2, 9.9, and 4.6 days from the number of days to the spike emergence, the number of days to physiological maturity and the grain filling period, respectively, compared to non-stress conditions (Table 5). The results showed that in general, days to physiological maturity was less under salt stress conditions than non-stress conditions, which is not far from the expectation (Table 5). The interaction effect of stress × genotype showed that under salinity stress, genotypes No. 4, 7, and 16 and under non-stress conditions, genotypes No. 10, 1, and 12 had the highest number of days to maturity (the data is not shown). It has been reported that the grain filling period is one of the sensitive stages under various environmental stresses, including salinity, and is one of the main limitations of wheat production worldwide (Gosh et al., 2016). According to Grieve et al. (1994), all wheat phenological stages are accelerated by exposure to salinity stress.

Table 3. Analysis of variance for agronomic traits of wheat promising genotypes

Source of Variation	df.	Mean Squares										
		Heading	Maturity	Grain filling	Spike length	Peduncle length	Plant height	No. kernel per spike	Kernel weight per spike	1000 kernel weight	Grain yield	SPAD index
Condition	1	821.63**	2930**	648.67**	2.64 ns	1.08 ns	1030.2*	458.90*	0.01 ns	355.14*	40154167**	420.0*
Rep (Condition)	4	12.31	0.73	11.75	0.57	77.79	84.62	54.28	0.17	22.15	397133	28.43
genotype	19	52.64**	7.95**	50.64**	2.53**	29.80**	67.05**	145.24*	0.31 ns	66.23**	1586687**	28.11 ns
Genotype × Condition	19	3.58 ns	5.64**	6.75 ns	0.87**	23.60**	28.65 ns	58.54 ns	0.19 ns	41.47 ns	805366 ns	8.96 ns
Residual	76	3.32	1.65	4.75	0.03	3.30	25.30	70.04	0.19	29.58	692361	18.53
Coefficient Variation	-	1.75	0.88	5.22	1.82	5.63	6.95	17.15	24.73	15.08	24.74	8.10

* and ** are significantly different at α = 0.05 and α = 0.01, respectively and ns is non-significant (N = 120)

Table 4. Analysis of variance for remobilization and current photosynthesis in wheat promising genotypes

Source of Variation	df.	Mean Squares											
		Dry matter at anthesis			Dry matter at maturity			Remobilization			Current Photosynthesis		
		Plant	Spike	Stem+Leaf	Plant	Spike	Stem+Leaf	Amount	Efficiency	Ratio	Amount	Efficiency	Ratio
Condition	1	1.681*	0.936**	0.108 ns	13.51**	7.064**	1.036 ns	0.474**	0.263*	2569.7**	11.199**	3.901**	2569.7**
Rep (Condition)	4	0.137	0.008	0.121	0.549	0.230	0.139	0.005	0.017	29.1	0.233	0.082	29.1
Genotype	19	0.359**	0.066**	0.179**	0.843**	0.763**	0.090*	0.102**	0.021**	189.1**	0.739**	0.459**	189.1**
Genotype × Condition	19	0.040 ns	0.015 ns	0.024 ns	0.110 ns	0.099 ns	0.031 ns	0.006 ns	0.004 ns	18.5 ns	0.080 ns	0.055 ns	18.5 ns
Residual	76	0.044	0.019	0.034	0.142	0.158	0.045	0.019	0.009	33.7	0.143	0.098	33.7
Coefficient Variation	-	8.62	15.78	11.86	10.70	15.74	21.30	24.91	26.61	25.17	19.23	24.25	7.54

* and ** are significantly different at α = 0.05 and α = 0.01, respectively and ns is non-significant (N = 120)

DOI: /10.5513/JCEA01/25.1.3866

Table 3. Mean comparison for investigated agronomic traits, drought tolerance indices under stress and salinity stress conditions

Condition	Heading (day)	Maturity (day)	Grain filling (day)	Spike length (cm)	Peduncle length (cm)	Plant height (cm)	No. kernel per spike	Kernel weight per spike (gr)	1000 kernel weight (gr)	Grain yield (kg/ha)	SPAD index
non-stress	106.7 ^{a}	150.8 ^{a}	44.1 ^{a}	10.0 ^{a}	32.1 ^{a}	75.3 ^{a}	50.8 ^{a}	1.77 ^{a}	37.8 ^{a}	3941.7 ^{a}	51.3 ^{b}
Salinity stress	101.5 ^{b}	140.9 ^{b}	39.5 ^{b}	9.7 ^{a}	32.3 ^{a}	69.5 ^{b}	46.9 ^{b}	1.76 ^{a}	34.3 ^{b}	2784.7 ^{b}	55.0 ^{a}
Genotype											
1	101.0 ^{ij}	147.3 ^{b}	46.3 ^{a}	8.9 ^{h}	32.4 $^{c-g}$	73.7 ^{bc}	50.5 ^{abc}	2.01 ^{ab}	40.2 ^{ab}	2571.3 ^{bc}	53.7 ^{abc}
2	105.2 ^{cde}	146.7 ^{bc}	41.5 ^{efg}	10.3 ^{cd}	33.0 $^{c-f}$	70.9 ^{bcd}	55.2 ^{ab}	1.74 ^{abc}	31.5 ^{cde}	3103.8 ^{abc}	54.8 ^{abc}
3	102.3 $^{f-i}$	146.3 ^{bcd}	44.0 $^{a-e}$	8.9 ^{h}	33.5 $^{b-e}$	74.0 ^{bc}	47.5 ^{bcd}	1.95 ^{ab}	41.5 ^{a}	4126.7 ^{ab}	55.8 ^{abc}
4	107.3 ^{bc}	149.2 ^{a}	41.8 $^{d-g}$	10.3 ^{cd}	30.3 ^{g}	73.3 ^{bc}	45.3 ^{v}	1.67 ^{abc}	36.2 $^{a-e}$	3083.2 ^{abc}	52.6 ^{abc}
5	101.2 ^{ij}	144.3 ^{f}	43.2 $^{b-f}$	9.1 ^{h}	33.9 ^{bcd}	72.1 ^{bcd}	46.2 ^{bcd}	1.61 ^{abc}	35.1 $^{a-e}$	3991.0 ^{a}	56.0 ^{abc}
6	101.3 ^{ijh}	146.0 $^{b-f}$	44.7 $^{a-d}$	9.5 ^{fg}	33.1 $^{c-f}$	73.7 ^{bc}	47.5 ^{bcd}	1.82 ^{ab}	38.4 ^{abc}	3695.9 ^{ab}	53.7 ^{abc}
7	101.7 $^{g-i}$	146.5 ^{bcd}	44.8 ^{abc}	9.3 ^{g}	32.4 $^{c-g}$	73.0 ^{bc}	52.1 ^{abc}	2.07 ^{a}	39.5 ^{ab}	3350.1 ^{abc}	50.4 ^{bc}
8	100.2 ^{j}	145.7 $^{b-f}$	45.5 ^{ab}	9.7 ^{f}	36.8 ^{a}	81.5 ^{a}	42.6 ^{cd}	1.70 ^{abc}	38.8 ^{abc}	3209.1 ^{abc}	50.6 ^{bc}
9	101.8 $^{g-i}$	144.3 ^{f}	42.5 $^{c-g}$	10.0 ^{e}	31.3 ^{efg}	73.9 ^{bc}	48.1 ^{bcd}	1.75 ^{abc}	36.3 $^{a-e}$	3660.7 ^{ab}	52.3 ^{abc}
10	106.5 ^{cd}	146.3 ^{bcd}	39.8 ^{g}	11.0 ^{a}	31.8 $^{d-g}$	72.1 ^{bcd}	37.9 ^{d}	1.16 ^{c}	30.6 ^{de}	2789.2 ^{bc}	50.0 ^{c}
11	112.3 ^{a}	146.2 $^{b-e}$	33.8 ^{i}	10.1 ^{de}	27.8 ^{h}	68.0 ^{cd}	49.9 ^{abc}	1.61 ^{abc}	31.9 ^{cde}	2339.3 ^{c}	53.3 ^{abc}
12	104.5 ^{def}	146.5 ^{bcd}	42.0 $^{c-f}$	10.7 ^{b}	31.0 ^{fg}	65.4 ^{d}	52.9 ^{abc}	1.88 ^{ab}	34.7 $^{a-e}$	3480.3 ^{abc}	57.5 ^{a}
13	104.5 ^{def}	145.8 $^{b-f}$	41.3 ^{efg}	10.4 ^{c}	32.2 $^{c-g}$	71.9 ^{bcd}	52.4 ^{abc}	1.82 ^{ab}	35.4 $^{a-e}$	3244.9 ^{abc}	54.7 ^{abc}
14	104.0 ^{efg}	144.8 ^{def}	40.8 ^{fg}	10.8 ^{ab}	32.4 $^{c-g}$	76.6 ^{ab}	52.9 ^{abc}	2.00 ^{ab}	37.8 $^{a-d}$	4026.3 ^{a}	53.4 ^{abc}
15	108.8 ^{b}	145.3 $^{c-f}$	36.5 ^{h}	10.3 ^{cd}	34.6 ^{bc}	72.9 ^{bc}	48.8 ^{bcd}	1.43 ^{bc}	29.8 ^{e}	2802.7 ^{bc}	50.8 ^{bc}
16	103.7 $^{e-h}$	146.2 $^{b-e}$	42.5 $^{c-g}$	9.7 ^{f}	32.1 $^{d-g}$	69.2 ^{cd}	50.1 ^{abc}	1.71 ^{abc}	33.7 $^{b-e}$	4178.4 ^{a}	56.3 ^{ab}
17	104.7 ^{def}	145.3 $^{b-e}$	40.7 ^{fg}	10.2 ^{cde}	32.0 $^{d-g}$	69.0 ^{cd}	44.9 ^{bcd}	1.74 ^{abc}	38.7 ^{abc}	3714.2 ^{ab}	51.8 ^{abc}
18	104.7 ^{def}	144.8 ^{def}	40.2 ^{g}	8.9 ^{h}	27.6 ^{h}	72.2 ^{bcd}	45.5 ^{bcd}	1.63 ^{abc}	35.5 $^{a-e}$	3514.0 ^{ab}	50.9 ^{bc}
19	102.8 $^{e-i}$	145.0 $^{c-f}$	42.2 $^{c-g}$	9.5 ^{fg}	30.8 ^{fg}	74.1 ^{bc}	45.2 ^{bcd}	1.79 ^{ab}	39.5 ^{ab}	3085.1 ^{abc}	52.6 ^{abc}
20	103.2 $^{e-i}$	144.5 ^{ef}	41.3 ^{efg}	9.6 ^{f}	35.8 ^{ab}	70.2 ^{bcd}	60.5 ^{a}	2.18 ^{a}	36.2 $^{a-e}$	3298.1 ^{abc}	52.1 ^{abc}

Means followed by similar letters in each column are not significantly different at P = 5%, Duncan Multiple Range Test (N = 120)

Ahmad et al. (2013) reported early ripening of wheat under salinity stress and consequent reduction of plant height and leaf area. Although the number of grain yield components in cereals is determined at the vegetative stage, the actual stage of grain production is between spike emergence and ripening, and shortening this stage reduces yield (Savin et al., 1996). Under salinity stress, the grain filling period decreases, and consequently, grain yield decreases. Genotypes No. 11 and 15 had the longest time until the spike emergence and the shortest grain filling period among other cultivars and genotypes (Table 5). The highest number of days to maturity with 149.2 and 147.3 days was related to genotype No. 4 and check cultivar Narin and the highest grain filling period with 46.3 and 45.5 days was related to check cultivar Narin and genotypes No. 8 (Table 5).

Morphological traits and SPAD index

Among spike length, peduncle length, plant height, and SPAD index, only plant height and SPAD index were affected by salinity stress at the level of 5% (Table 3). The effect of genotypes on all three morphological traits and the interaction of stress × genotype on spike and peduncle length was also significant (Table 3). Comparison of means showed that the wheat height decreased significantly by 7.7% with exposure to salinity stress compared to non-stress conditions (Table 5). Otu et al. (2018) reported that wheat exposure to salinity reduced plant height and shoot dry weight, and attributed such destructive effects to the direct effect of salinity stress on photosynthesis. Salinity stress also led to a 7.2% increase in the SPAD index (Table 5). Wheats grown under higher salinity treatments were characterized by considerably higher photosynthetic pigment content per leaf area (Shah et al., 2017). They have reported that plants under increasingly saline treatments exhibited more green leaves compared to non-saline conditions. However, the overall size and volume of the green biomass was lower for the saline treatments (Shah et al., 2017). Genotypes No. 10, 12, and 13 had longer spike lengths compared to other cultivars and genotypes, respectively (Table 5). The interaction effect of stress × genotype showed that under salinity stress, genotypes No. 10, 12, and 13 and under non-stress conditions, genotypes No. 4, 10, 13, and 14 had the highest spike length and peduncle length (the data is not shown). Genotypes No. 8, 14, and 19 also had the highest plant height, and genotypes No. 8, 20, and 15 had the highest peduncle length (Table 5).

Grain yield and yield components

Based on the results of the analysis of variance, the number of grains per spike and 1000-grain weight at a 5% level and grain yield at a 1% level of probability was affected by salinity stress (Table 3). The effect of the genotype was also significant on the number of grains per spike at a level of 5% and 1000-grain weight and grain yield at a 1% level of probability (Table 3). Grain weight per spike was not affected by any of the treatments and their interaction (Table 3). The study showed a decrease of 7.7, 9.2, and 29.3% in the number of grains per spike, 1000-grain weight, and wheat grain yield under salinity stress compared to non-stress conditions (Table 5). Hassan et al. (2015) reported that salinity reduced the number of grains per spike, 1000-grain weight, and grain yield in salinity-sensitive cultivars of wheat. Sodium toxicity, pollen sterility, reduced production of assimilates, and reduced allocation of assimilates to grains have been reported as reasons for the reduction in grain yield under salinity stress (Dadshani et al., 2019). Genotype No. 20 and check cultivar Ofogh with 60.5 and 55.2 grains, respectively, had the highest and genotype No. 10 with 37.9 grains had the lowest number of grains per spike (Table 5). Check cultivars of Arg and Narin with 41.5 gram and 40.2 gram had the highest 1000-grain weight and genotype No. 15 with 29.8 gram had the lowest 1000-grain weight among other cultivars and genotypes (Table 5). Means comparison for grain yield of genotypes also showed that genotype No. 16, check cultivar Arg and genotypes No. 14 and 5 with 4178.4, 4126.7, 4026.3, and 3991.0 kg/ha, in the superior statistical group compared to the others and genotype, had the highest grain yield, respectively. Genotype No. 11, which had the highest number of days to spike emergence and the shortest grain filling period, had the lowest grain yield

with 2339.3 kg/ha (Table 5). According to the results, genotypes with higher grain yield had less number of days to spike emergence and longer grain filling periods than the total average (Table 5). In the climatic conditions of South Khorasan province, which also faces the problem of high temperature and drought at the grain filling period and maturity, cultivars and genotypes are suitable that the spikes emergence occurred earlier and had normal physiological maturity to avoid high temperature and drought at the grain filling period and maturity and as a result, their grain filling period occurs at a more suitable temperature.

Dry matter remobilization and current photosynthesis

Analysis of variance showed that the dry matter of the whole plant and spike at the pollination stage, dry matter whole plant, and spike at maturity, remobilization, and current photosynthesis indices were significantly affected by salinity stress but the dry matter of stem + leaf at pollination stage and dry matter of stem + leaf at maturity were not affected by salinity stress (Table 4). The effect of genotype on all the mentioned traits was significant but the interaction of stress × genotype was not significant on any of them (Table 4). The results showed that in non-stress condition, spike and whole plant dry matter at pollination and maturity was higher compared to the salinity condition. Salinity stress led to a significant reduction of 9 and 17.3% of whole plant dry matter at pollination and maturity and 17.9% and 17.7% of spike dry matter at pollination and maturity compared to non-stress conditions, respectively (Table 6). The results also showed that exposure to salinity stress significantly increased the amount, efficiency and ratio of dry matter remobilization and decreased the amount, efficiency, and ratio of current photosynthesis in wheat (Table 6). The amount of dry matter remobilization under salinity and normal conditions were 0.62 and 0.50 g/plant, and on the other hand, the amount of current photosynthesis under salinity and normal conditions were 1.66 and 2.27 g/plant, respectively (Table 6). Raeisi et al., (2021) reported carbohydrate remobilization from the stem increased by 36.8% in salinity stress compared to the control. The increase in carbohydrate remobilization under stress conditions may be due to the increased demand for sinks in conditions of limited photosynthesis because sink demand is the primary determinant of stem remobilization (Bonnet and Incoll, 1993). Jamil et al. (2007) reported that reduction in the current photosynthesis under salinity stress may be due to lower stomatal conductance, a decrease in metabolic processes, especially carbon sequestration, and inhibited photosynthetic capacity or a combination of these. Moradi and Abdelbagi (2007) also concluded that reduced plant photosynthesis may be due to a reduction in chlorophyll accumulation or changes in chloroplast structure under salinity stress. As was observed in our results, salinity stress tended to enhance the SPAD index, which measured per leaf area, but it should be noted that the total pigment content per plant decreases as a result of smaller leaves under salinity stress. Remobilization of compounds stored in the stem to growing seeds is one of the mechanisms involved in the formation of economic yield and its stability, especially in stressful conditions, and can be an important and supportive process to largely compensate for the decrease in grain yield (Netanos and Koutroubas, 2012). Among the cultivars and genotypes studied, the highest amounts of plant and stem + leaf dry matter in the pollination stage were in genotypes No. 16 and 6, respectively, and the highest amounts of spike dry matter in the pollination stage were in genotype No. 7, check cultivar of Arg and genotype No. 17, respectively (Table 6). However, at the maturity stage, the highest amounts of plant and spike dry matter were related to genotype No. 20 and the lowest to genotype No. 9, and the highest amounts of stem + leaf dry matter were related to check cultivars of Ofogh and genotype No. 6 (Table 6). The amount and the efficiency of dry matter remobilization in genotypes No. 14, 16, the check cultivar of Arg, and genotypes No. 7 and 17, and the ratio of dry matter remobilization in genotypes No. 9, 5, and 14 were higher than other cultivars and genotypes (Table 6). In other words, the cultivars and genotypes mentioned earlier that had higher grain yield had more dry matter remobilization as well. Genotypes No. 20, 4, 17, and 1 also had the highest current photosynthesis

Table 6. Mean comparison for investigated agronomic traits, drought types under non-stress and saline conditions

Condition	Dry matter at anthesis (gr)			Dry matter at maturity (gr)			Dry matter Remobilization			Current Photosynthesis		
	Plant	Spike	Stem+Leaf	Plant	Spike	Stem+Leaf	Amount (gr/plant)	Efficiency (gr/gr)	Ratio (%)	Amount (gr/plant)	Efficiency (gr/gr)	Ratio (%)
non-stress	2.54 a	0.95 a	1.59 a	3.86 a	2.77 a	1.09 a	0.50 b	0.31 b	18.4 b	2.27 a	1.47 a	81.6 a
Salinity stress	2.31 b	0.78 b	1.53 a	3.19 b	2.28 b	0.91 a	0.62 a	0.41 a	27.7 a	1.66 b	1.11 b	72.3 b
Genotype												
1	2.15 hi	0.84 c-h	1.31 efg	3.59 bcd	2.72 a-d	0.88 cd	0.43 fg	0.33 bcd	16.2 f	2.28 a-d	1.77 a	83.8 a
2	2.61 a-d	0.89 a-g	1.72 ab	3.60 bcd	2.34 c-g	1.27 a	0.45 fg	0.26 d	19.6 def	1.89 cde	1.14 cde	80.4 abc
3	2.68 a-d	1.03 ab	1.65 a-d	3.75 abc	2.83 abc	0.92 cd	0.73 abc	0.45 ab	26.2 a-d	2.10 a-d	1.27 bcd	73.8 c-f
4	2.32 e-h	0.87 a-g	1.45 c-g	3.89 ab	2.90 ab	0.99 a-d	0.46 fg	0.31 bcd	16.1 f	2.45 ab	1.70 ab	83.9 a
5	2.44 e-h	0.84 b-h	1.60 bcd	3.11 def	2.16 fgh	0.95 bcd	0.65 b-e	0.42 abc	32.0 ab	1.51 ef	0.94 de	68.0 ef
6	2.79 ab	0.94 a-e	1.85 a	3.41 b-e	2.17 e-h	1.24 ab	0.62 c-f	0.33 bcd	28.9 abc	1.56 ef	0.84 e	71.1 def
7	2.73 abc	1.04 a	1.68 abc	3.86 abc	2.84 abc	1.01 a-d	0.67 a-d	0.40 abc	24.7 b-e	2.18 a-d	1.31 bcd	75.3 b-e
8	2.11 hi	0.81 d-h	1.30 fg	3.11 def	2.22 d-h	0.89 cd	0.41 g	0.34 bcd	18.9 def	1.81 de	1.43 abc	81.1 abc
9	2.26 f-i	0.70 gh	1.56 b-e	2.70 f	1.71 h	0.99 a-d	0.57 c-g	0.37 a-d	33.4 a	1.14 f	0.76 e	66.6 f
10	2.52 b-f	0.87 a-g	1.65 a-d	3.84 abc	2.71 a-e	1.13 abc	0.52 d-g	0.32 bcd	19.7 def	2.19 a-d	1.34 bcd	80.3 abc
11	2.23 ghi	0.78 a-g	1.45 c-g	3.35 cde	2.41 b-g	0.94 cd	0.51 d-g	0.35 bcd	21.6 c-f	1.90 cde	1.32 bcd	78.4 a-d
12	2.01 i	0.77 e-h	1.24 g	3.03 ef	2.21 d-h	0.82 d	0.43 fg	0.34 bcd	19.2 def	1.79 de	1.44 abc	80.8 abc
13	2.46 c-g	0.89 a-f	1.56 bcd	3.78 abc	2.67 a-f	1.11 a-d	0.46 fg	0.29 cd	17.8 ef	2.22 a-d	1.41 abc	82.2 ab
14	2.71 a-d	0.97 a-d	1.75 ab	3.59 bcd	2.68 a-f	0.91 cd	0.84 a	0.49 a	31.7 ab	1.84 de	1.07 cde	68.3 ef
15	2.24 ghi	0.67 h	1.57 bcd	3.52 bcd	2.42 b-g	1.10 a-d	0.48 efg	0.32 bcd	20.5 def	1.95 b-e	1.27 bcd	79.5 abc
16	2.81 a	0.94 a-e	1.87 a	3.82 abc	2.75 a-d	1.07 a-d	0.80 ab	0.43 ab	29.1 abc	1.95 b-e	1.05 cde	70.9 def
17	2.56 a-e	1.02 abc	1.54 b-f	3.65 abc	2.78 abc	0.86 cd	0.67 a-d	0.45 ab	26.1 a-d	2.11 a-d	1.35 bcd	73.9 c-f
18	2.29 e-i	0.84 b-h	1.45 c-g	3.83 abc	2.91 ab	0.92 a-d	0.53 d-g	0.36 a-d	18.8 def	2.38 abc	1.67 ab	81.2 abc
19	2.13 e-i	0.74 fgh	1.40 d-g	2.97 ef	2.02 gh	0.95 bcd	0.45 fg	0.32 bcd	23.7 c-f	1.57 ef	1.16 cde	76.3 a-d
20	2.44 d-g	0.86 b-g	1.58 bcd	4.14 a	3.05 a	1.09 a-d	0.49 d-g	0.31 bcd	16.6 f	2.56 a	1.62 ab	83.4 a

Means followed by same letter in each column are not significantly different at $P = 5\%$, Duncan Multiple Range Test (N = 120)

amount, efficiency, and its ratio in grain filling period (Table 6). Pirdashti et al. (2004) also reported that high-yielding cultivars remobilize larger amounts of dry matter from their aerial parts. These genotypes seem to be more capable of storing photosynthetic materials as well as more efficient in transmitting these reserves. Genetic diversity is one of the most important factors affecting remobilization in different cultivars (Blum, 1998). Since different genotypes of a plant have different genetic structures, differences in the amount, efficiency, and ratio of dry matter remobilization are not uncommon, as, in one study, wheat hexaploid genotypes react differently in terms of dry matter accumulation and distribution between organs and its transfer (Mehrpouyan et al., 2012). Under environmental stress, the current photosynthetic capacity of the plant decreases, and grain filling depends on the remobilization of stem reserves, which contributes to the formation of grain yield of 22 to 66% of dry grain weight (Blum, 1998). Sharbatkhari et al. (2014) also stated that the highest and lowest remobilization rate from stem and internodes under salinity stress was related to the Bam and Ghods cultivars, respectively.

Stress indices

Grain yield under non-stress (Yp) and stress condition (Ys) and stress indices of the studied genotypes are presented in Table 7. Based on the yield stability index (YSI), yield index (YI), and relative stress index (RSI), whose high numerical values indicate higher tolerance of the cultivar to stress, as well as the stress sensitivity index (SSI) and tolerance index (TOL), whose low numerical values indicate higher tolerance of cultivar to stress, genotypes No. 16, 14 and 6 were recognized as the most tolerant genotypes to salinity stress, and genotype No. 2, 10 and 11 were also recognized as the most sensitive genotypes to salinity stress, respectively (Table 7). In terms of stress tolerance index (STI), mean productivity (MP), geometric mean productivity (GMP), and harmonic average index (HARM), whose high numerical values indicate higher tolerance of the cultivar to stress, genotypes No. 16, 3, and 14 were the most tolerant and No. 11, check cultivar of Narin and genotype No. 10 were the most sensitive to salinity stress, respectively (Table 7).

The most suitable index for selecting stress-tolerant cultivars is an index that has a high correlation with grain yield in both conditions, so by examining the correlation between indices and grain yield in two environments, it is possible to identify the most appropriate index (Naeemi et al., 2008). The results of the correlation between the mentioned indices and grain yield in the two environments are presented in Figure 2. In this figure, the correlation coefficients are shown as small and large circles, and the larger the circles, the more significant the correlation between the two statistics. The colour spectrum of white to red and blue to white also represent positive and negative coefficients, respectively. The results showed that there was no significant correlation between grain yield under non-stress conditions (Yp) and grain yield under salinity conditions (Ys), in other words, high-yield genotypes under non-stress conditions do not necessarily have good yield under salinity stress (Figure 2). The results showed that all stress indices had a high correlation with grain yield under salinity stress (Ys) but less correlation was observed for grain yield under non-stress conditions (Yp). Grain yield under salinity stress (Ys) was positively and significantly correlated with YI, HM, GMP, STI, RSI, YSI, and MP indices and negatively and significantly correlated with SSI and TOL indices, respectively. On the other hand, grain yield under non-stress conditions (Yp) had the highest positive and significant correlation with MP, STI, GMP, and HM indices, respectively, and there was not a significant correlation between Yp and other indices (Figure 2). As a result, YI, HM, GMP, STI, RSI, YSI, and MP indices are suitable for the selection of wheat cultivars and genotypes in the areas that are most exposed to salinity stress, respectively, and MP, STI, GMP, and HM indices, are suitable for selection in areas not exposed to salinity stress, respectively. Shafazadeh et al. (2004) also stated that the three indices of STI, GMP, and MP had a positive and significant correlation with the wheat genotypes yield in both stress and non-stress environments and they are suitable for identifying drought-tolerant genotypes with high-yield potential. Amini et al. (2016) reported STI, MP, and GMP are suitable indices to identify high-yielding genotypes in both salinity and non-stress conditions.

Table 7. Average grain yield of 20 promising wheat genotypes and tolerance and susceptibility indices and their ranking

Genotype	Yp	R.	Ys	R.	TOL	R.	MP	R.	GMP	R.	HM	R.	SSI	R.	STI	R.	YI	R.	YSI	R.	RSI	R.
G1	3.38	18	1.77	17	1.61	15	2.58	19	2.45	19	2.32	19	1.62	17	0.39	19	0.64	17	0.52	17	0.74	17
G2	4.60	2	1.61	19	2.99	20	3.11	14	2.72	17	2.39	17	2.22	20	0.48	17	0.58	19	0.35	20	0.50	20
G3	4.69	1	3.56	4	1.13	11	4.13	2	4.09	2	4.05	2	0.82	8	1.08	2	1.28	4	0.76	8	1.07	8
G4	3.58	16	2.58	13	1.00	8	3.08	16	3.04	14	3.00	14	0.95	12	0.59	14	0.93	13	0.72	12	1.02	12
G5	4.60	2	3.38	5	1.22	13	3.99	4	3.94	4	3.90	4	0.90	9	1.00	4	1.21	5	0.73	9	1.04	9
G6	3.76	14	3.63	3	0.13	3	3.70	6	3.69	5	3.69	5	0.12	3	0.88	5	1.30	3	0.97	3	1.37	3
G7	3.60	15	3.10	7	0.50	5	3.35	10	3.34	9	3.33	9	0.47	5	0.72	9	1.11	7	0.86	5	1.22	5
G8	3.43	17	2.99	10	0.44	4	3.21	13	3.20	12	3.19	11	0.44	4	0.66	12	1.07	10	0.87	4	1.23	4
G9	4.25	5	3.07	8	1.18	12	3.66	7	3.61	7	3.56	7	0.95	11	0.84	7	1.10	8	0.72	11	1.02	11
G10	3.86	12	1.72	18	2.14	19	2.79	18	2.58	18	2.38	18	1.89	19	0.43	18	0.62	18	0.45	19	0.63	19
G11	3.15	20	1.53	20	1.62	16	2.34	20	2.20	20	2.06	20	1.75	18	0.31	20	0.55	20	0.49	18	0.69	18
G12	4.50	4	2.46	14	2.04	18	3.48	9	3.33	10	3.18	12	1.55	16	0.71	10	0.88	14	0.55	16	0.77	16
G13	3.89	11	2.60	12	1.29	14	3.25	12	3.18	13	3.12	13	1.13	14	0.65	13	0.93	12	0.67	14	0.95	14
G14	4.08	8	3.97	2	0.11	2	4.03	3	4.02	3	4.02	3	0.09	2	1.04	3	1.43	2	0.97	2	1.38	2
G15	3.29	19	2.31	15	0.98	7	2.80	17	2.76	16	2.71	16	1.02	13	0.49	16	0.83	15	0.70	13	0.99	13
G16	4.22	6	4.13	1	0.09	1	4.18	1	4.17	1	4.17	1	0.07	1	1.12	1	1.48	1	0.98	1	1.38	1
G17	4.22	6	3.21	6	1.01	9	3.72	5	3.68	6	3.65	6	0.82	7	0.87	6	1.15	6	0.76	7	1.08	7
G18	3.97	9	3.06	9	0.91	6	3.52	8	3.49	8	3.46	8	0.78	6	0.78	8	1.10	9	0.77	6	1.09	6
G19	3.93	10	2.24	16	1.69	17	3.09	15	2.97	15	2.85	15	1.47	15	0.57	15	0.80	16	0.57	15	0.81	15
G20	3.82	13	2.78	11	1.04	10	3.30	11	3.26	11	3.22	10	0.93	10	0.68	11	1.00	11	0.73	10	1.03	10

Yp, Ys, TOL, MP, GMP, HM, SSI, STI, YI, YSI, RSI indicate grain yield under control condition, grain yield under drought stress condition, tolerance index, mean productivity, geometric mean productivity, harmonic mean, stress susceptibility index, stress tolerance index, yield index, yield stability index, relative stress index, respectively.

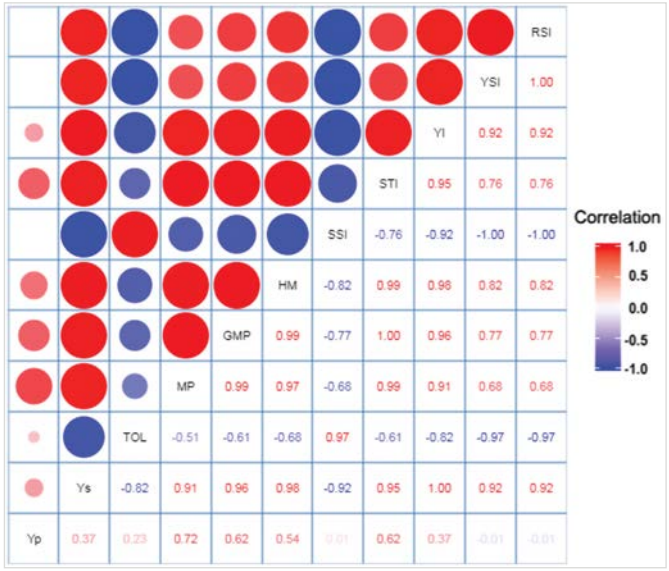

Figure 2. View of correlation between stress tolerance and sensitivity indices with grain yield in two environments

A more appropriate method compared to simple correlation analysis in selecting and identifying superior genotypes for stress and non-stress conditions are to use a biplot because in this method genotypes are compared based on all traits simultaneously (Amiri et al., 2014). In PCA, the primary components are orthogonal linear combinations of the original variables. The first principal component is responsible for much of the variation in the original data. The second principal component tries to capture as much variance as possible in the data. Examination of the biplot diagram in the present experiment showed that the share of the first component in explaining the changes of all indicators is equal to 81.36% and the share of the second component is 18.30% (Figure 3). Eigenvalues for PC1 and PC2 were 8.949 and 2.012, respectively. Given that the first principal component includes changes that cannot be explained by the second principal component and vice versa, it is possible to display the changes of the above two components perpendicular to each other so that the studied genotypes were marked as points at the graph based on these components and a total of 99.66% of the changes were explained by the first and second principal components (Figure 3). As shown in Figure 3, the first principal component has a positive and high correlation with grain yield under stress conditions and MP, STI, GMP, HM, YI, and RSI indices and it has a negative correlation with TOL and SSI indices, therefore this component is related to salinity stress tolerance. In all these indices except for TOL and SSI, their high numerical values are desirable and as the component increases, genotypes with high grain yield and tolerance to salinity stress are selected. The second principal component also had a positive and high correlation with grain yield under non-stress conditions and TOL and SSI indices in which low numerical values are desirable, therefore the second component indicates sensitivity to salinity stress and any increase in its value would lead to the selection of genotypes more sensitive to salinity stress (Zebarjadi et al., 2016) (Figure 3). The selection of genotypes with high values of the first component and low values of the second component leads to the identification of suitable genotypes for both stress and non-stress environments (Shahryari and Mollasadeghi, 2011). According to the biplot diagram, genotypes No. 16 and 14 with more value of the first component and less of the second component are the most tolerant genotypes to salinity stress (Figure 3). The pedigree of the mentioned genotypes in Table 1 indicates that they are the results of the crossing of Sistan, Bam, Arg and Kavir, which are commercial cultivars cultivated in the saline fields of Iran.

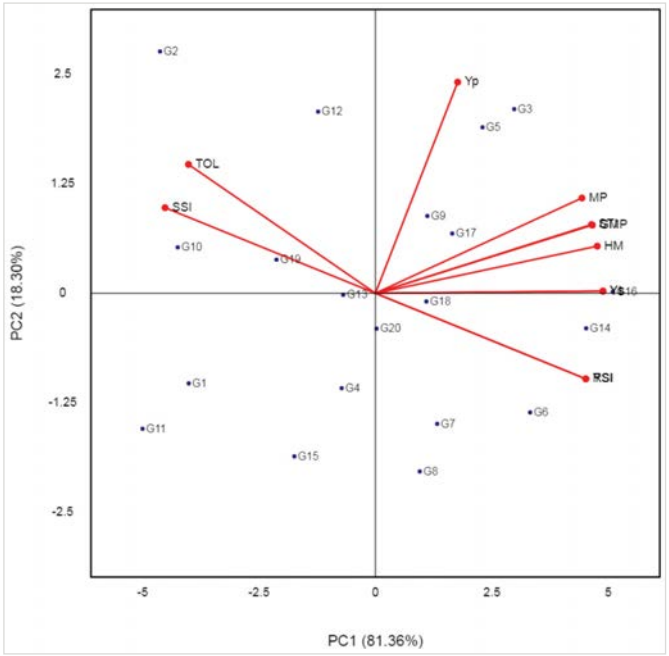

Figure 3. Biplot diagram of promising wheat genotypes based on the first and second components

These cultivars were selected from Iran's national wheat breeding program and have high tolerance to salinity stress and they are used in wheat breeding programs in order to increase tolerance to salinity stress.

CONCLUSION

Overall, the results showed that phenological, morphological, grain yield components and grain yield of wheat under salinity stress had a significant decrease compared to non-stress conditions. Dry matter remobilization increased under salinity stress but current photosynthesis decreased under this condition. Genotypes with more dry matter remobilization also had higher grain yields. The amount and efficiency of dry matter remobilization in genotypes No. 14, 16, Arg cultivar and genotypes No. 7 and 17 were higher than other cultivars and genotypes. Genotypes No. 16, Arg cultivar, and genotypes No. 14 and 5 had the highest grain yield. Based on the results of correlation analysis of stress indices with grain yield in stress and non-stress conditions, YI, HM, GMP, STI, RSI, YSI, and MP were the best indices in wheat for the selection of salt tolerant genotypes, respectively.

REFERENCES

Ahmad, M., Shahzad, A., Iqbal, M., Asif, M., Hirani, A. H. (2013) Morphological and molecular genetic variation in wheat for salinity tolerance at germination and early seedling stage. Australian Journal of Crop Science, 7 (1), 66-74. Available at: http://www.cropj.com/january2013.html [Accessed 1 January 2013].

Amini, A. (2013) Evaluation of bread wheat (*Triticum aestivum* L.) lines in preliminary regional yield trials in saline areas (temperate and warm zones). Cereals Research Department, Seed and Plant Breeding Research Institute., p. 22.

Amini, A., Amirnia, R., Ghazvini, H. A. (2016) Evaluation of salinity tolerance in bread wheat genotypes under field conditions. Seed and Plant Journal, 1 (31), 95-115. DOI: https://dx.doi.org/10.22092/spij.2017.111250

Amiri, R., Bahraminejad, S., Sasani, S., Ghobadi, M. (2014) Genetic evaluation of 80 irrigated bread wheat genotypes for drought tolerance indices. Bulgarian Journal of Agricultural Science, 20, 101-111. Available at: https://journal.agrojournal.org/page/en/details.php?article_id=806 [Accessed 2 December 2013].

Arora, N. K. (2019) Impact of climate change on agriculture production and its sustainable solutions. Environmental Sustainability, 2, 95-96. DOI: https://doi.org/10.1007/s42398-019-00078-w

Azizi-Chakherchaman, S. H., Mostafaei, H., Imanparast, L., Eivazian, M. R. (2009) Evaluation of drought tolerance in lentil advanced genotypes in Ardabil region. Journal of Food, Agriculture and Environment, 7, 283-288. Available at: https://pubag.nal.usda.gov/catalog/774952 [Accessed 1 January 2009].

Bahrani, A. (2011) Remobilization of dry matter in wheat: Effects of nitrogen application and post-anthesis water deficit during grain filling. International Conference on Biology, Environment and Chemistry. pp. 155-160. DOI: https://doi.org/10.1080/01140671.2011.599397

Becker-Reshef, I., Justice, C., Barker, B., Humber, M., Rembold, F., Bonifacio, R., Zappacosta, M., Budde, M., Magadzire, T., Shitote, C. (2020) Strengthening agricultural decisions in countries at risk of food insecurity: The GEOGLAM Crop Monitor for EarlyWarning. Remote Sensing of Environment, 237, 111553. DOI: https://doi.org/10.1016/j.rse.2019.111553

Betran, F. J., Beck, D., Banziger, M., Edmeades, G. O. (2003) Genetic analysis of inbred and hybrid grain yield under stress and non-stress environments in tropical maize. Crop Science, 43, 807-817. DOI: https://doi.org/10.2135/cropsci2003.8070

Bidinger, F.R., Mahalakshmi, V., Rao, G.D. (1987) Assessment of drought resistance in pearl millet (*Pennisetum americanum* (L.) Leeke). II. Estimation of genotype response to stress. Australian Journal of Agricultural Research, 38, 49–59. DOI: http://dx.doi.org/10.1071/AR9870037

Blum, A. (1998) Improving wheat grain filling under stress by stem reserve mobilization (Reprinted from Wheat: Prospects for global improvement. Euphytica, 100, 77-83. DOI: https://doi.org/10.1023/A:1018303922482

Bonnet, G. D., Incoll, L. D. (1993) Effects on the stem of winter barley of manipulating the source and sink during grain filling. Journal of Experimental Botany, 44, 83-91. DOI: https://doi.org/10.1093/jxb/44.1.83

Bouslama, M., Schapaugh, W.T. (1984) Stress tolerance in soybean. Part 1: evaluation of three screening techniques for heat and drought tolerance. Crop Science, 24, 933–937. DOI: https://doi.org/10.2135/cropsci1984.0011183X002400050026x

Clarke, J. M., DePauw, R. M., TownleySmith, T. F. (1992) Evaluation of methods for quantification of drought tolerance in wheat. Crop Science, 32, 723–728. DOI: https://doi.org/10.2135/cropsci1992.0011183X003200030029x

Dabiri, Sh. (2016) Evaluation of advanced bread wheat genotypes for remobilization of stored assimilates to grain and spike photosynthesis in rainfed and supplementary irrigation conditions. Ph.D. thesis, Faculty of Agricultural Sciences, Sari Agricultural Sciences and Natural Resources University, Mazandaran, Iran.

Dadshani, S., Sharma, R. C., Baum, M., Ogbonnaya, F. C., Léon, J., Ballvora, A. (2019) Multi-dimensional evaluation of response to salt stress in wheat. PLoS ONE, 14, e0222659. DOI: https://doi.org/10.1371/journal.pone.0222659

Dong, Y., Liu, J., Zhang, Y., Geng, H., Rasheed, A., Xiao, Y., Cao, S., Fu, L., Yan, J., Wen, W., Zhang, Y., Jing, R., Xia, X., He, Z. (2016) Genome-wide association of stem water soluble carbohydrates in bread wheat. PLoS One, 11, e0164293. DOI: https://doi.org/10.1371%2Fjournal.pone.0164293

Ehdaie, B., Alloush, G.A., Madore, M.A., Waines, J.G. (2006) Genotypic variation for stem reserves and mobilization in wheat. I. Post-anthesis changes in internodes dry matter. Crop Science, 46, 735-746. DOI: https://doi.org/10.2135/cropsci2005.04-0033

Fernandez, G. C. J. (1992) Effective selection criteria for assessing plant stress tolerance. In: Kuo, C.G. (Eds), Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress. Publication, Tainan, Taiwan.

Fischer, R. A., Maurer, R. (1978) Drought resistance in spring wheat cultivars. Part 1: Grain yield response. Australian Journal of Agricultural Research, 29, 897- 912. DOI: https://doi.org/10.1071/AR9780897

Fischer, R.A., Wood, T. (1979) Drought resistance in spring wheat cultivars III. Yield association with morphological traits. Australian Journal of Agricultural Research, 30, 1001–1020. DOI: https://doi.org/10.1071/AR9791001

Gavuzzi, P., Rizza, F., Palumbo, M., Campaline, R.G., Ricciardi, G.L., Borghi, B. (1997) Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. Canadian Journal of Plant Science, 77, 523–531. DOI: https://doi.org/10.4141/P96-130

Ghosh, B., Md, N. A., Gantait, S. (2016) Response of rice under salinity stress: a review update. Rice Research, 4, 167. DOI: https://doi.org/10.4172/2375-4338.1000167

Golabadi, M., Arzani, A., Maibody, S.A.M. (2006) Assessment of drought tolerance in segregating populations in durum wheat. African Journal of. Agricultural Research, 5, 162-171. DOI: https://doi.org/10.5897/AJAR.9000070

Grieve, C. M., Francois, L. E., Maas, E. V. (1994) Salinity affects the timing of phasic development in spring wheat. Crop Science, 34, 1544–1549. DOI: https://doi.org/10.2135/cropsci1994.0011183X003400060024x

Hasan, A., Hafiz, H. R., Siddiqui, N., Khatun, M., Islam, R., Mamun, A. A. (2015) Evaluation of wheat genotypes for salt tolerance based on some physiological traits. Journal of Crop Science and Biotechnology, 18, 333–340. DOI: https://doi.org/10.1007/s12892-015-0064-2

Homayoun, H. (2011) Remobilization of stem reserves in wheat varieties under normal and drought stress conditions. Advances in Environmental Biology, 5 (7), 1721-1724. Available at: http://www.aensiweb.com/old/aeb_June_2011.html [Accessed 1 June 2011].

Jamil, M., Rehman, S., Jae Lee, K., Man Kim, J., Kim, H. S., Rha, E. S. (2007) Salinity reduced growth, photochemistry and chlorophyll content in Radish. Agricultural science, 64, 111-118. DOI: https://doi.org/10.1590/S0103-90162007000200002

Jamshidi, A., Javanmard, H.R. (2017) Evaluation of barley (*Hordeum vulgare* L.) genotypes for salinity tolerance under field conditions using the stress indices. Ain Shams Engineering Journal, 9 (4), 2093-2099. DOI: https://doi.org/10.1016/j.asej.2017.02.006

Johnson, R. A., Wichern, D. W. (2007) Applied Multivariate Statistical Analysis (6th ed.). Prentice-Hall International, Englewood Cliffs, NJ, USA.

Joudi, M., Ahmadi, A., Mohamadi, V., Abbasi, A. R., Mohamadi, H., Esmaeilpour, M., Bayat, Z., Torkashvand, B. (2010) Evaluation of stem reserves accumulation and remobilization in Iranian wheat cultivars under irrigated and post-anthesis drought stress conditions. Iranian Journal of Field Crop Science, 41 (2), 315-328. DOI: https://dorl.net/dor/20.1001.1.20084811.1389.41.2.11.2

Majidi, M. M., Mirlohi, A., Amini, F. (2009) Genetic variation, heritability and correlations of agro-morphological traits in tall fescue (*Festuca arundinacea* Schreb). Euphytica, 167, 323-331. DOI: https://doi.org/10.1007/s10681-009-9887-6

Mashi, A., Galeshi, S. (2006) The Effect of Salinity on the Yield and Protein Percentage of Hull-less Barley (*Hordeum vulgare*). Agricultural sciences and natural resources bulletin of Khazar, 12, 11-23.

Mehrpouyan, M., Zakavati, B., Ajalli, J. (2012) A Survey on Reserve Remobilization from Different Aerial Organs in 10Common Wheat Genotypes (*Tiriticum aestivum* L.) Under With and Without Drought Stress Conditions. Journal of Crop Production and Processing, 2 (3), 69-82.

Mitra, J. (2001) Genetics and genetic improvement of drought resistance in crop plants. Current Science, 80, 758-762. DOI: https://doi.org/10.2307/24105661

Moradi, F., Abdelbagi, M. I. (2007) Response of photosynthesis, chlorophyll Fluorescence and ROS- Scavenging Systemes to Salt stress during seedling and reproductive stages in rice. Annals of Botany, pp. 1-13. DOI: https://doi.org/10.1093/aob/mcm052

Naeemi, M., Akbari, Gh. A., Shirani Rad, A. H., Modares Sanavi, S. A. M., Sadat Nuri, S.A., Jabari, H. (2008) Evaluation of drought tolerance in different canola cultivars based on stress evaluation indices in terminal growth duration. Journal of Crop Production, 1 (3), 83-98. DOI: https://dorl.net/dor/20.1001.1.2008739.1387.1.3.6.1

Netanos, D. A., Koutroubas, S. D. (2012) Dry matter and N accumulation and translocation for Indica and Japonica rice under Mediterranean conditions. Field Crops Research, 74, 93-101. DOI: https://doi.org/10.1016/S0378-4290(01)00203-9

Nouri, A., Etminan, A., Jaime, A., Silva, T. D., Mohammadi, R. (2011) Assessment of yield, yield related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum* var. durum Desf.). Australian Journal of Crop Science, 5, 8-16. Available at: http://www.cropj.com/january2011.html [Accessed 1 January 2011].

Otu, H., Celiktas, V., Duzenli, S., Hossain, A., El Sabagh, A. (2018) Germination and early seedling growth of five durum wheat cultivars (*Triticum durum* Desf.) is affected by different levels of salinity. Fresenius Environmental Bulletin, 27, 7746–7757. Available at: https://www.prt-parlar.de/download_feb_2018/ [Accessed 1 November 2018].

Papakosta, D.K., Gagianas, A.A. (1991) Nitrogen and dry matter accumulation, remobilization, and losses for Mediterranean wheat during grain filling. Agronomy Journal, 83, 864-870. DOI: https://doi.org/10.2134/agronj1991.00021962008300050018x

Piaskowski, J. L., Brown, D., Campbell, K. G. (2016) Near-infrared calibration of soluble stem carbohydrates for predicting drought tolerance in spring wheat. Agronomy Journal, 108, 285-93. DOI: https://doi.org/10.2134/agronj2015.0173

Pirdashti, H., Tahmasbi Sarvastani, Z., Nemat Zadeh, Gh., Esmaeil, A. (2004) Study of dry matter and nitrogen remobilization of different rice cultivars in drought stress condition. In: Proceeding of 8th Congress of Agronomy and Plant Breeding, Guilan University, Iran, 24-26 August 2004, p. 148.

Pour-Aboughadareh, A., Yousefian, M., Moradkhani, H., Moghaddam Vahed, M., Poczai, P., Siddique, K. H. M. (2019) iPASTIC: An online toolkit to estimate plant abiotic stress indices. Applications in Plant Sciences, 7 (7), e11278. DOI: https://doi.org/10.1002/aps3.11278

Raeisi, R., Abooie Mehrizi, F., Poustini, K. (2021) Evaluation of soluble carbohydrates remobilization and some physiological traits of different bread wheat (*Triticum aestivum* L.) cultivars under salt stress and non-stressed conditions. Iranian Journal of Field Crop Science, 52 (2), 229-240. DOI: https://dx.doi.org/10.22059/ijfcs.2020.299064.654697

Rebetzke, G., Van Herwaarden, A., Jenkins, C., Weiss, M., Lewis, D., Ruuska, S., Tabe, L., Fettell, N. A., Richards, R. A. (2008) Quantitative trait loci for water-soluble carbohydrates and associations with agronomic traits in wheat. Australian Journal of Agricultural Research, 59, 891-905. DOI: https://doi.org/10.1071/AR08067

Richard R. A. (1992) Increasing salinity tolerance of grain crops: Is it worthwhile? Plant and Soil, 146(1-2), 89-98. DOI: https://doi.org/10.1007/BF00012000

Rosielle, A.A., Hambling, J. (1981) Theoretical aspects of selection for yield in stress and non-stress environments. Crop Science, 21, 943–946. DOI: https://doi.org/10.2135/cropsci1981.0011183X002100060033x

Ruuska, S. A., Rebetzke, G. J., Van Herwaarden, A. F., Richards, R. A., Fettell, N.A., Tabe, L., Jenkins, C. L. D. (2006) Genotypic variation in water-soluble carbohydrate accumulation in wheat. Functional Plant Biology, 33, 799-809. DOI: https://doi.org/10.1071/fp06062

Savin, R., Stone, P. J., Nicolas, M. E. (1996) Responses of grain growth and malting quality of barley to short period of high temperature in field studies using portable chamber. Euphytica, 87, 465-477. DOI: https://doi.org/10.1071/AR9960465

Schauer, N., Fernie, A. R. (2006) Plant metabolomics: towards biological function and mechanism. Trends in Plant Science, 11(10), 508-516. DOI: https://doi.org/10.1016/j.tplants.2006.08.007

Shafazadeh, M. K., Yazdansepas, A., Amini, A., Ghannadha, M. R. (2004) Study of terminal drought tolerance in promising winter and facultative wheat genotypes using stress susceptibility and tolerance indices. Seed and Plant Journal, 20(1), 57-71. DOI: https://dx.doi.org/10.22092/spij.2017.110607

Shah, S. H., Houborg, R., McCabe, M. F. (2017) Response of Chlorophyll, Carotenoid and SPAD-502 Measurement to Salinity and Nutrient Stress in Wheat (*Triticum aestivum* L.). Agronomy, 7 (3), 61. DOI: https://doi.org/10.3390/agronomy7030061

Shahryari, R., Mollasadeghi, V. (2011) Introduction of two principle components for screening of wheat genotypes under end seasonal drought. Advances in Environmental Biology, 5 (3), 519-523. Available at: http://www.aensiweb.com/AEB/current.php [Accessed 2 February 2011].

Sharbatkhari, M., Galeshi, S., Shabr, S., Soltani, A., Nakhoda, B. (2014) Study on agro-physiological traits related to stem reserve remobilization under terminal salinity in wheat. Journal of Crop Production, 7 (1), 25-44. DOI: https://dorl.net/dor/20.1001.1.20088739.1393.7.1.2.5

Singh, S., Sengar, R. S., Kulshreshtha, N., Datta, D., Tomar, R. S., Rao, V. P., Garg, D., Ojha, A. (2015) Assessment of multiple tolerance indices for salinity stress in bread wheat (*Triticum aestivum* L.). Journal of Agricultural Science, 7 (3), 49-57. DOI: https://doi.org/10.5539/jas.v7n3p49

Van-Ginkel, M., Calhoun, D. S., Gebeyehu, G., Miranda, A., Tian-you, C., Pargas Lara, R., Rajaram, S. (1998) Plant traits related to yield of wheat in early, late, or continuous drought conditions. Euphytica, 100, 109-121. DOI: https://doi.org/10.1023/A:1018364208370

Zebarjadi, A., Asgar, S., Najafi, A., Rezaiezad, A. (2016) Evaluation of drought tolerance of rapeseed genotypes using drought resistance indices. Environmental Stresses in Crop Science, 8, 345-348. DOI: https://dx.doi.org/10.22077/escs.2016.248