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WHEAT ADVANCED LINES ASSESSMENT FOR SALT TOLERANCE IN TERMS OF MORPHO-PHYSIOLOGICAL INDICATORS AND GRAIN YIELD

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SUMMARY

The wheat advanced lines of the F_5 generation, obtained through interspecific hybridization (*T. durum* × *T. aestivum*), incurred studies for salt tolerance in terms of morphophysiological traits and grain yield under normal and saline soil conditions. The results revealed that salt caused a significant decrease in the photosynthetic pigments, photosystem II activity, and relative water content in the leaves of advanced wheat lines. Overall, the saline stress conditions considerably affected the photosynthetic pigments in most of the advanced lines, while in some genotypes, it was relatively less. Thus, the chlorophyll (a+b), carotenoids, photosystem II activity, and relative water content were more pronounced in the hybrids Leyaqatli-80 × Mirbashir-128, Tale-38 × Kyrmyzy gul-1, Gobustan × Sheki-1, and Mirbashir-50 × Shiraslan-23 than in other hybrids. These hybrids showed greater salt tolerance. On grain yield losses in saline soil, the hybrids Murov × Daghdash, Tale-38 × Kyrmyzy gul-1, Gobustan × Sheki-1, Barakatli-95 × Vugar, Mirbashir-50 × Shiraslan-23, Gobustan × Barakatli-95, Garabagh × Mirbashir-128, and Garabagh × Shark displayed higher resistance. This resistance was for ear weight, the number of grains, and grain weight. In the future, growing these advanced wheat lines under wider saline areas as salt-tolerant cultivars can be successful.

Keywords: Wheat interspecific (*T. durum* × *T. aestivum*) advanced lines, saline stress conditions, heterosis, dominance, morphophysiological traits, spike traits, productivity

Key findings: The study identified the promising wheat interspecific (*T. durum* × *T. aestivum*) advanced lines for heterotic and dominance effects over better parents for yield-related traits that can help in developing high-yielding wheat genotypes.

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INTRODUCTION

Salinization is one of the main abiotic environmental stresses considerably affecting crop productivity (Grewal, 2010). Wheat is one of the three major cereal crops (rice, maize, and wheat) with wide cultivation, being the main food source for nearly 2 billion people, or more than 36% of the world's population. Climate change occurring on a global level has worsened the environmental situation on the earth, disrupting biological diversity due to the gradual reduction of high-quality and productive arable areas. As a result, threats have arisen for the ecosystem; irreversible variations occurring on the planet have led to global warming, salinization, and desertification of territories, and serious obstacles have occurred in crops' development. Saline soils also cover a large area in the republic. Approximately 60% of the lands of the Kur-Araz lowland of the Republic of Azerbaijan consist of moderately and severely saline soils. Currently, the implementation of several agrotechnical measures transpires both worldwide and in the republic to bring saline soils into a state suitable for cultivation. However, even after these measures, relatively salt-resistant plants require planting on the reclaimed lands (Azizov and Guliyev, 1999).

Salinization results from both natural and anthropogenic factors. Natural factors include rising groundwater levels, while anthropogenic factors comprise an unbalanced supply of mineral fertilizers and improper irrigation (Khan *et al.,* 2016). However, the rising sea level, as a consequence, triggers rising groundwater levels that are one of the main natural factors of soil salinization. Soil salinization causes water deficiency in the plant, which ultimately disrupts the normal physiological processes in tissues, and eventually affects the growth and yield traits in crop plants (Greenway and Munns, 1980).

Studies have shown that salt tolerance of various crop plants varies with differing degrees during their ontogenesis. Plants are more sensitive to salts in the early stages of development, especially during seedling growth and biomass accumulation (Greenway and Munns, 1980). Research has also established that chloride salinity reduces the water content in plant leaves, disrupts the mechanism of stomatal movement, and limits the absorption of carbon dioxide. In plants, this is successful through the synthesis of proline and the accumulation of NADP (nicotinamide adenine dinucleotide phosphate) in plants under saline conditions. These compounds regulate the formation of reactive oxygen species and lipid peroxidation. This situation leads to affecting and delaying the growth and development and decreasing the productivity and quality traits of crop plants (Basalah, 2010).

Violation of the ecological balance and the presence of abiotic stress factors in nature require the development of more flexible wheat cultivars suitable for various regions of Azerbaijan. Past studies have shown the greater significance of breeding research work in this direction in Azerbaijan (Rustamov *et al.,* 2017). One of the most important tasks facing modern science is the creation of new cultivars that are productive and resistant to stress conditions by using tolerant plant genotypes as source material. Therefore, the study of physiological and biochemical processes in plant metabolism is of considerable scientific and practical importance (Mecliche *et al.,* 2015).

Thus, based on the research conducted worldwide and in Azerbaijan regarding plants' salt tolerance, one can conclude that in the future, it will indeed be possible to obtain salt-resistant wheat cultivars adapted to salinity stress conditions. The presented study aimed to evaluate the wheat's advanced lines of F_5 generation obtained through interspecific hybridization (*T. durum* × *T. aestivum*) for salt tolerance in terms of morphophysiological traits and grain yield under normal and saline soil conditions.

MATERIALS AND METHODS

The object of the study is both the normal wheat (experimental plot of the laboratory of chloroplast photochemistry of the Institute of Molecular Biology and Biotechnology, Absheron, AR) and hybrid forms cultivated in the saline area of the Ujar Reference Station of the Institute of Soil Science. The 24 hybrids (F4) generation included Layagatli-80 × Mirbashir-128, Kyzyl bugda × Guneshli, Tartar × Karabakh, Tale-38 × Gyrmyzi gul-1, Gobustan × Sheki-1, Murov × Dagdash, Bezostaya-1 × Gyrmyzy gul-1, Dagdash × Murov, Nurlu-99 × Layagatli-80, Garabagh × Karakilchig-2, Sheki-1 × Gobustan, Vugar × Barakatli-95, and Gyrmyzy gul-1 × Tale-38. Others were Berakatli-95 × Vugar, Qarabagh × Tartar, Aran × Gyrmyzy gul-1, Mirbashir-50 × Shiraslan-23, Qarabagh × Gobustan, Barakatli-95 × Gobustan, Gobustan × Gyrmyzy gul-1, Gobustan × Barakatli-95, Gobustan × Qarabagh, Qarabagh × Mirbashir-128, and Qarabagh × Shark. Sowing proceeded according to the scheme P♀-F4-P♂ 5 cm × 25 cm. During the vegetation period, the samples received watering at the development stages, with agrotechnical work carried out on the experimental plot.

Determination of photosynthetic pigments

The 0.1 g leaf samples of the advanced lines taken from both normal and soil saline conditions sustained homogenization by grinding in 96% alcohol with the addition of $CaCO_3$ in a mortar. Afterward, the samples underwent centrifuging at 200 g to obtain a pure extract of chlorophyll pigments. The chlorophyll and carotenoid contents' determination continued by measuring the optical density of a chlorophyll solution in alcohol at a wavelength of 665, 645, and 440 nm using the SP-2000 spectrophotometer (Wintermans and De-Mots, 1965).

$$Cchl_a\ (mq/l) = 9.784 \times D_{665} - 0.990 \times D_{645},$$
$$Cchl_b\ (mq/l) = 21.426 \times D_{645} - 4.650 \times D_{665},$$
$$Cchl_{(a+b)}\ (mq/l) = 5.134 \times D_{665} - 20.436 \times D_{645},$$
$$C_{car}\ (mq/l) = 4.695 \times D_{440} - 0.268 \times C\ chl_{(la+b)},$$
where $Cchl_{(a+b)}$ is the concentration in mq/l.

Determination of Photosystem II activity

All the measurements, performed in triplicate, had the mean error and standard deviation calculated. Determining the activity of the second photosystem II by Fv/Fm used a MINI-PAM photosynthesis analyzer (photosynthesis yield analyzer, Germany), where, Fv = Fm-F0; F0 is the fluorescence of leaves illuminated with weak light after exposure in the dark, and Fm is the fluorescence of leaves saturated with light.

Determination of relative water content (RWC)

Leaf water loss (LWL) determination used the methodology of Tambussi *et al.* (2005). According to the method for determining the water content in leaves, the samples entailed drying at a temperature of 60 °C until completely dry. The process comprised pulling out the leaves and keeping them in water for 24 h, covering the surface with several layers of wet filter paper. After the leaf's complete saturation in water, drying with filter paper followed before weighing them again. Afterward, the leaf samples incurred further drying in a thermostat at a temperature of 105 °C until obtaining an absolutely dry mass. The reports' compilation was according to the following formula:

$$RWC = \frac{M_F - M_D}{M_T - M_D} \cdot 100\%$$

Where, RWC is the relative humidity, M_F is the leaf mass before, M_T is the leaf mass after water saturation, and M_D is the dry leaf mass.

Plant height and structural elements selection

The salt effect on the plant height and productivity of advanced wheat lines taken from normal and saline soil conditions and the variations that occurred sustained comparative studies. The observation on plant height and the elements of the crop structure followed the current methodology (Musaev *et al.,* 2008).

Table 1. The amount of salts in the soil (full water gravity analysis).

Layer depth (cm)	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na+k	Total salts (%)	Dry residue (%)
	Mq.ekv (%)								
1,315/4	No	2.20	0.60	0.749	2.50	0.50	0.549	0.26	0.47
		0.134	0.021	0.036	0.050	0.006	0.012		
1,310/2	No	2.60	0.60	0.249	2.25	0.003	0.949	0.26	0.43
		0.159	0.021	0.012	0.045	0.949	0.022		
1,330/1	No	2.40	1.00	0.249	2.00	0.006	1.149	0.26	0.42
		0.146	0.035	0.012	0.040	1.149	0.026		
1,300/5	No	1.60	0.80	1.748	2.75	0.006	0.898	0.29	0.37
		0.098	0.028	0.087	0.055	0.898	0.020		
1,010/3	No	2.60	1.00	0.749	2.50	0.012	0.849	0.31	0.33
		0.159	0.035	0.036	0.050	0.849	0.019		

The amount of salts in the soil (full water gravity analysis)

The salinity of the experimental soil is available in Table 1, and the soil salinization occurred mainly due to chlorides, sulfates, and HCO_3. These soils received classification as slightly saline. Here, the HCO_3 and Cl contents were greater than the released (from 0.01). In these soils, the salt types obtained chlorination, chloro-sulfates, and sulfate-chlorination, depending on the Cl : SO_4 ratio.

Determination of the tolerance index

In determining the resistance of varieties to salinity stress, using the stress tolerance index given by Rosielle and Hambelen in 1981 was as follows (Rosielle and Hambelen, 1981).

$$Tol = Yp - Ys$$

Where, Tol is durability, Yp is productivity under normal conditions, and Ys is the yield under saline conditions. The effect of salt on the yield indicators of hybrid wheats taken from normal and saline soil conditions and the occurring changes involved comparative studies. If the tolerance index is low in the varieties, that variety will be highly resistant to salinity.

Statistical analyses

After analysis of variance, the least significant difference (LSD) test at $p \leq 0.05$ proceeded using STATISTIX 8.1. Graphical presentation of data, as performed, used MS-Excel software, with the standard error also calculated in the same way.

RESULTS

In obtaining the salt-tolerant wheat pure lines, a comparative assessment of the morphophysiological and productive indicators in advanced wheat lines for salt tolerance ensued. The soil salts had a specific, considerable effect on the individual advanced wheat lines (Table 2). The advanced lines with relative resistance reached assessment for the chlorophyll pigments. Given the influence of salinity, the amount of XLA + XLB, as well as carotenoids in the plant leaves at the flowering stage, sustained relative reduction, observing wheat genotypes with significant variations.

Photosynthetic pigments

The salt-stress effect caused an increase in the photosynthetic pigments in some hybrids and a relatively smaller amount in other advanced lines. Thus, the effect of salt on the sum of Chl (a + b) pigments and the carotenoids was less in the advanced lines, i.e., Leyagatli-80 × Mirbashir-128, Taleh-38 × Kyrmyzy gul-1, Gobustan × Sheki-1, Aran × Kyrmyzy gul-1, and Mirbashir-50 × Shiraslan-23. These lines showed salt tolerance. The advanced lines Kyrmyzy gul-1 × Taleh-38, Nurlu-99 × Leyagatli 80, and Gobustan × Barakatli-95

Table 2. The effect of salinity on physiological traits of advanced wheat F_5 populations during flowering phase.

No.	Advanced Wheat Lines	Chlorophyll (a+b)		Carotenoids		RWC (%)	
		Control	Salt	Control	Salt	Control	Salt
1	Leyagatli-80 × Mirbashirr-128	3.52±0.74	3.21±0.17	2.02±0.44	2.04±0.25	86	81
2	Kyzil buğda × Gunashli	2.93.±0.44	2.34±0.36	1.31±0.72	1.03±0.16	78	74
3	Tartar × Garabagh	2.22±0.54	1.34±0.21	3.21±0.24	2.44±0.22	86	87
4	Tale-38 × Kyrmyzy gul -1	2.73±0.51	1.92±0.48	2.44±0.62	2.72±0.12	83	79
5	Gobustan × Sheki-1	2.33±0.72	2.42±0.22	2.18±0.14	2.21±0.15	88	84
6	Murov × Dagdaş	2.62±0.88	2.12±0.19	3.14±0.62	2.76±0.13	81	89
7	Bezostaya-1 × Kyrmyzy gul-1	2.11±0.38	1.74±0.13	1.25±0.11	1.51±0.25	81	82
8	Daghdash × Murov	3.34±0.42	1.81±0.31	3.99±0.12	2.43±0.31	81	90
9	Nurlu-99 × Leyagatli-80	2.14±0.15	1.15±0.28	2.13±0.16	1.22±0.28	84	76
10	Garabagh × Garakylchyk-2	2.42±0.11	1.24±0.63	1.51±0.32	1.74±0.43	83	69
11	Sheki-1 × Kobustan	2.68±0.18	2.65±0.24	2.83±0.19	2.15±0.32	83	88
12	Vugar × Barakatli -95	2.76±0.31	1.54±0.32	4.91±0.12	2.43±0.19	87	89
13	Kyrmyzy gul-1 × Tale-38	2.65±0.22	2.87±0.84	2.52±0.31	2.42±0.15	86	84
14	Barakatli-95 × Vugar	2.9±0.33	2.63±0.51	3.26±0.16	3.22±0.15	89	82
15	Garabagh × Tartar	2.53±0.42	1.87±0.54	3.52±0.14	2.54±0.15	88	83
16	Aran × Kyrmyzy gul-1	2.12±0.54	1.76±0.34	1.84±0.21	1.31±0.15	91	82
17	Mirbashşir-50 × Shiraslan-23	2.98±0.71	2.65±0.44	3.54±0.36	2.97±0.15	91	89
18	Garabagh × Gobustan	2.96±0.16	1.33±0.39	2.12±0.32	1.11±0.15	75	32
19	Gobustan × Barakatli-95	2.23±0.17	1.23±0.18	2.71±0.23	1.43±0.15	80	75
20	Gobustan × Kyrmyzy gul-1	2.42±0.13	1.63±0.15	2.78±0.54	1.97±0.15	88	74
21	Barakatli-95 × Gobustan	2.55±0.57	1.97±0.12	3.12±0.04	1.98±0.15	74	83
22	Gobustan × Garabagh	2.54±0.553	1.43±0.33	2.82±0.41	1.24±0.15	82	89
23	Garabagh × Mirbashir-128	2.34±0.39	2.32±0.21	3.11±0.14	2.78±0.15	84	82
24	Garabagh × Shark	2.95±0.19	2.75±0.54	3.21±0.29	2.87±0.15	76	84

expressed greater sensitivity, with these genotypes observed with a reduction in the pigment amount due to salt (Table 2).

Relative water content (RWC)

Another important physiological indicator is the water storage capacity of plants. According to measurements, the relative water content (RWC) was higher (44%) in the advanced lines Mirbashir-50 × Shiraslan-23 and 39% in the Barakatli-95 × Vugar and Garabagh × Mirbashir-128, found more tolerant than other wheat genotypes (Table 2). Among the hybrids Kyrmyzy gul-1 × Taleh-38, Nurlu-99 × Leyagatli-80, and Gobustan × Barakatli-95, a greater decrease resulted in the relative water content. Under the influence of salts, the RWC reduction was 15% and 7% in the wheat cultivars Barakatli-95 and Gobustan, respectively. The decrease in RWC due to stress indicates that the cell does not have the turgor necessary for the tension process to take place (Katterji *et al.,* 1997).

Photochemical activity of chloroplasts

The salt tolerance of the advanced lines, as studied, revealed variations in the photochemical activity of chloroplasts. It was notable that some hybrids had more differences than others, and some had relatively fewer. Thus, tolerance to the activity of Photosystem II corresponds to the physiological indicators, which was more pronounced in hybrids. These wheat hybrids had greater internal fluorescence and high activity of the photosystem II. Said activity was higher in the hybrids Leyaqatli-80 × Mirbashir-128, Tale-38 × Kyrmyzy gul-1, Gobustan × Sheki-1, and Mirbashir-50 × Shiraslan-23 than other hybrids, and these hybrids exhibited greater salt tolerance (Figure 1).

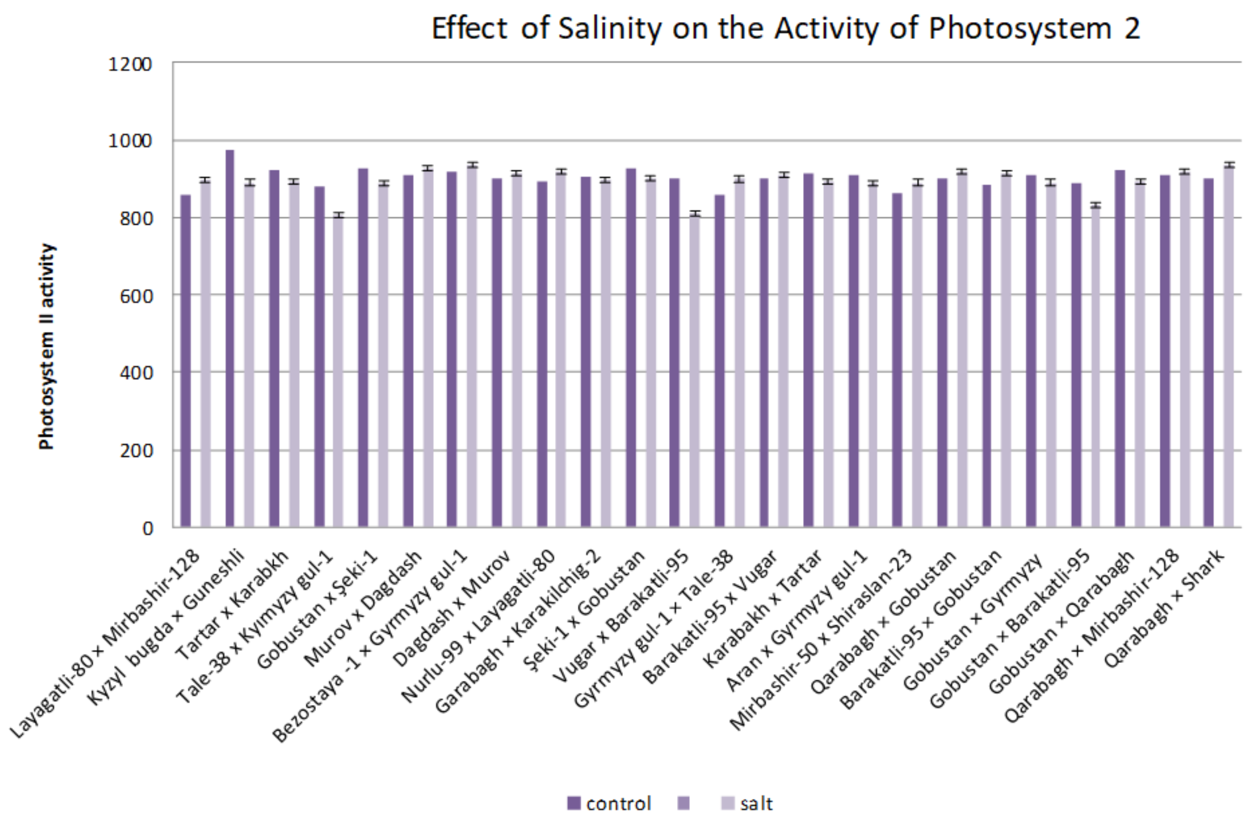

Figure 1. Effect of salinity on the activity of Photosystem II in the flowering phase of F_5 wheat populations.

Spike and grain weight and the number of grains per spike

The study of genotypes' yield losses continued through spike weight, grain weight, and the number of grains per spike, as the main productivity indicators. Wheat's advanced lines incurred comparative studies beginning with the spike weight, then the grain weight per spike, and the number of grains per spike. They are critical indicators of plant productivity both under normal and salinity stress conditions. First, obtaining the salt tolerance index ensued before identifying the variations in the advanced lines for yield-related traits. Comparing hybrid forms under salinity stress conditions, it was apparent that some hybrids suffered relatively less yield loss (Table 3). The advanced wheat lines showed differences for spike weight, grain weight, and grain number under normal and soil saline conditions (Table 3). However, the zero percent yield loss resulted in the advanced line Murov × Dagdash, and the said genotype appeared completely tolerant to salt stress with no yield loss. In other advanced lines, the yield losses were low in Garabagh × Shark (3.2%), Barakatli-95 × Vugar (3.3%), and Kyrmyzy gul-1 × Tale-38 (3.9%), which were identified as long-lived hybrids with lower yield losses. Similarly, hybrids Sheki-1 × Gobustan (4%), Tale-38 × Kyrmyzy gul-1 (4%), Garabagh × Mirbashir-128 (5.1%), Mirbashir-50 × Shiraslan-23 (5.6%), Leyagatli-80 × Mirbashir-128 (5.6%), Dagdash × Murov (6%), Garabagh × Tarter (7.9%), and Barakatli-95 × Gobustan (9%) gave considerably low yield losses. One of the most useful indicators of wheat is grain yield. High salt concentration in soil causes a decrease in grain yield (Katerji *et al.,* 2005; Turki *et al.,* 2012).

Table 3. Effect of salinity on the spike-related traits in advanced wheat lines.

No.	Advanced Wheat Lines	Plant height (cm)		Grain number		Grain weight (g)		Grain yield loss(%)
		Control	Salt	Control	Salt	Control	Salt	
1	Leyagatli-80 × Mirbashir-128	78±0.74	65±0.71	52±0.74	48±0.74	3.6±0.74	3.4±0.74	5.6
2	Kyzyl bugda × Gunashli	85±0.14	63±0.74	45±0.13	35±0.74	2.2±0.74	1.5±0.74	32
3	Tartar × Garabagh	79±0.19	65±0.44	44±0.64	42±0.74	3.0±0.74	2.4±0.74	20
4	Tale-38 × Kyrmyzi Kul-1	75±0.56	70±0.16	54±0.13	49±0.74	2.5±0.74	2.3±0.74	4
5	Gobustan × Sheki-1	90±0.44	70±0.23	32±0.14	33±0.35	2.5±0.46	2.2±0.76	8
6	Murov × Dagdash	59±0.94	60±0.74	42±0.64	37±0.32	3.3±0.39	3.2±0.35	0
7	Bezostaya-1 × Kyrmyzi gul-1	75±0.71	68±0.23	37±0.54	27±0.82	2.8±0.41	2.1±0.43	25
8	Dagdash × Murov	78±0.82	68±0.12	46±0.98	41±0.84	3.4±0.32	3.2±0.26	6
9	Nurlu-99 × Leyagatli-80	72±0.14	60±0.47	67±0.42	33±0.45	3.0±0.23	2.2±0.74	27
10	Garabagh × Garagylchig-2	80±0.18	71±0.32	20±0.14	16±0.74	1.7±0.74	1.1±0.22	36
11	Sheki-1 × Gobustan	64±0.64	58±0.34	42±0.52	39±0.18	2.9±0.47	2.8±0.32	4
12	Vugar × Barakatli -95	76±0.92	64±0.44	60±0.72	53±0.14	3.8±0.44	3.6±0.51	5.3
13	Kyrmyzi gul-1 × Tale-38	85±0.21	76±0.38	52±0.72	42±0.34	2.6±0.12	2.5±0.94	3.9
14	Barakatli-95 × Vugarr	70±0.13	70±0.78	60±0.28	57±0.37	3.1±0.42	3.0±0.19	3.3
15	Garabagh × Tartar	78±0.49	64±0.19	52±0.27	51±0.32	3.7±0.74	3.4±0.14	7.9
16	Aran × Kyrmyzi gul-1	76±0.49	60±0.71	60±0.31	48±0.45	1.9±0.19	1.4±0.17	21.2
17	Mirbashir-50 × Shiraslan-23	98±0.29	74±0.19	62±0.39	57±0.42	3.6±0.22	3.4±0.21	5.6
18	Garabagh × Gobustan	70±0.16	62±0.28	38±0.37	31±0.47	1.7±0.36	1.2±0.38	29.5
19	Gobustan × Barakatli-95	68±0.64	60±0.56	36±0.41	32±0.14	2.7±0.19	2.2±0.18	19.1
20	Gobustan × Kyrmyzi gul-1	86±0.28	82±0.38	46±0.43	35±0.74	2.6±0.34	2.1±0.54	19.2
21	Barakatli-95 × Gobustan	66±0.14	60±0.71	54±0.35	44±0.15	3.1±0.37	3.4±0.49	9
22	Gobustan × Garabagh	67±0.51	60±0.17	42±0.77	21±0.79	2.9±0.48	2.3±0.38	21
23	Garabagh × Mirbashir-128	72±0.78	67±0.45	60±0.85	9±0.27	3.7±0.12	3.5±0.17	5.1
24	Garabagh × Shark	71±0.63	68±0.71	62±0.34	12±0.79	3.7±0.82	3.6±0.98	3.2

The average values drawn from three replicates for each hybrid at p = 0.05 at n = 3 and ±SD indicate the mean standard deviation.

Plant height and yield

According to morphological parameters, in advanced lines the plant height also enhanced under both ecological environments. The advanced lines Murov × Dagdash (60 cm) and Fertile-95 × Vugar (70 cm) appeared with negative effects of the salinity for plant height, and eventually yield losses. A relatively small effect of salinity manifested in the advanced lines Garabagh × Shark (68 cm), Sheki-1 × Gobustan (64 cm), and Tale-38 × Kyrmyzy gul-1 (70 cm). The hybrids demonstrated tolerance in previous generations, and these properties are also evident in subsequent generations. In the first-generation hybrids (F1) of the hard and soft wheat, studying hereditary changes at different levels succeeded in the main quantitative indicators. From 24 combinations of Murov × Dagdash, Tale-38 × Kyrmyzy gul-1, Gobustan × Sheki-1, Barakatli-95 × Gobustan, Garabag × Mirbashir-128, and Garabag × Shark, the signs of positive heterosis and dominance for the studied quantitative indicators continued to transmit to subsequent generations (Khanishova and Azizov, 2023).

Grain yield loss

In the study of plant productivity, yield loss is also an essential indicator for assessing yield, expressed as a percentage. Among the 24 hybrids, the least yield loss according to this indicator appeared in Murov × Dagdash (0%), Tale -38 × Kyrmyzy gul-1 (4%), Sheki × Gobustan (4%), and Karabakh × Shark (4%). These hybrids assessment can reach a salt-resistant classification based on their yield indicator. The highest yield loss resulted in the hybrids Kyzyl bugda × Guneshli (32%), Karabakh × Gobustan (29.5%), and Bezostaya × Kyrmyzy gul-1 (25%). The genetic structure of genotypes always reacts differently to stress factors. Thus, the genetic structure of plants regulates the rate and sequence of protein synthesis required in a stressful situation. Several difficulties in growing salt-tolerant genotypes showed an association with resistance to salt stress, including the complex and polygenic nature of genes. In the process of evolution, all organisms, including plants, develop protective mechanisms for their survival from environmental stress factors. Therefore, when assessing resistance to stress factors, it is necessary to consider the individual characteristics of each plant genotype (Khanishova *et al.,* 2024).

DISCUSSION

Under salinity stress conditions, numerous destructive variations occur in plant chloroplasts, preventing the normal course of photosynthesis. Similarly, it is notable for more dispersed chloroplasts in plants facing salinity, weakening the intensity of photosynthesis. A decrease in the relative water content due to salt stress conditions indicates the absence of turgor, which is necessary for the process of tension in the cells. Thus, results from the presented study have established salt stress negatively affects the relative water content in leaves of wheat hybrids. The obtained results showed plants' resistance to any stress conditions was due to various physiological adaptive reactions to stress conditions.

The effect of long-term salinization with NaCl on tolerant (Karchia 65) and sensitive (HD-2687) wheat genotypes entailed studies. Their results revealed salinity decreased the relative water and chlorophyll content, while ascorbic acid and H_2O_2 increased. In sensitive cultivars, this variation occurred more sharply than in resistant genotypes (Khan *et al.,* 2010). In various wheat cultivar leaves, the establishment of variations in the water potential and other physiological parameters under salinity conditions has also succeeded in past research. By adding 100 mM NaCl to the soil, a study assumed that growth restoration under salt stress occurs due to the accumulation of IST (indole-3-acetic acid-IAA). Moreover, it increased elasticity of the cell wall, decreased osmotic potential due to weak transpiration, and accumulated ABT (abscisic acid) in the growth zone, as observed in barley (Belovalova, 2011).

Studies conducted to probe genes that control resistance under salt stress conditions have shown the expression of these genes enhanced at the highest salt concentration and ensured plant resistance (Garratt *et al.*, 2002). However, research has established that the effect of salts may be less at one stage of development and more at another. According to most studies, the stage of greatest sensitivity of plants to salinity is the beginning of ontogenesis grains. Plants are more sensitive to salt effects during the formation of rudiments of spikelets and tillering nodes in plants. Among the complex measures to obtain the maximum grain yield from plants under saline soils, a special place exists with the acquisition of plants capable of adapting to such soils (Maas and Hoffman, 1997). Therefore, to solve these problems, extensive research is progressive in the areas of efficient use of genetic biodiversity existing in the world and in the search for new genetic sources. Such research includes the involvement of wild ancestors, which are carriers of many positive traits. Additionally, studies continue in the process of creating new varieties using interspecific and intergeneric hybridizations. In eliminating this threat, targeted research work should progress (Aliyev and Akperov, 2002).

Currently, in Azerbaijan, under the leadership of Academician J.A. Aliyev, high-level research is continuous on salt tolerance in local and imported wheat varieties and other crops (Huseynova *et al.,* 2008). In general, the growth and development of plants depend on the process of photosynthesis in their green organs. Therefore, environmental stressors affecting photosynthesis also influence growth and development (Villora *et al.,* 1997). A positive correlation between the rate of photosynthesis and productivity has emerged in various plants under salinity (Perez *et al.,* 1996). The decrease in RWC due to stress signifies that the cell does not have the turgor necessary for the tension process to take place (Katterji *et al.*, 1997). The response of plants to stressors is different, depending on the genetic material. Thus, the genetic material regulates the speed and consistency of protein synthesis required when experiencing stress.

Hopefully, plant growth and development depend on the photosynthesis process occurring in plants' green parts. Consequently, environmental stress factors that affect photosynthesis also considerably modify the plant's growth and development. Under the influence of Na+ ions, the activity of ATPase pumps regulating the balance of Na^+ and K^+ ions in the cells gets disrupted. Subsequently, Na+ ions enter the cells, and the cell organelles pass from the turgor state to the plasmolysis state. The tolerance of plants to salinity is a complex physiological mechanism (Ibrahimova *et al.,* 2021). The effect of different salt concentrations on the physiological parameters of the F2 and F3 populations has undergone studies in detail in previous years. Thus, the scrutiny of hybrids sensitive and tolerant to the effects of salt was successful (Khanishova *et al.,* 2022). Hybrids with a high content of chlorophyll pigments, carotenoids, photosystem II activity, and high relative water content entailed selection for their longevity characteristics (Khanishova *et al.,* 2024). In salinity stress conditions, several destructive variations occur in plant chloroplasts, preventing the normal course of photosynthesis. However, one must note that in plants facing salinity, chloroplasts are more dispersed, weakening the intensity of photosynthesis (Ibrahimova *et al*., 2025).

In experiments conducted with the gradual addition of NaCl salt to the nutrient medium of plants, a decrease in the photochemical activity of chloroplasts and electron transport between photosystems was evident. In these experiments, after plants first experienced incubation with low concentrations of NaCl, adaptation to salinity resulted in their growth and development and in the structure and function of the photosynthetic apparatus. The authors also studied the effect of salinity on the rate of NADP reduction and noted intefr-varietal differences in this indicator. Based on the results obtained, a conclusion was that the main reason for the decrease in the rate of reduction of NADP under salinity conditions is the decline in the rate of the Calvin cycle (Villora *et al.*, 1997). Some difficulties in the cultivation of salt-tolerant forms refer to the complexity and polygenic nature of genes. It is common that under salt stress, the external water potential decreases, the absorption of biogenic metal ions by the roots becomes difficult, and chlorine and sodium ions have a toxic effect on plant metabolism. These three possible effects of salt stress have a detrimental impact on plant growth, development, and yield (Munns *et al.*, 2006; Muhammad *et al.*, 2015). Toxic levels of sodium in plant organs damage biological membranes and subcellular organelles, reducing growth, and causing abnormal development before the plant's death. Several physiological processes, such as photosynthesis, respiration, starch metabolism, and fixation of nitrogen, also slow down in salt conditions, leading to a decrease in crop productivity. In response to this, the plant synthesizes low molecular weight solutes, including soluble carbohydrates, for better absorption of water during salinity. Genotypes with a powerful genetic apparatus cope with this task and grow well in salt conditions. In the process of evolution, protective mechanisms against environmental stressors materialize in all organisms, including plants. Thus, based on the research conducted in the world and in this country on salt tolerance, one can conclude that it is possible to obtain salt-tolerant wheat varieties adapted to salinity in the future.

CONCLUSIONS

The results revealed salinization negatively affected the spike-related traits and caused yield loss. However, among the 24 wheat populations tested, most advanced lines emerged with relatively low yield losses. The chlorophyll (a+b), carotenoids, photosystem II activity, and relative water content were more pronounced in the hybrids Leyaqatli-80 × Mirbashir-128, Tale-38 × Kyrmyzy gul-1, Gobustan × Sheki-1, and Mirbashir-50 × Shiraslan-23 than the other hybrids, and these hybrids showed greater salt tolerance. On grain yield losses on saline soil, eight hybrids expressed minimum yield loss. These are Murov × Daghdash, Tale-38 × Kyrmyzy gul-1, Gobustan × Sheki-1, Barakatli-95 × Vugar, Mirbashir-50 × Shiraslan-23, Gobustan × Barakatli-95, Garabagh × Mirbashir-128, and Garabagh × Shark. They displayed higher resistance for ear weight, the number of grains, and grain weight. In the future, these advanced wheat lines will rise to grow under the wider saline areas as salt-tolerant cultivars.

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