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Original Research

The Effect of Salinity on the Physiological and Productivity Traits of Soft Wheat Genotypes

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Abstract

Soil salinity constrains the vital activities of plants, thereby diminishing their growth and productivity. Consequently, the study of the physiological characteristics and productivity of salt tolerance in plants is of significant importance. In the field trial area, normal soils (the experimental field of the "Chloroplast Photochemistry" laboratory of the Institute of Molecular Biology and Biotechnology of the Republic of Azerbaijan) and saline soils (where the salinity in the soil is mainly sulfates (1.5% H_2SO_4), at the experimental field of the Institute of Soil Science of the Republic of Azerbaijan in the Agsu-Kurdamir region) were selected. Physiological processes occurring in the leaves during the vegetative growth phase were examined. Salt decreased the levels of photosynthetic pigments, photosystem II activity, and productivity in the leaves of the genotypes in different ways. In addition to the general responses to species-specific salinity, the unique characteristics of each genotype also played an important role. As a result, the total chl *a* + chl *b* pigment content, carotenoid content, PSII activity, and productivity of the Azamatli-95, Gobustan, Kiymatli-2/17, and Nurlu-99 genotypes were more pronounced than the other varieties, and these varieties showed greater tolerance to salt stress.

Keywords: wheat, salt stress, pigment, photosystem activity, hybrid

Introduction

Every year, about 40,000 hectares of land around the world become unfit for use due to salinization [1]. Since more than 50% of Azerbaijan's territory consists of arid and saline lands, this problem is also relevant for our republic [2]. Soil salinization is one of the main environmental factors limiting plant productivity. Salt stress reduces the amount of chlorophyll and total protein in plant cells, causes stomatal closure, and induces oxidative stress due to the generation of reactive oxygen species in the cell, which leads to a decrease in the intensity of photosynthesis and, ultimately, a reduction in productivity. Plants grown in saline areas are unable to absorb water and minerals such as K^+ and Ca^{2+}, which slows down cell development [3]. Excessive accumulation of harmful ions, such as Na^+ and Cl^-, in the cell disrupts ion homeostasis, exerting toxic, osmotic, and oxidative effects on the plant. Therefore, maintaining the K^+/Na^+ ratio in the cell is essential for plant growth and development under salt stress conditions [4]. The effect of NaCl on plant metabolism and resistance to high salinity has not yet been sufficiently studied [5,

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6]. High concentrations of NaCl cause osmotic stress, alter the light phase of photosynthesis, and damage the photosynthetic apparatus. Many plants adapt to extreme conditions by changing the composition of photosynthetic membranes. Such plants respond to stress with qualitative and quantitative changes in the composition of thylakoid membrane proteins. Since the photosystem II (PSII) complex is the most sensitive part of the photosynthetic apparatus, it suffers more from abiotic stresses than the photosystem I (PSI) complex [7]. Currently, both globally and in our republic, a number of agrotechnical measures are being implemented to restore saline soils to a condition suitable for cultivation. However, even after these measures have been carried out, it is necessary to plant relatively salt-tolerant plants on reclaimed land. Therefore, obtaining new, salt-tolerant plants, including wheat varieties, is one of the main tasks facing modern breeders. To achieve this goal, it is necessary to study the mechanisms of salt tolerance formation in plants at the molecular-genetic, cellular, and organism levels. Numerous studies conducted in this area have extensively investigated the effect of salt on various processes occurring in plant organisms and have elucidated its osmotic and toxic mechanisms for plant organisms [8]. Studies conducted to investigate the expression of genes that synthesize proteins providing resistance to salt stress have shown that the expression of these genes increases at high salt concentrations [9]. Currently, under the leadership of J.A. Aliyev, the mechanisms of salt tolerance in wheat species and varieties imported from abroad and cultivated in our republic are being studied at the molecular-genetic, organelle, cellular, and organism levels [10]. One of the important issues is the study of salt tolerance in new varieties imported into our republic, as well as in wheat species and varieties widely distributed in Azerbaijan, and the selection and use of resistant forms in breeding. As is well known, salt tolerance depends on the structure and activity of the genetic apparatus of plants. Therefore, the study of plant genotypes with different levels of salt tolerance, the identification of sources of resistance genes, and their use as donors in breeding are among the pressing issues of today. Experiments with various agricultural crops have shown that the application of mineral fertilisers increases the salt tolerance of plants and allows for higher yields when grown on relatively saline soils [11]. The ability of plants to withstand the effects of salt depends on environmental factors: soil, water, and climate. For example, many crops are less salt-tolerant when grown in hot and dry climates than when grown in cool and humid climates. In hot and dry climates, crop yield and quality decline more sharply than in cool and humid climates. To accurately assess salt tolerance, it is necessary to carefully study the relationship between environmental factors and salt tolerance. Salt exposure reduces plant productivity, but this reduction and the concentrations that cause it vary among plant species [12]. Researchers have shown that wild species of the same genus are more salt-tolerant than cultivated ones. This indicates the advisability of using wild species to create new salt-tolerant forms.

Materials and Methods

The objects of the study were 12 varieties of soft wheat of the species *T. aestivum* L. (Akinci-84, Gobustan, Nurlu-99, Kiymatli-2/17, Pirshakhin, Gyrmyzy Gul 1, Azamatli-95, Ruzi-84, Tale-38, Saratovskaya-29 (Saratov), Dagdash (Turkey), 4th FEFWSN-No.16 (imported variety), taken from the seed base of the Azerbaijan Agricultural Research Institute, cultivated on normal and saline soils of the Republic of Azerbaijan, and studied in detail (Table 1).

Determination of Photosynthetic Pigments

To determine the amount of pigments, 0.3-0.5 g of fresh plant material was dissolved in 2-3 mL of 100% acetone in a porcelain flask, and a small amount of $CaCO_3$ and $MgCO_3$ was added to prevent pigment decomposition. The pigments were extracted sequentially with several portions of solvent. Each time, the pigment solution was filtered through a glass filter. The obtained extract was diluted to 10 mL with acetone and centrifuged at 200 g. The amount of pigments was determined using an SF-26 spectrophotometer at wavelengths of 662 nm, 644 nm, and 440.5 nm and calculated using the following formulas [13].

$$\text{Chl } a \text{ (mg/L)} = 9.784 \times D_{662} - 0.990 \times D_{644}$$
$$\text{Chl } b \text{ (mg/L)} = 21.426 \times D_{644} - 4.650 \times D_{662}$$
$$\text{Chl } a{+}b \text{ (mg/L)} = 5.134 \times D_{662} - 20.436 \times D_{644}$$
$$C_{Car} \text{ (mg/L)} = 4.695 \times D_{440.5} - 0.268 \times C_{(\text{chl } a+b)}$$

We did the measurements three times. We also calculated the mean error and the root mean square deviation. All procedures related to pigment separation were done in a dark room at a temperature of 0-40°C.

Determination of the Photochemical Activity of Chloroplasts

Determination of the Photochemical Activity of the Processes Occurring in PSI and PSII

Photochemical activity of chloroplasts was measured using a polarographic device with a Clark-type platinum electrode. The chloroplast solution was placed in a small beaker containing 3 mL of water, illuminated with a lamp providing 30,000 lux, and the oxygen release rate was recorded using a polarograph. The reaction medium used to measure PSII activity contained 0.05 M sucrose, 0.05 M Tris-HCl (pH 7.8), 0.05 M EDTA, 0.01 M Tris-NaCl, 0.01 M MgCl, and 0.01 M Fe_3(FeCN). The reaction medium used to measure photosystem I activity was composed of 0.05 M sucrose, 0.05 M Tris-HCl (pH 7.8), 0.01 M NaCl, 0.01 M $MgCl_2$, 0.01 M Na

Table 1. Results of a complete analysis of irrigation water.

No.	CO_3	HCO_3 meq/%	Cl meq/%	SO4 meq/%	Total anions	Ca+Mg meq/%	Ca meq/%	Mg meq/%	Na+K meq/%	Total salts	Dry residue
1	ND	1,0 / 0,061	2,8 / 0,098	11,49 / 0,552	15,29	3,75	2,0 / 0,04	1,75 / 0,021	11,54 / 0,265	1,037	1,12
2	ND	0,6 / 0,021	2,3 / 0,081	21,23 / 1,02	24,13	20,5	10,5 / 0,021	10,0 / 0,012	3,63 / 0,083	1,535	1,50
3	ND	0,8 / 0,048	2,8 / 0,098	13,49 / 0,648	17,09	7,25	4,25 / 0,085	3,0 / 0,036	9,84 / 0,226	1,141	1,44
4	ND	1,0 / 0,061	2,0 / 0,07	7,9 / 0,38	10,90	4,25	1,75 / 0,035	2,5 / 0,03	6,65 / 0,153	0,729	0,68

Note: *ND = not detected; meq/% = milliequivalents percent.

ascorbate, and 0.01 M methylviologen. For this purpose, 5 g of large leaves are cleaned, washed, dried, and cut into small pieces with scissors; then 50 mL of separation medium is added and mixed in a homogeniser for 1 min until a homogeneous mass is obtained. The homogenate is filtered four times and centrifuged to separate large particles. It is centrifuged at 200 g for 5 min, and the sediment is discarded (Sediment usually consists of large particles (capsules, nuclei, and impurities) that may interfere with chloroplast function). The supernatant is again spun at 1000 g for 10 min. At this point, the supernatant no longer contains chloroplasts. Therefore, the supernatant is discarded, and 1 mL of separation medium is added to the pellet and homogenized. The chloroplasts obtained are placed in a refrigerator, and then their activity is measured [14].

The composition of the isolation medium for chloroplast separation is as follows:

1. 0.4 M Sucrose
2. 0.05 M Tris-HCl (pH 7.8)
3. 0.01 M $MgCl_2$
4. 0.01 M NaCl
5. 0.05 M EDTA (Ethylenediaminetetraacetic acid)

Tolerance İndex

To assess the salt tolerance of soft wheat (*T. aestivum* L.) varieties under field conditions, plants were grown under two contrasting environments: normal conditions at the Apsheron experimental base (control) and saline soils from the Agsu-Kurdamir region of Azerbaijan. Irrigation was applied according to schedule, phenological observations were recorded, and harvests were collected following standard procedures. Structural analyses were conducted on four yield components: spike weight, grain weight per spike, number of grains per spike, and 1000-grain weight.

The Tolerance Index (TOL) was calculated for each genotype according to Rosielle and Hamblin (1981) as follows [15]:

$$TOL = Yp - Ys$$

Where, Yp is the yield of a genotype under non-stress (control) conditions, Ys is the yield of the same genotype under saline stress.

A lower TOL value indicates higher salt tolerance, while a higher TOL value indicates greater sensitivity [16].

Statistical Analysis Methods

Cluster analysis and the results obtained with its help were performed using modern computer programs. Cluster analysis is a multidimensional non-parametric statistical method used to group genotypes belonging to both the same and different points [17]. The effects of salinity on the yield of wheat grown under normal and saline soil conditions, as well as the resulting changes, have been studied extensively. Plant observations were conducted in accordance with the established methodology for the structural elements of the crop [18].

The salinity of the experimental soil is presented in Table 1. As can be seen from Table 1, soil salinity was mainly due to chlorides, sulfates, and HCO_3^-. However, sulfates predominated (1.5% H_2SO_4). The soils are classified as moderately saline.

Results and Discussion

Chlorophyll Pigments: We began by investigating the changes in the quantities of chlorophyll *a*, chlorophyll *b*, chlorophyll *a*+*b*, and carotenoids. These are physiological indicators, and we were looking at their response to salinity. As shown in Table 2, the activity of chlorophyll pigments was studied under both normal and saline conditions. The degree of chlorophyll depression was calculated as a percentage relative to the control, based on the formula for chlorophyll depression.

$$Z = 100 - \frac{Y}{X} \times 100$$

Where Z = degree of depression; Y = experimental variant; X = control variant.

Table 2. The present study examined the effect of salinity (1.5% H_2SO_4) on pigment content in wheat genotypes at the tillering stage.

No.	Genotypes	Control |	Salinity	% Change Compared to Control	Control |	Salinity	% Change Compared to Control
		Chl *a*+b	Chl *a*+*b*		Carotenoids	Carotenoids	
1	Akinci-84	3.53±0.062	2.66 ±0.058	24	0.41±0.010	0.34 ±0.012	17
2	Gobustan	2.43±0.011	1.98 ±0.042	19	0.69±0.017	0.50 ±0.016	18
3	Nurlu-99	2.72±0.041	2.18 ±0.059	20	0.62±0.002	0.17 ±0.008	73
4	Kiymatli-2/17	2.94±0.084	2.44 ±0.105	17	0.56±0.018	0.41 ±0.020	27
5	Pirshahin	3.40±0.089	2.26 ±0.109	34	0.65±0.016	0.56 ±0.019	14
6	Gyrmyzy Gul 1	3.67±.0.066	2.25 ±0.074	39	0.67±0.011	0.31 ±0.017	54
7	Azamatli-95	3.23±0.095	2.58 ±0.137	20	0.82±0.024	0.70 ±0.032	15
8	Ruzi-84	3.40±0.078	2.22 ±0.100	35	0.81±0.001	0.19 ±0.006	77
9	Tale 38	3.77±0.046	2.47 ±0.079	34	0.38±0.006	0.36 ±0.011	5
10	Saratov-29	2.99±0.049	2.27 ±0.052	24	0.43±0.003	0.30 ±0.008	30
11	Dagdash	3.62±0.035	2.02 ±0.055	44	0.42±0.010	0.38 ±0.013	10
12	4th FEFWSN-No.16	3.61±0.063	2.32 ±0.079	36	0.54±0.008	0.34 ±0.012	37

Note: For each hybrid, the average value of 3 replicates (n = 3) was calculated, with p=0.05, and ±SD represents the standard deviation of the mean.

As shown in Table 2, salinity stress caused changes in the chlorophyll *a*+*b* content of the varieties. During the tillering phase, the chlorophyll *a*+*b* content significantly decreased in the Red Rose-1 and Dagdash samples. These varieties are categorized as sensitive due to their inadequate resistance to salinity during this phase. Akinci-84, Gyrmyzy Gul 1, Saratov-29, Nurlu-99, Azamatli-95, Gobustan, and Kiymatli-2/17 exhibited only slight fluctuations in chlorophyll *a*+*b* content under the influence of salinity stress during the tillering phase, showing moderate tolerance. The varieties of Azamatli-95, Gobustan, and Kiymatli-2/17 are definitely salt-tolerant. The carotenoid content in the Dagdash, Pirshahin, Azamatli-95, Gobustan, Akinci-84, and Tale-38 samples decreased slightly under salt stress, while in the Kiymatli-2/17, Saratov-29, and 4th FEFWSN-No.16 genotypes, the decrease was relatively mild. However, in the Nurlu-99, Ruzi-84, and Gyrmyzy Gul 1 genotypes, the reduction in carotenoid content was more pronounced.

The following analysis focuses on the activity of photosystems II and I. The impact of salinity on photosynthesis is multifaceted, with effects that are both indirect, characterized by stomatal closure, and direct, manifesting as interference with the photosynthetic apparatus. Concurrently, the impact of salinity on photosynthesis in salt-tolerant plants is also evidenced by a reduction in leaf surface area. The following table illustrates the effect of salinity on the activity of the photosystems in the chloroplasts of different wheat genotypes.

As demonstrated in Table 3, the PSI and PSII of the Pirshahin and Dagdash genotypes exhibited heightened sensitivity to the effects of salinity, while the photosystems of the Kiymatli-2/17, Nurlu-99, Gobustan, Saratov-29, Akinci-84, and Azamatli-95 genotypes demonstrated enhanced resilience. This finding suggests that the photosynthetic apparatus of these genotypes exhibits enhanced tolerance to salinity.

A comparative study of soft wheat (*Triticum aestivum* L.) varieties was conducted concerning yield components under both normal and saline conditions. The samples were cultivated under standard conditions, and phenological observations were meticulously recorded. The harvest was conducted similarly, and a structural analysis was performed based on ear weight, number of spikelets, grain weight per ear, number of grains, and weight of 1,000 grains. The results underwent statistical processing in comparison with normal conditions, with the objective of selecting traits that demonstrated significant changes. The results of the study are presented in Table 4.

Table 5 shows the main elements of the yield of soft wheat genotypes cultivated on saline soils. As demonstrated in Table 6, the impact of salinity on the yield components of all soft wheat varieties resulted in a modest decline in some, while in the majority, a substantial reduction was observed. The spike weight plays a crucial role in productivity, forming the foundation of overall yield. Changes in spike weight have also had an impact on the weight and number of grains per spike, as well as the 1000-grain weight.

Table 6 clearly shows the salt tolerance indices of the wheat varieties. Differences among the varieties are evident based on changes in the structural elements of the spike (spike weight, grain weight, number of grains, and 1000-grain weight).

Table 3. Effect of salinity on the activity of Photosystems II and I (mk mol O_2/mg chl. s.)

No.	Genotypes	PSII		PSI	
		Control |	Salinity	Control |	Salinity
1	Akinci-84	85±2,1	79±1,2	125±5,4	119±3,2
2	Gobustan	91±3,3	85±2,1	130±5,8	125±5,4
3	Nurlu-99	94±4,4	83±1,9	129±4,6	120±4,3
4	Kiymatli-2/17	99±5,6	85±1,7	133±3,5	126±6,2
5	Pirshahin	87±2,7	60±2,1	109±2,9	90±3.4
6	Gyrmyzy Gul 1	81±1,2	59±1,8	95±3,4	70±5,6
7	Azamatli-95	105±3,9	95±1,5	150±5,5	130±6,4
8	Ruzi-84	93±2,2	70±2,2	110±4,2	95±3,2
9	Tale-38	87±1,5	60±0,8	95±4,3	70±2,1
10	Saratov-29	96±4,1	90±1,6	121±3,5	109±6,1
11	Dagdash	87±2,4	60±1,9	98±2,8	71±2,3
12	4th FEFWSN-No.16	98±4,3	70±2,5	116±4,4	100±4,2

Table 4. Characteristics of the structural elements of soft wheat varieties grown under optimal conditions on the Absheron Peninsula.

No.	Genotypes	Spike Weight (g)	Grain Weight (g)	Number of Grains	1000 Grain Weight (g)
1	Akinci-84	2.65±0.58	2.42±0.14	42±1.76	43.2±0.92
2	Gobustan	3.94±0.37	3.34±0.34	40±2.68	45.1±0.11
3	Nurlu-99	3.45±0.21	3.23±0.16	5±0.42	53.7±0.42
4	Kiymatli-2/17	3.97±0.32	2.93±0.24	50±1.63	45.1±0.32
5	Pirshahin	3.48±0.17	3.25±0.21	36±0.78	45.2±0.16
6	Gyrmyzy Gul 1	3.68±0.31	3.11±0.66	47±0.15	42.1±0.45
7	Azamatli-95	4.02±0.25	3.80±0.42	41±2.12	42.4±0.84
8	Ruzi-84	3.64±0.23	3.21±0.33	34±0.71	49.2±0.93
9	Tale-38	3.00±0.28	2.10±0.01	40±2.82	48.1±0.17
10	Saratov-29	3.60±0.10	2.72±0.11	45±0.62	45.4±0.42
11	Dagdash	3.60±0.14	2.03±0.10	36±0.56	39. 2±0.96
12	4th FEFWSN-No.16	3.78±0.31	3.02±0.54	47±0.44	46.3±0.33

Examining the tolerance indices shows that differences were evident among the varieties based on changes in spike weight. There was a reduction in the grain weight per spike. The number of grains per spike in Nurlu-99, Kiymatli-2/17, and Pirshahin varieties remained unchanged or showed minimal variation. These varieties exhibited differences in 1000-grain weight. This is in line with the other yield components.

As shown in Fig. 1, based on tolerance indices, the varieties were grouped into three main clusters. Group I comprised Gyrmyzy Gul 1, Dagdash, Kiymatli-2/17, Azamatli-95, Ruzi-84, Saratovskaya-29, and 4th FEFWSN-No.16, further divided into two subgroups. The first subgroup, including Gyrmyzy Gul 1, Dagdash, Kiymatli-2/17, Azamatli-95, and Ruzi-84, was classified as salt-tolerant. Group II included Akinci-84, Tale-38, and Nurlu-99, which exhibited moderate tolerance. In these varieties, salinity caused reductions of 0.4-1.2% in spike weight, 0.4–0.96% in grain weight per spike, and 0.6-14.3% in 1000-grain weight. Group III, consisting of Gobustan and Pirshahin, was classified as salt-sensitive, showing decreases of 1.5-1.8% in spike weight and 1.3-1.7% in grain weight per spike.

The use of statistical methods plays a crucial role in validating the accuracy of the results obtained in scientific research. Therefore, in our study, these

Table 5. Characteristics of the structural elements of soft wheat varieties on saline soils in the Agsu district.

No.	Genotypes	Spike Weight (g)	Grain Weight (g)	Number of Grains	1000 Grain Weight (g)
1	Akinci-84	2.35±0.58	2.17±084	26±1.76	43.7±0.78
2	Gobustan	2.14±0.37	1.98±0.46	34±2.68	40.1±0.98
3	Nurlu-99	3.35±0.21	3.13±0.32	45±0.42	39.4+0.45
4	Kiymatli-2/17	2.67±0.32	2.27±0.16	46±1.63	32.5±0.70
5	Pirshahin	1.98±0.17	1.55±0.84	32±0.78	29.4±0.14
6	Gyrmyzy Gul 1	2.98±0.31	2.44±0.16	31±0.15	34.1±0.44
7	Azamatli-95	3.42±0.25	3.14±0.43	33±2.12	38.5±0.23
8	Ruzi-84	3.24±0.23	2.72±0.89	29±0.71	36.5±0.18
9	Tale-38	2.12±0.28	1.79±0.23	30±2.82	40.0±0.43
10	Saratov-29	1.89±0.10	1.76±0.43	28±0.62	37.7±0.17
11	Dagdash	1.96±0.14	1.43±1.06	26±0.56	37.2±0.78
12	4th FEFWSN No.16	2.58±0.31	2.12±0.12	27±0.44	33.8±0.98

Table 6. Tolerance indices of yield components for soft wheat samples.

No.	Sample Names	Spike Weight (g)	Grain Weight (g)	Number of Grains	1000 Grain Weight (g
1	Akinci-84	0.30	0.25	16	0.6
2	Gobustan	1.8	1.3	6	5
3	Nurlu-99	0.5	0.1	0	14.3
4	Kiymatli-2/17	1.3	0.66	4	12.6
5	Pirshahin	1.5	1.7	4	15.8
6	Gyrmyzy Gul 1	0.7	0.6	16	7.1
7	Azamatli-95	0.6	0.66	8	3.6
8	Ruzi-84	0.4	0.49	5	12.7
9	Tale-38	0.8	0.3	10	8.1
10	Saratov-29	0.7	0.96	17	7.7
11	Dagdash	0.63	0.6	10	2
12	4th FEFWSN No.16	1.2	0.9	20	12.5

methods were prioritized. By applying these methods, the similarities and differences between the studied varieties based on yield traits were determined.

The dendrogram clearly shows the varieties that are closely related in terms of their salinity tolerance. The samples in the first group are divided into subgroups. The varieties grouped in the subgroups are more similar to each other in terms of their salinity tolerance. For instance, three subgroups were formed within the first group. The Gyrmyzy Gul 1, Dagdash, Kiymatli-2/17, Azamatli-95, and Ruzi-84 varieties are grouped in the first subgroup of the first group. Examining the tolerance indices clearly shows that the varieties are almost identical in terms of changes in spike weight and grain weight. The subsequent varieties are arranged according to the principle of proximity. The first subgroup is more tolerant than the second, and the second is more tolerant than the third. This principle is also observed in the second main group.

During periods of salinity stress, a series of deleterious changes occur within the chloroplasts of plants, thereby impeding the normal process of photosynthesis. It is also observed that in salt-sensitive plants, there is a greater breakdown of chloroplasts and a reduction in photosynthesis intensity [19]. This mechanism is chiefly linked to the build-up of reactive oxygen species (ROS). ROS are produced at high levels during stress. This causes damage to chloroplast

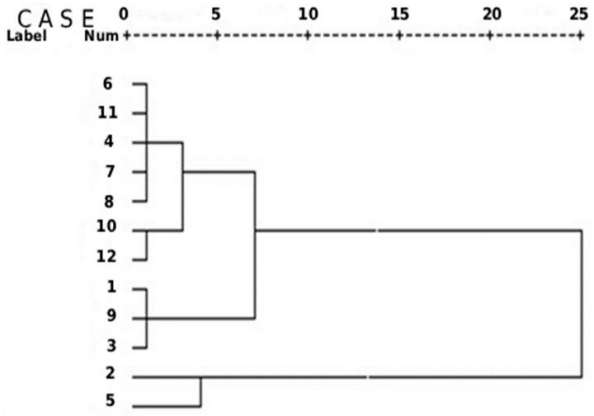

Fig. 1. The following dendrogram has been constructed based on the tolerance indices.

membranes, particularly thylakoid structures, and limits the activity of photosystems [20, 21]. Experiments on three wheat varieties and one local variety have proven that 200 mM NaCl significantly reduces the maximum photochemical efficiency (Fv/Fm) of PSII [22].

The decrease in the amount of photosynthetic pigments in various barley genotypes under the effect of salinity has been recorded in the experiments of several authors [23, 24]. In these experiments, barley seedlings were initially grown in Hoagland's nutrient medium. After one week, they were transferred to NaCl solutions of 50, 100, 200, 300, and 400 mM concentrations. Three days later, changes in the growth of both aerial organs and roots were recorded. At the same time, the amounts of chlorophyll *a*, chlorophyll *b*, and carotenoids were determined. The amount of carotenoids increased with the increasing salinity concentration, while the chlorophyll content decreased. Carotenoids have been shown to dissipate excess light energy by deactivating triplet chlorophyll and singlet oxygen. This process serves to protect the photosynthetic apparatus in photosystem II from photodamage. Genotypes with fewer changes in growth processes and pigment content were recommended for selection [23, 24].

One of the internal factors that can affect the photosynthetic activity of plants is the change in the water content of the leaves. The increase or decrease in water primarily regulates the function of the stomata. It has been observed that certain species of plants are characterized by the presence of trichomes, which are light grey in colour, on the surface of their leaves. It has been demonstrated that these leaves maintain a lower temperature by reflecting a substantial proportion of light. However, given that the light wavelengths necessary for the photosynthesis process are also reflected, there is a concomitant decrease in the absorption of carbon dioxide. These adaptations increase water use efficiency in salty and arid conditions by regulating transpiration rates [25].

The objective of efforts to enhance the hairiness of plants is to improve their capacity for water utilization. One way to prevent dehydration is to have a thick layer of cuticle in the epidermis, which reduces water loss. When crops are under water stress, the spike and other assimilatory organs must be actively photosynthesizing. The cuticle also makes it harder for carbon dioxide to get in, but it does not significantly inhibit photosynthesis in the leaves. Most studies have found that when plants are under stress, this is largely due to osmolytes keeping the water potential of their leaves close to normal levels [26, 27].

Academic researcher C.A. Aliyev [28] has stated that in plants under stress, the root system and stress proteins that are controlled by certain genes, as well as the plant's architecture and its different photosynthetic properties, are really important. Recent studies have confirmed this idea at the molecular level, demonstrating that the expression levels of the *SOS1*, *NHX1*, and *HKT1*; 5 genes are significantly higher in salt-tolerant genotypes than in salt-sensitive varieties. Photosynthesis is an important process for food and feed production and for making protein in grains [28, 29].

The water potential of the leaves of various plant species and varieties under salinity conditions, along with the changes in other physiological indicators, has been identified in the work of several researchers [30]. High concentrations of Na^+-K^+ and total salts interrupt enzyme activity and hinder protein synthesis [31]. This situation is also a direct consequence of ionic toxicity: an increase in intracellular Na^+ ions blocks the activity of K^+ channels, leading to an imbalance in enzyme systems [32].

In a multitude of experiments conducted under conditions of salinity, a decline in electron transfer between PSII and PSI has been observed [33]. In experiments where NaCl salt was gradually introduced into the plant nutrient medium, a reduction in the photochemical activity of chloroplasts and electron transfer between photosystems was observed [34]. The main reason for this is the disruption of the oxidation-reduction balance of the plastoquinone pool and the degradation of the D1 protein, a core component of the photosystem II reaction center responsible for electron transport [35].

The impact of salt stress on plants varies depending on the developmental stage. In particular, during the growth stages of wheat, especially in the tillering phase, there is a more significant impact on the amount of chlorophyll pigments. In later stages, the effect varies as the root system develops, leading to an increase in prolamins and carbohydrate content in the roots. This, in turn, results in the formation of a protective system and helps plants alleviate stress [36].

Salinity stress exerts a multifaceted influence on the yield components of the spike during its maturation stage. A plethora of experiments conducted by numerous researchers has determined that, while salinity stress does not affect the length of the spike, the number of spikelets, or the number of grains, it has a detrimental effect on the size of the grains and their weight. This has been demonstrated to result in a decline in productivity indicators due to the associated stress [37, 38].

Conclusions

In our research on the evaluation of salt tolerance, the studied genotypes were grouped, revealing more tolerant forms that can be cultivated in relatively saline soils in farm enterprises for crop production. For the first time, the physiological and yield characteristics of 8 wheat varieties in the saline soils of Azerbaijan have been studied in a comparative manner. It has been determined that Akinci-84, Nurlu-99, Azamatli-95, Gobustan, and Kiymatli-2/17 varieties are more tolerant than others based on the changes in chlorophyll and carotenoid content under the influence of salinity.

During the study of the photochemical activity of chloroplasts, it became clear that under salinity conditions, Kiymatli-2/17, Nurlu-99, Gobustan, Saratov-29, Akinci-84, and Azamatli-95 varieties exhibited higher activity compared to other genotypes. Under salinity stress, Saratovskaya-29, Kiymatli-2/17, Gobustan, and Azamatli-95 varieties were distinguished from others by having a higher relative water content and lower water deficiency in their leaves. Among the tested varieties of soft wheat (*T. aestivum L.*), the following varieties — Valuable 2/17, Majestic-95, Nurlu-99, and Akinci-84 — are recommended as genetic sources for selection in the development of salt-tolerant varieties.

Conflict of Interest

The authors declare no conflict of interest.

AI Usage Disclosure Statement

During the preparation of this manuscript, AI-based tools, including ChatGPT (GPT-5.5, OpenAI) and DeepL (DeepL SE), were used exclusively for translation assistance, language editing, grammar correction, and improving the academic clarity and readability of the manuscript. The authors take full responsibility for the scientific content, data, analyses, and conclusions presented in this article.

References

1. ALKHATIB R., ABDO N., MHEIDAT M. Photosynthetic and ultrastructural properties of eggplant (*Solanum melongena*) under salinity stress. Horticulturae, **7** (7), 181, **2021**.
2. AZİZOV G., GULİYEV A. Azerbaijan Salinized Soils, Increase of Their Melioration and Fertility. Elm: Baku, Azerbaijan, pp.75, **1999** [In Russian].
3. HASEGAWA P.M., BRESSAN R.A., ZHU J.K. Plant cellular and molecular responses to high salinity. Annual Review of Plant Biology, **51** (1), 463, **2000**.
4. JABEEN Z., FAYYAZ H.A., IRSHAD F., HUSSAIN N., HASSAN M.N., LI J., REHMAN S., HAIDER W., YASMIN H., MUMTAZ S., BUKHARI S.A.H., KHALOFAH A., AL-QTHANIN R.N., ALSUBEIE M.S. Sodium nitroprusside application improves morphological and physiological attributes of soybean (*Glycine max* L.) under salinity stress. Plos One, **16** (4), e0248207, **2021**.
5. ABBASI H., JAMIL M., HAQ A., ALI S., AHMAD R., MALIK Z., PARVEEN Z. Salt stress manifestation on plants, mechanism of salt tolerance and potassium role in alleviating it: a review. Zemdirbyste-Agriculture, **103** (2), 229, **2016**.
6. QADOS, A.M.A. Effect of salt stress on plant growth and metabolism of bean plant *Vicia faba* (L.). Journal of the Saudi Society of Agricultural Sciences, **10** (1), 7, **2011**.
7. STEFANOV M.A., RASHKOV G.D., YOTSOVA E.K., BORISOVA P.B., DOBRIKOVA A.G., APOSTOLOVA E.L. Different sensitivity levels of the photosynthetic apparatus in *Zea mays* L. and *Sorghum bicolor* L. under salt stress. Plants, **10** (7), 1469, **2021**.
8. IBRAHİMOVA U., TALAİ J.M.D., HASAN M., HUSEYNOVA I., RAJA W., RASTOGI A., GHAFFARİ H., ZİVCAK M., YANG X., BRESTİC M. Dissecting the osmotic and oxidative stress responses in salt-tolerant and salt-sensitive wheat genotypes under saline conditions. Plant, Soil & Environment, **71** (1), 36, **2025**.
9. WARREN R.S., GOULD A.R. Salt tolerance expressed as a cellular trait in suspension cultures developed from the halophytic grass Distichlis spicata. Zeitschrift für Pflanzenphysiologie, **107** (4), 347, **1982**.
10. HUSEYNOVA I.M., SULEYMANOV S.Y., AZİZOV I.V., RUSTAMOVA S.M., MAGERRAMOVA E.G., ALİEV J.A. Effects of high concentrations of sodium chloride on photosynthetic membranes of wheat genotypes. Scientific works of the Institute of Botany of ANAS, 28, **2008** [In Azerbaijani/Russian].
11. TRAYE I.D., OLI N.M., WENG X., LI K., SULIMAN M.S.E., GUO X., ZHOU G.S., ZHU G.L., XU Y. Salinity Tolerance in Wheat: Mechanisms and Breeding Approaches. Plants, **14** (11), 1641, **2025**.
12. NEDRET T.Ş., BENGU T. A physiological investigation on the mechanism of salinity tolerance in some barley culture forms. Journal of Forensic Sciences, **27**, 1, **2004**.
13. WINTERMANS J.F.G.M., DE MOTS A. Spectrophotometric characteristics of chlorophylls a and b and their phenophytins in ethanol. Biochimica et Biophysica Acta (BBA)-Biophysics including

Photosynthesis, **109** (2), 448, **1965**.
14. BOSE J., MUNNS R., SHABALA S., GILLIHAM M., POGSON B., TYERMAN S.D. Chloroplast function and ion regulation in plants growing on saline soils: lessons from halophytes. Journal of Experimental Botany, **68** (12), 3129, **2017**.
15. ROSIELLE A.A., HAMBLIN J. Theoretical Aspects of Selection for Yield in Stress and non-Stress Environments. Crop Science, **21** (6), 943, **1981**.
16. SAOUDI W., TAAMALLI W., ABDELLY C., BADRI, M. Morphological and physiological behaviour of sea barley (*Hordeum marinum* ssp *marinum*) genotypes originating from Soliman Sebkha under increasing salinity. Journal of Oasis Agriculture and Sustainable Development, **5** (2), 27, **2023**.
17. MOHAMMADI S.A., PRASANNA B.M. Analysis of genetic diversity in crop plants—salient statistical tools and considerations. Crop science, **43** (4), 1235, **2003**.
18. MUSAYEV A.C., HUSEYNOV H.S., MAMMADOV Z.A. Methodology of field experiments on research work in the field of breeding of grain crops. Muallim: Baku, Azerbaijan, pp. 88, **2008** [In Azerbaijani].
19. KHOSRAVİNEJAD F., HEYDARİ R., FORBOODMA T. Effekts of salinity on fotosynthetic pigments / Resporation and water content in two barley Varietis. Pakistan Journal of Biological Sciences, **11** (20), 2438, **2008**.
20. HASANUZZAMAN M., BHUYAN M.B., ZULFIQAR F., RAZA A., MOHSIN S.M., MAHMUD J.A., FUJITA M., FOTOPOULOS V. Reactive oxygen species and antioxidant defense in plants under abiotic stress: Revisiting the crucial role of a universal defense regulator. Antioxidants, **9** (8), 681. **2020**.
21. FOYER C.H., HANKE G. ROS production and signalling in chloroplasts: cornerstones and evolving concepts. The Plant Journal, **111** (3), 642, **2022**.
22. MOHAMMADİ S., JAHANBAKHSH S., RAZAVİ K., SADATİ S.Y.R., AĞAMİRZAOĞLU M. Evaluation of Some Physiological and Molecular Mechanisms of Wheat Cultivars Under Salt Stress. Yuzuncu Yıl University Journal of Agricultural Sciences, **35** (1), 91, **2024**.
23. SUN T., RAO S., ZHOU X., LI L. Plant carotenoids: recent advances and future perspectives. Molecular Horticulture, **2** (1), 3, **2022**.
24. GORHAM J. Mechanisms of salt tolerance of halophytes. Marcel Dekker Inc: New York, USA, pp. 53, **1995**.
25. BERTOLINO L.T., CAINE R.S., GRAY J.E. Impact of stomatal density and morphology on water-use efficiency in a changing world. Frontiers in Plant Science, **10**, 225, **2019**.
26. HAGHPANAH M., HASHEMIPETROUDI S., ARZANI A., ARANITI, F. Drought tolerance in plants: physiological and molecular responses. Plants, **13** (21), 2962, **2024**.
27. BOYER J.S. Turgor and the transport of CO_2 and water across the cuticle (epidermis) of leaves. Journal of Experimental Botany, **66** (9), 2625, **2015**.
28. ALIYEV J.A., AKPAROV Z.I. Genetic resources of plants of Azerbaijan. News of ANAS (Series of biological sciences). Elm , Baku (**1999**) [In Russian].
29. ABDEHPOUR Z., EHSANZADEH P., GHANATI F. Expression level of NHX1 and SOS1 genes is key to high salt tolerance of ancient emmer wheat: implications to tackling salt stress penalties of wheat yield. Functional Plant Biology, **52** (8), **2025**.
30. JESCHKE W.D. K^+-Na^+ exchange at cellular membranes, intracellular compartmentation of cations, and salt tolerance. Salinity Tolerance in Plants: Strategies for Crop Improvement, 37, **1984**.
31. ASSAHA D.V., UEDA A., SANEOKA H., AL-YAYAI R., YAISH M.W. The role of Na^+ and K^+ transporters in salt stress adaptation in glycophytes. Frontiers in Physiology, **8**, 509, **2017**.
32. KEİSHAM M., MUKHERJEE S., BHATLA S.C. Mechanisms of sodium transport in plants-progresses and challenges. International Journal of Molecular Sciences, **19** (3), 647, **2018**.
33. GÓMEZ-CADENAS A., ARBONA V., JACAS J., PRIMO-MILLO E., TALON M. Abscisic acid reduces leaf abscission and increases salt tolerance in citrus plants. Journal of Plant Growth Regulation, **21** (3), 234, **2002**.
34. ALIYEVA N.K., ALIYEVA D.R., SULEYMANOV S.Y., RZAYEV F.H., GASIMOV E.K., HUSEYNOVA I.M. Comparative Analysis of Mesophyll and Bundle Sheath Chloroplasts from Maize Plants Subjected to Salt Stress. Biochemistry (Moscow), **90** (4), 522, **2025**.
35. DANG K., MU J., TIAN H., GAO D., ZHOU H., GUO L., SHAO X.W., GENG Y.Q., ZHANG Q. Zinc regulation of chlorophyll fluorescence and carbohydrate metabolism in saline-sodic stressed rice seedlings. BMC Plant Biology, **24** (1), 464, **2024**.
36. JAVADOVA L.H., JAFAROVA R.H., SHEİKH-ZAMANOVA F.A., RZAYEVA S.P. Diagnostics of salt tolerance of hard and soft wheat varieties according to physiological parameters. Journal of Agricultural Science, **3** (4), 40, **2005** [In Azerbaijani/Russian].
37. ROYO A., ARAGUES R. Effect of salinity on various morpho-physiological characters and grain yield in barley. Investigacion Agraria. Produccion y Proteccion Vegetales (Espana), **10** (1), 71, **1995** [In Spanish].
38. KHANİSHOVA M., TAGHİYEVA K., AZİZOV I. Assessment of salt tolerance of wheat and maize genotypes according to physiological and yield indicators International Journal of Botany Studies, **7** (2), 501, **2022**.