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# PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS OF SOYBEAN GENOTYPES UNDER DIVERSE WATER REGIMES

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## SUMMARY

This study pursued tests on 17 local and exotic soybean (*Glycine max* L. Merr.) cultivars with two different water regimes. In the optimal irrigated condition (control), the soybean plants gained five times irrigation in the scheme of 1:3:1 during the vegetation period, with the total volume of water used for that irrigation being 5000–5500 $m^3$/ha. For the water deficit condition, irrigation was only three times on the scheme 1:1:1, using a total volume of water at 3000–3500 $m^3$/ha. In the optimal irrigated condition, water provision was only once during the formation of soybean leaves, three times during the budding period, and once again at the beginning of the blooming period. In that condition, the provision of an artificially created water deficit condition and drought with one irrigation ensued at the beginning of the blossoming period. According to the results, chlorophyll "b" pigment was more sensitive to water deficit conditions than chlorophyll "a." The increase in chlorophyll "b" under drought conditions increased chlorophyll's protection function, the primary photosynthetic pigment, with its reception of photons from sunlight. Stress enzyme activity increased to different extents compared with optimal water supply conditions in the soybean cultivars under water deficit conditions. The number of chloroplast pigments in plant leaves and the activity of peroxidase, catalase, and superoxide dismutase enzymes in leaves strongly influenced local and exotic soybean genotypes during the blooming-harvest period under drought conditions. With water deficit conditions, the number of pods per plant and 1000-grain weight reduced from 8.6% to 63.7% and 1.7% to 12.8% in the local and 3.8% to 28.3% and 5.6% to 58.8% in exotic soybean cultivars compared with water optimal conditions.

**Keywords:** Soybean (*Glycine max* L. Merr.), genotypes, diverse water regimes, water deficit condition, peroxidase, catalase, chlorophyll, carotenoids

**Key findings:** Under water stress conditions, the peroxidase enzyme activity was notably higher in local soybean cultivars Genetic-1 and Tomaris and the exotic cultivar Selecta-301 compared with other genotypes.

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**INTRODUCTION**

Drought is one of the radical environmental stresses limiting crop productivity in most regions of the world; however, more persistent in warm and dry areas (Porudad *et al.,* 2003; Sanaev *et al.,* 2021; Chorshanbiev *et al.,* 2023). Worldwide, crops' growth, development, and yield have constant impacts from various abiotic stresses, environmental factors, and climate change (Dennis and Bruening*,* 2000; Marguba *et al.,* 2020; Khamdullaev *et al.,* 2021; Shavkiev *et al.,* 2021; 2022). The drought tolerance trait in crops is vital as it relates to productivity. It is necessary to make relevant fundamental changes and improvements in crop research and the intensive selection of desirable genotypes to improve this feature (Maleki *et al.,* 2013; Makamov *et al.,* 2023).

Often, the crucial stages of plant growth mostly have impacts from environmental stresses, including drought (Leila, 2007). Increased aridity causes the accumulation of salts and ions in the upper soil layers around the roots to boost osmotic stress and ion toxicity. The plant's first response to stress is a biophysical effect. As drought stress increases, the cell wall begins to dry out and loosen due to cell volume decline; consequently, the cell's development potential and growth weaken. However, these factors also depend on the area and the number of leaves in plants (Bagheri, 2009).

Drought tolerance is the ability of species and cultivar to grow and develop under high, arid conditions. Physiological and morphological characteristics that affect productivity in a long, dry period depend on various factors. These losses not only hinge on the drought that occurred during the crop life and the water permeability of the soil in the root part, but the biological characteristics also affect the crop plants (Mohsenzadeh *et al.,* 2006). The leaves of dehydrated plants stop growing and accumulate abscisic acid, proline, and glycine-betamine (Abernethy and McManus*,* 1998). There are various physiological and biochemical mechanisms in crop plants adapting to drought. During cotton growth, the agroecological conditions lead to changes in the attributes of plants (Shavkiev *et al.,* 2020; 2021; Matniyazova *et al.,* 2022).

Environmental influences on the protein content and other biochemical substances significantly transpired in soybeans. Past studies on determining the productive level of irrigation to increase yield and improve seed quality of soybean revealed that 65% of irrigation methods significantly impact increasing protein content and productivity of soybeans (Kresovic *et al.*, 2017). Their results further authenticated that the irrigation method was notably the most favorable for soybeans and the most convenient choice for maximizing yield and ensuring the best chemical composition of soybean grains. Legumes are a cheap and most valuable food substitute for meat worldwide. Legumes have high nutritional value, providing proteins with essential amino acids, complex carbohydrates, minerals, and vitamins (Maphosa and Victoria, 2017; Staniak *et al*., 2021; Kulmamatova *et al*., 2023). The fat and protein content of soybeans supposedly depends on the genetic source and environmental condition effects (Bellaloui, 2012; Assefa *et al.,* 2018; Kurbanbaev et al., 2021).

Water deficit conditions harm chlorophyll synthesis, leaf morphology, dry matter accumulation, and soybean seed yield. Optimal irrigation substantially enhanced the number of grains per pod and seed size in soybean; however, a little delay also affected the ripening. Lutz *et al*. (1973) reported that water deficit can intensely reduce the seed yield if it occurs early in ontogeny. When water deficit condition befalls during the flower formation and seeding periods of soybean, a significant decline in harvest and its components happens in the plant (Cure *et al*., 1983).

During the ontogeny of the soybean plant, the enzyme activity depends on the specific characteristics of the cultivar, meteorological conditions, and the means used for plant protection. The plants' exposure to adverse environmental conditions resulting in chemical damage, isozymes of this heterogeneous nature show multifunctional properties (Neverova, 2001). In the soybean plant, the peroxidase enzyme serves as a bioindicator that determines the plant's resistance to stresses, and its activity changes before inflicting damage on the plant cell participating in the protection mechanism. In the presence of different peroxidase substrates in the solution, mutual inhibition and activation of the enzyme can be noticeable, showing the type of differential oxidation of the substrates. The mechanism of peroxidase effect on the activity of the oxidation reaction may slightly weaken in the environment with two different substrates.

Soybean peroxidase is characteristic of the following unique properties, i.e., high-temperature resistance (inactivation occurs at temperatures above 80 °C), high reactivity, preservation of resistance to organic solvents, and low pH environments (Rogozhin and Peretolchin, 2010). Peroxidase is a two-component enzyme, a combination of an active group that enters into chemical interaction with substrates and a protein part (apoenzyme) that enhances the catalytic effect of this group. Peroxidase is an isozyme with a polyfunctional, heterogeneous composition that appears in organisms exposed to changing adverse environmental conditions (Kartasheva *et al.,* 2000).

Drought stress causes an imbalance between antioxidant defenses and reactive oxygen species (ROS), which cause oxidative stress. ROS is necessary for intracellular signal transmission; however, its high concentration can also damage various derivatives, including chloroplasts (Smirnoff, 1993). ROS can initiate lipid peroxidation and degrade proteins, lipids, and nucleic acids (Hendry, 2005). The mechanism of lipid peroxidation consists of free radical scavenging enzymes, such as, catalase, peroxidase, and superoxide dismutase (Fridovich and Rao, 2000). Chloroplasts contain several enzymatic and non-enzymatic antioxidants that help prevent ROS accumulation (Srivalli *et al.,* 2003).

Under water deficit conditions, ROS formation increases, and the antioxidant system protects the cell by controlling intracellular ROS concentration. Another expected consequence of water stress-induced cellular accumulation of ROS is increased lipid peroxidation. Peroxidation of lipids in the cell membrane is one of the most harmful responses of the observed cell in response to water deficit stress conditions. The amount of lipid peroxidation is evidently one of the factors indicating the severe stress plants face (Thankamani *et al.,* 2003). Therefore, this study sought to investigate the physiological and biochemical characteristics of local and exotic soybean varieties under water deficit conditions.

## MATERIALS AND METHODS

The pertinent research used 17 local and exotic soybean (*Glycine max* L. Merr.) cultivars, employing two different water regimes during 2018–2020 at the experimental field of the Institute of Genetics and Experimental Plant Biology, Academy of Sciences of the Republic of Uzbekistan, Tashkent region, Uzbekistan. The soybean local cultivars were Selecta 302, Selecta 201, Selecta 301, Sparta, Duar, Arleta, Nena, Evrika, and Amigo, while the exotic cultivars were Sochilmas, Genetic-1, Orzu, Tomaris, Baraka, and Ustoz. The weather in the experimental area was moderately hot, and the annual average temperature corresponds to 13.9 °C. The average yearly rainfall was 449 mm, mainly in spring and the least in summer months.

The experimental fields have irrigation and gray soil, with a humus content of 0.8%–1.2% and available phosphorus (30–38 mg $kg^{-1}$) (Kulmamatova *et al.,* 2022). The terrain is slightly sloping and not saline. The volume weight of the soil is 1.32–1.33 $g/cm^3$, and the limited field moisture capacity (LFMC) was 22%, with the sizot waters located deep (8 m and more) (Khamdullaev *et al.,* 2021; Shavkiev *et al.,* 2022).

Different irrigation schemes ran in soybean studies. In the water deficit condition, irrigation three times had the pattern 1-1-1, using 3000–3500 $m^3$/ha of water. In the optimal irrigated condition (control), watering five times was according to the 1-3-1 scheme with 5000–5500 $m^3$/ha of water spent. Physiological and biochemical analyses of soybean plants of all the genotypes during the flowering-harvest period ensued in the laboratory when the soil moisture was optimal (70%–72%) compared with the limited field moisture capacity (50%–55%). Agrotechnical activities proceeded in the same way in both conditions. Mineral fertilizers' application included feeding three times, i.e., before planting, during planting, and during the vegetation period (first feeding at the beginning of budding, second at general budding, and third at blooming - harvesting). The NPK application rate was 30-40:70-90:30-40 kg $ha^{-1}$, respectively, to the soybean plants during the growing season.

In soybean plant leaves, the peroxidase enzyme activity (Lowry, 1951), catalase enzyme activity (Korolyuk *et al.,* 1988), superoxide dismutase enzyme activity (Elstner et al., 1995), proline amino acid content (Bates *et al.,* 1973), and oil content in grains determination followed the method according to Mirkhamidova *et al*. (2002). In the presented research, valuable economic traits were also verifiable in soybean plants following the standard methods (Methods of conducting field experiments, 2007). Susceptibility levels of soybean cultivars to water deficit conditions also employed the formula of Ebarhart and Russell (1966), with the adaption coefficient (FC) determined as follows:

$$Кмос\% = \left(\frac{x_1}{x_2} x100\right) - 100\%$$

Where:

$x^1$ is the indicator of the sign in the case of water deficit

$x^2$ is the indicator of the sign in the optimal supply of water

**Statistical analysis**

Analysis of the variance for various traits of soybean cultivars under two different irrigation regimes ran according to Steel *et al*. (1997). In this case, the Fisher criterion (F), the standard deviations (SD), the standard error (SE), and the degree of significant differences ($P \leq 0.05$*, $P \leq 0.01$**, and $P \leq 0.001$***) determined the reliability of the differences among the genotypes for each trait. The correlation coefficient determination also ensued among the various variables (Kwon and Torrie, 1964). In this case, when r was less than 0.3, the correlation between the traits was weak; when $r$ = 0.3–0.7, it was average, and when r was higher than 0.7, it revealed a strong association.

## RESULTS

In this study, the chloroplast pigments responsible for photosynthesis, including chlorophyll "a," chlorophyll "b," and carotenoids, gained assessment during the blooming period of soybean cultivars.

**Pigments in leaves during the blossoming period**

Studying the chlorophyll "a" in the leaves of soybean cultivars under optimal water conditions during the blooming period revealed the highest recorded values were in the exotic cultivars Selecta-302, Arleta, and Nena (3.74 ± 0.15 mg/g, 3.71 ± 0.21 mg/g, and 3.71 ± 0.39 mg/g, respectively), while the lowest value was in cultivar Duar (3.37 ± 0.26 mg/g). In the local cultivars, the highest values of the chlorophyll "a" were notable in the cultivars Tomaris and Baraka (3.68 ± 0.23 mg/g and 3.65 ± 0.33, respectively), with the lowest value in cultivar Genetic-1 (3.44 ± 0.42 mg/g) (Table 1).

Under water deficit conditions, the amount of chlorophyll "a" in the leaves of all genotypes decreased to a different extent. In the case of water deficit condition, the highest index of chlorophyll "a" content in exotic cultivars appeared in Selecta-302 and Nena

**Table 1.** The amount of pigments in the leaves of local and exotic soybean cultivars during the flowering period under different water regimes.

| No. | Cultivars | Chlorophyll "a" (mg/g) | | | Chlorophyll "b" (mg/g) | | | Carotenoid (mg/g) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Irrigated/ | Drought | Кмос (%) | Irrigated | Drought | Кмос (%) | Irrigated/ | Drought | Кмос (%) |
| 1 | Selecta-302 | 3.74±0.15 | 3.57±0.10 | -4.5 | 2.12±0.12 | 2.00±0.10 | -5.7 | 1.82±0.13 | 1.85±0.17 | +1.6 |
| 2 | Selecta-201 | 3.66±0.18 | 3.19±0.30 | -12.8 | 2.09±0.22 | 1.83±0.32 | -12.4 | 1.51±0.23 | 1.89±0.16 | +25.2 |
| 3 | Amigo | 3.58±0.32 | 2.72±0.67 | -24.0 | 2.06±0.30 | 1.90±0.53 | -7.8 | 1.03±0.18 | 1.21±0.18 | +17.5 |
| 4 | Selecta-301 | 3.66±0.29 | 3.12±0.38 | -14.8 | 2.12±0.43 | 1.88±0.48 | -11.3 | 1.44±0.30 | 1.81±0.09 | +25.7 |
| 5 | Arleta | 3.71±0.21 | 2.61±0.07 | -29.6 | 2.01±0.38 | 1.90±0.27 | -5.5 | 1.25±0.10 | 1.33±0.18 | +6.4 |
| 6 | Sparta | 3.81±0.08 | 3.39±0.36 | -11.0 | 2.04±0.41 | 1.52±0.18 | -25.5 | 1.38±0.31 | 1.51±0.17 | +9.4 |
| 7 | Duar | 3.37±0.26 | 3.36±0.30 | -0.3 | 2.01±0.45 | 1.40±0.09 | -30.3 | 1.60±0.09 | 1.86±0.11 | +16.3 |
| 8 | Vilana | 3.62±0.22 | 3.42±0.26 | -5.5 | 2.05±0.34 | 1.42±0.35 | -30.7 | 1.65±0.10 | 1.87±0.17 | +13.3 |
| 9 | Chara | 3.62±0.26 | 2.84±0.40 | -21.5 | 1.08±0.50 | 1.03±0.51 | -4.9 | 1.35±0.28 | 1.60±0.20 | +18.5 |
| 10 | Evrika-357 | 3.68±0.36 | 2.89±0.08 | -21.5 | 1.21±0.43 | 1.10±0.24 | -9.1 | 1.42±0.03 | 1.78±0.14 | +25.4 |
| 11 | Nena | 3.71±0.39 | 3.54±0.28 | -4.6 | 1.94±0.34 | 1.67±0.45 | -13.9 | 1.67±0.20 | 1.74±0.15 | +4.2 |
| 12 | Ustoz MM-60 | 3.58±0.29 | 3.55±0.18 | -0.8 | 1.96±0.02 | 1.85±0.06 | -5.6 | 1.83±0.11 | 1.89±0.12 | +3.3 |
| 13 | Baraka | 3.65±0.33 | 3.53±0.31 | -3.3 | 2.47±0.48 | 1.94±0.47 | -21.5 | 1.66±0.20 | 2.04±0.16 | +22.9 |
| 14 | Sochilmas | 3.52±0.25 | 3.27±0.35 | -7.1 | 1.70±0.41 | 1.28±0.32 | -24.7 | 1.58±0.24 | 1.67±0.27 | +5.7 |
| 15 | Genetic-1 | 3.44±0.42 | 3.15±0.21 | -8.4 | 2.04±0.24 | 1.70±0.36 | -17.9 | 1.14±0.11 | 1.26±0.21 | +10.5 |
| 16 | Orzu | 3.58±0.19 | 3.03±0.20 | -15.4 | 1.41±0.24 | 1.22±0.10 | -13.5 | 1.12±0.13 | 1.25±0.17 | +11.6 |
| 17 | Tomaris | 3.68±0.23 | 3.62±0.21 | -1.6 | 2.56±0.10 | 2.07±0.28 | -19.1 | 1.51±0.23 | 1.89±0.16 | +25.2 |

(3.57 ± 0.10 mg/g and 3.54 ± 0.28 mg/g, respectively), with the lowest values coming from cultivars Amigo and Arleta (2.61 ± 0.07 mg/g and 2.72 ± 0.67 mg/g, respectively). In local cultivars under water deficit conditions, the highest index of chlorophyll "a" content resulted in the cultivar Tomaris (2.72 ± 0.67 mg/g), whereas the lowest indicator was from Orzu (3.03 ± 0.20 mg/g).

By determining the sensitivity of the soybean genotypes to water deficit conditions based on chlorophyll "a," strong sensitivity occurred in the exotic cultivars Arleta and Chara obtained from the Russian selection, the Eureka-357 genotype from the Kazakhstan selection, and the genotype Orzu of the local collection. Weak sensitivity to water deficit was noticeable in the exotic cultivars, Duar from the Russian selection, Nena from the Kazakhstan selection, and the local cultivars, viz., Ustoz MM-60 and Tomaris. More notably, local soybean cultivars showed less genotypic sensitivity to water deficit conditions versus exotic soybean cultivars. It might be due to resistance in local genotypes to unfavorable external environment factors.

The amount of chlorophyll "b" in the studied leaves of soybean cultivars during the blooming period under optimal supply revealed that exotic cultivars Selecta-302 and Selecta-301 have the highest values (1.08 ± 0.50 mg/g and 1.21 ± 0 .43 mg/g, respectively), while cultivars Chara and Eureka-357 had the lowest (1.03 ± 0.51 mg/g and 1.10 ± 0.24 mg/g, respectively). In the group of local cultivars, the Tomaris cultivar was recorded with the highest indicator (2.56 ± 0.10 mg/g), whereas the lowest was the cultivar Orzu (1.41 ± 0.24 mg/g). Additionally, during the blossoming period, the chlorophyll "b" content with optimal water supply was moderately higher in local soybean genotypes compared with exotics.

Under water deficit conditions, the chlorophyll "b" decreased in all studied genotypes. In exotic cultivars, the highest index of chlorophyll "b" content showed in the leaves of cultivar Selecta-302 (2.00 ± 0.10 mg/g); however, the lowest indices came from the cultivars Chara and Eureka-357 (1.03 ± 0.51 mg/g and 1.10 ± 0.24 mg/g, respectively). In soybean local cultivars, the highest index of chlorophyll "b" manifestation was by the cultivar Tomaris (2.07 ± 0.28 mg/g), and the lowest index was in cultivars Orzu and Sochilmas (1.22 ± 0.10 mg/g and 1.28 ± 0.32 mg/g, respectively).

By determining the sensitivity of studied genotypes to water deficit conditions in terms of chlorophyll "b," the strong sensitivity arose in genotypes Duar, Vilana, and Sparta obtained from the Russian selection, genotype Eureka-357 from Kazakhstan, and cultivar Sochilmas from the local collection. However, weak sensitivity to the water deficit regime emerged in cultivars Arleta and Sparta belonging to the Russian selection, cultivar Nena from Kazakhstan, and genotype Ustoz MM-60 from the local assortment.

The carotenoids' assessment in the leaves of soybean cultivars during the blooming period under optimal water supply indicated the highest value in cultivar Nena (1.82 ± 0.13 mg/g) and the lowest value in cultivar Amigo (1.03 ± 0.18 mg /g) in exotic cultivars. In local varieties, the highest value for carotenoids was in the cultivar Ustoz MM-60 (1.83 ± 0.11 mg/g), with the lowest in cultivars Orzu and Genetic-1 (1.12 ± 0.13 mg/g and 1.14 ± 0.11 mg/g, respectively).

The increased carotenoid content in soybean cultivar leaves was visible under water deficit conditions compared with the optimal water supply. Under water shortage conditions, the highest index of carotenoid content resulted in the exotic cultivars Selecta-201 and Vilana (1.89 ± 0.16 mg/g and 1.87 ± 0.17 mg/g, respectively); however, cultivars Amigo and Arleta gave the lowest indexes (1.21 ± 0.18 mg/g and 1.33 ± 0.18 mg/g, respectively). For soybean local cultivars, the highest carotenoid content emerged in the cultivar Baraka (2.04 ± 0.16 mg/g), whereas the lowest was in the cultivars Orzu and Genetic-1 (1.25 ± 0.17 mg/g and 1.26 ± 0.21 mg/g, respectively). A strong sensitivity surfaced in the exotic genotypes Selecta-301 and Selecta-201 from Russian selection, Eureka-357 from Kazakhstan, and cultivars Tomaris and Baraka from local selection in assessing the sensitivity of soybean genotypes to water deficit conditions in terms of carotenoid content. However, weak sensitivity to the water deficit regime emanated from the cultivars Chara, Arleta, and Selecta-302 under the Russian selection genotypes, cultivar Nena from Kazakh selection, and local genotypes Ustoz MM-60 and Sochilmas.

**Peroxidase enzyme activity in soybean plant leaves**

Peroxidase enzyme has exhibited to protect crop plants from various stress factors. In this study, the peroxidase enzyme activity evaluation in the local and exotic soybean cultivars' leaves ran under two different water regimes, i.e., optimal water supply and water deficit conditions (Figure 1). In soybean exotic cultivars with optimal water supply, the highest peroxidase enzyme value was in cultivar Selecta-301 (140.7 E/mg protein), and the lowest indicator was in cultivar Selecta-302 (77.89 E/mg protein). For soybean local cultivars, the highest peroxidase enzyme activity appeared in the cultivar Sochilmas (137.62 E/mg proteins), whereas the lowest activity in cultivars Genetic-1 and Ustoz MM-60 (121.07 E/mg proteins and 121.46 E/mg proteins, respectively). An enhanced peroxidase enzyme activity resulted in exotic and local soybean cultivar leaves under water deficit conditions compared with the optimal water supply. Under stress conditions, peroxidase enzyme activity was substantially higher in local genotypes Genetic-1 and Tomaris and exotic cultivar Selecta-301 than in other cultivars.

In this relevant study, a look at the activity of the catalase enzyme, one of the crucial enzymes for the plant's resistance to stress factors, also succeeded. Results disclosed that the catalase enzyme was more active under water deficit conditions than under optimal water supply (Figure 2). The catalase enzyme activity in the exotic and local soybean cultivar leaves has indicative influences from the moisture found in the plants during the period of gross ripening. Outcomes further revealed that the catalase enzyme was more active in local cultivars versus soybean cultivars belonging to Russian selection under drought conditions. It indicates that breeders have selected suitable local

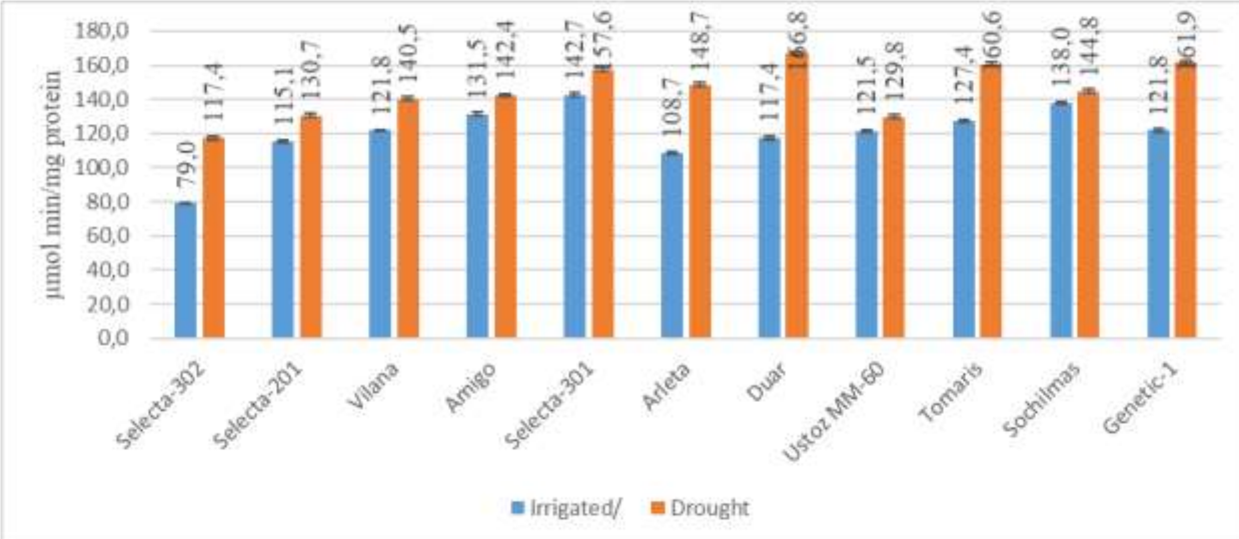


**Figure 1.** Activity of peroxidase enzyme in leaves of soybean cultivars under different water regimes.

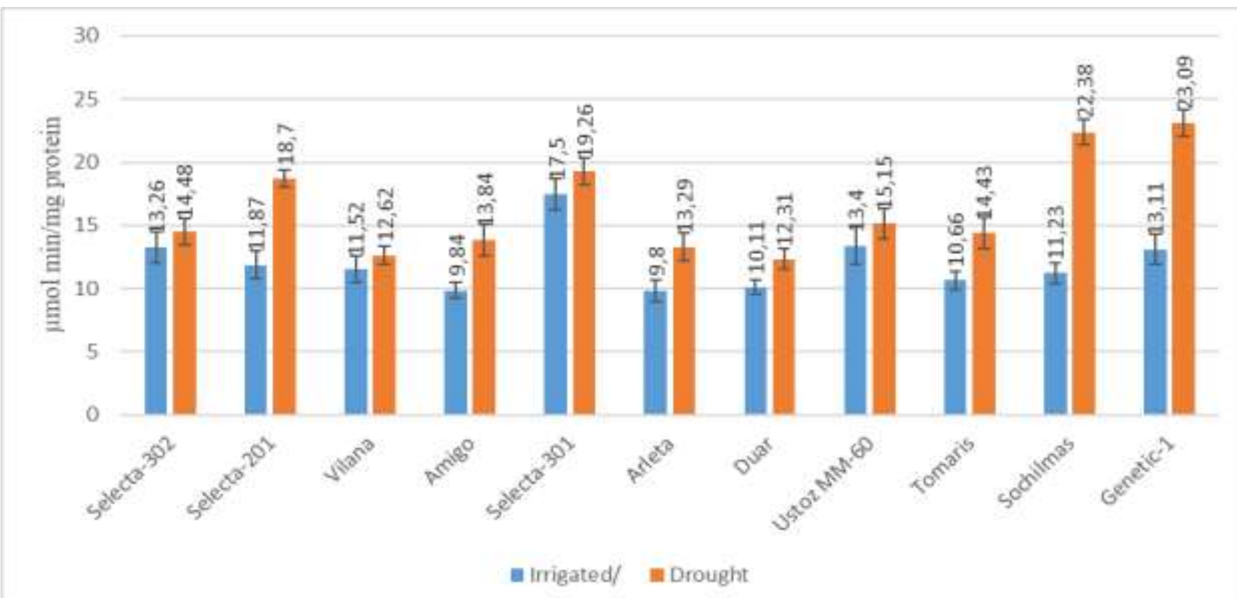


**Figure 2.** Activity of catalase enzyme in leaves of soybean cultivars under different water regimes.

cultivars for soil and climate conditions of Uzbekistan.

A study on the activity of superoxide dismutase enzyme in plant leaves shows in Figure 3. The amount of the superoxide dismutase enzyme ranged from 3.09 E/mg protein to 27.8 E/mg protein in exotic cultivars under optimal water supply. Similarly, in local soybean cultivars, the range was 6.45 E/mg protein to 27.19 E/mg protein. These results show soybean cultivars' varied sensitivity to water regime conditions (Figure 3). The superoxide dismutase enzyme actively increased in soybean cultivars Selecta-301, Tomaris, Ustoz MM-60, Genetic-1, and Sochilmas under water deficit conditions compared with the optimal water regime; however, in cultivars Selecta-302, Selecta-201,

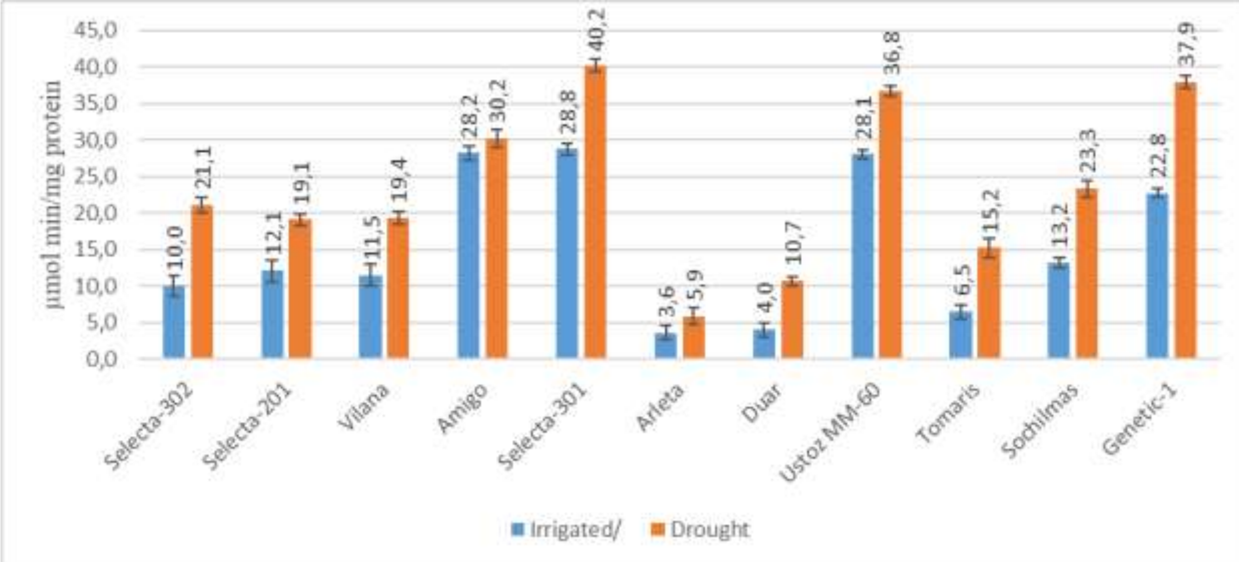


**Figure 3.** Superoxide dismutase enzyme activity in plant leaves under different water regimes.

Amigo, Duar, and Vilana with water deficit conditions, the activity of this enzyme decreased in varying degrees.

The enhanced activity of the superoxide dismutase enzyme might be due to the increased resistance of these cultivars to drought. Local cultivars Tomaris, Ustoz MM-60, Genetic-1, and Sochilmas and exotic cultivar Selecta-301 showed amplified activity of the superoxide dismutase enzyme, causing an intense protective function by breaking down various toxic substances that occur in plant cells due to drought.

Further studies on the oil content in the seeds of exotic and local soybean cultivars transpired (Table 2). According to the results, the oil content ranged from 16.7% ± 0.9 % to 26.7% ± 1.2% with optimal water supply. In local soybean cultivars, the highest oil content appeared in the seeds of cultivar Tomaris (26.0% ± 0.6%), whereas the lowest value for the said trait was in the cultivar Genetic-1 (16.7% ± 0.9%). In the soybean exotic cultivars with drought, the highest oil content emerged in the cultivar Nena (23.6% ± 0.3%) belonging to the Kazakhstan selection and cultivar Selecta-201 (24.0% ± 2.0%) from the Russian collection. A relatively low value with an optimal water regime was notable in the cultivar Arleta (18.7% ± 2.1%) (Table 2).

Under water deficit conditions, the varied values of oil content resulted in soybean local cultivars Tomaris (24.7% ± 1.7%), Sochilmas (22.0% ± 0.6%), Baraka (21.3% ± 2.3%), Ustoz MM-60 (19.0% ± 2.4%), Orzu (17.7% ± 2.7%), and Genetic-1 (15.7% ± 2.9%). According to the analysis of the coefficient of adaptation (Kmos [FC]) indicators, the seed oil content with water deficit conditions in soybean cultivars ranged from 4.3% to 18.1% in local cultivars and 1.3% to 22.8% in exotic cultivars compared with the optimal water regime.

**Economic characteristics**

The trait pods per plant is the most influential yield component assessed in soybean's various genotypes under different water regimes. With optimal water supply, the highest number of pods per plant emanated in exotic cultivars Arleta and Selecta-301 (292.6 ± 1.2 and 290.0 ± 1.9 units, respectively), whereas the lowest in genotype Sparta (97.3 ± 2.0 units) (Table 3). In local soybean cultivars, genotypes Tomaris and Baraka gave the highest number of pods per plant (319.0 ± 2.4 and 309.0 ± 4.4 units, respectively), with the lowest in cultivar Genetic-1 (80.3 ± 6 .9 units).

**Table 2.** Oil content in the grain of local and exotic soybean cultivars under different water conditions.

| No. | Cultivars | Irrigated | Δ | V% | Drought | Δ | V% | Кмос (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | Selecta-302 | 26.3±1.8 | 3.2 | 7.8 | 20.3±1.3 | 2.3 | 8.8 | -22.8 |
| 2 | Selecta-201 | 24.3±0.6 | 1.0 | 4.2 | 24.0±2.0 | 3.5 | 9.4 | -2.4 |
| 3 | Amigo | 26.7±1.2 | 2.1 | 7.8 | 21.7±1.9 | 3.2 | 8.8 | -18.7 |
| 4 | Selecta-301 | 22.6±1.4 | 2.5 | 10.3 | 22.3±1.7 | 2.9 | 12.7 | -1.3 |
| 5 | Arleta | 20.6±2.1 | 3.8 | 8.3 | 18.7±2.1 | 3.8 | 10.3 | -9.2 |
| 6 | Sparta | 22.7±1.7 | 3.1 | 9.5 | 22.0±1.0 | 1.7 | 7.9 | -3.1 |
| 7 | Duar | 24.7±0.7 | 1.2 | 4.7 | 22.3±0.9 | 1.5 | 6.8 | -9.7 |
| 8 | Vilana | 22.6±1.2 | 2.1 | 9.1 | 22.3±1.3 | 2.3 | 10.3 | -1.3 |
| 9 | Chara | 22.7±1.7 | 2.9 | 8.7 | 22.0±1.2 | 2.0 | 9.1 | -3.1 |
| 10 | Evrika-357 | 22.7±1.2 | 2.1 | 9.2 | 20.0±1.7 | 3.0 | 5.0 | -11.9 |
| 11 | Nena | 24.3±1.7 | 2.9 | 10.1 | 23.6±0.3 | 1.6 | 2.4 | -2.9 |
| 12 | Ustoz MM-60 | 22.3±1.5 | 2.5 | 6.2 | 19.0±1.0 | 1.7 | 9.1 | -14.8 |
| 13 | Baraka | 24.3±0.9 | 1.5 | 6.3 | 21.3±2.3 | 4.0 | 8.9 | -12.3 |
| 14 | Sochilmas | 23.0±0.6 | 1.0 | 4.5 | 22.0±0.6 | 1.0 | 4.3 | -4.3 |
| 15 | Genetic-1 | 16.7±0.9 | 1.5 | 9.2 | 15.7±2.9 | 5.0 | 11.2 | -6.0 |
| 16 | Orzu | 21.6±2.1 | 3.7 | 7.4 | 17.7±2.7 | 4.6 | 6.9 | -18.1 |
| 17 | Tomaris | 26.0±0.6 | 1.0 | 3.8 | 24.7±1.7 | 2.9 | 7.7 | -5.0 |

**Table 3.** Mean performance of local and exotic soybean cultivars for the number of pods per plant and 1000-grain weight under different water regimes.

| Cultivars | | Pods plant$^{-1}$ | | | 1000-grain weight (g) | | |
|---|---|---|---|---|---|---|---|
| | | Irrigated | Drought | Кмос (%) | Irrigated | Drought | Кмос (%) |
| 1 | Selecta-302 | 226.0±1.0 | 213.3±3.0 | -5.6 | 145.9±3.3 | 140.4±3.9 | -3.8 |
| 2 | Selecta-201 | 144.5±1.7 | 106.0±1.0 | -26.6 | 159.2±1.2 | 133.0±2.5 | -16.5 |
| 3 | Amigo | 180.2±5.5 | 74.3±3.4 | -58.8 | 141.8±5.6 | 135.1±1.1 | -4.7 |
| 4 | Selecta-301 | 290.0±1.9 | 136.0±0.9 | -53.1 | 164.7±2.5 | 136.5±3.4 | -17.1 |
| 5 | Arleta | 292.6±1.2 | 214.4±3.3 | -26.7 | 174.0±3.3 | 137.4±2.2 | -21.0 |
| 6 | Sparta | 97.3±2.0 | 56.7±3.9 | -41.7 | 134.1±4.9 | 96.9±5.1 | -27.7 |
| 7 | Duar | 190.6±2.9 | 156.2±2.7 | -18.0 | 130.7±4.6 | 100.7±3.6 | -23.0 |
| 8 | Vilana | 158.5±0.9 | 136.6±2.8 | -13.8 | 135.9±4.0 | 97.5±5.6 | -28.3 |
| 9 | Chara | 126.8±5.5 | 95.8±3.3 | -24.4 | 126.8±5.5 | 121.8±5.4 | -3.9 |
| 10 | Evrika-357 | 178.6±1.5 | 127.0±0.9 | -28.9 | 138.3±2.8 | 121.6±5.6 | -12.1 |
| 11 | Nena | 231.0±4.3 | 152.0±3.8 | -34.2 | 152.0±3.8 | 123.8±2.3 | -18.6 |
| 12 | Ustoz MM-60 | 244.3±4.2 | 88.7±1.7 | -63.7 | 164.8±5.3 | 154.9±2.9 | -6.0 |
| 13 | Baraka | 309.0±4.4 | 187.3±4.0 | -39.4 | 144.2±4.5 | 141.7±2.1 | -1.7 |
| 14 | Sochilmas | 114.5±1.5 | 99.3±1.5 | -13.2 | 131.2±4.2 | 114.4±1.1 | -12.8 |
| 15 | Genetic-1 | 80.3±4.9 | 73.4±0.3 | -8.6 | 138.3±3.3 | 126.9±4.0 | -8.2 |
| 16 | Orzu | 176.0±1.8 | 110.2±4.3 | -37.4 | 163.7±3.8 | 154.3±5.5 | -5.7 |
| 17 | Tomaris | 319.0±2.4 | 255.3±7.3 | -20.0 | 156.9±3.7 | 151.0±7.4 | -3.8 |

Under water deficit conditions, the number of pods per plant decreased to varying degrees in soybean cultivars. In exotic soybean cultivars, the highest number of pods per plant occurred in cultivar Arleta and Selecta-302 (214.4 ± 3.3 and 213.3 ± 3.0 units, respectively), while the lowest indicator was is in cultivar Sparta (56.7 ± 7, nine pieces). In local soybean cultivars, cultivar Tomaris again provided the highest number of pods per plant (255.3 ± 7.3 units), whereas the lowest indicator was in the cultivar Genetic-1 (73.4 ± 0.3 units).

The analysis of the coefficient of adaptation (FC) showed that the number of pods per plant decreased from 8.6% to 63.7% in the local soybean cultivars and from 5.6% to 58.8% in the exotic soybean cultivars under water deficit conditions versus the optimal water regime. For pods per plant, strong genotypic sensitivity to water deficit conditions was observable in the local cultivar Ustoz MM-60 and in exotic cultivars Amigo and Selecta-301. The least genotypic sensitivity recorded was in the local soybean cultivar Genetic-1 and exotic cultivar Selecta-302. However, other soybean cultivars showed average genotypic sensitivity to water deficit conditions for the variable.

On seed quality traits, 1000-seed weight is valuable in increasing soybean productivity, seed germination potential, and seed oil (Yuldashov *et al.,* 2021). With optimal water supply in exotic soybean cultivars, the highest 1000-seed weight surfaced in the cultivar Arleta (174.0 ± 3.3 g.), whereas the lowest was in the cultivar Chara (126.8 ± 5.5 g.) (Table 3). In local soybean cultivars, Ustoz MM-60 and Orzu (164.8 ± 5.3 and 163.7 ± 3.8 g, respectively) attained the highest 1000-seed weight, with cultivar Sochilmas as the lowest indicator (131.2 ± 4.2 g). Under water deficit conditions, all the genotypes showed a decreased 1000-grain weight compared with optimal water supply conditions. In the exotic cultivars, the highest 1000-grain weight resulted in cultivar Selecta-302 (140.4 ± 3.9 g), while the lowest in cultivars Sparta and Vilana (96.9 ± 5.1 and 97.5 ± 5.6 g, respectively).

The 1000-grain weight decreased from 1.7% to 12.8% in local soybean cultivars and from 3.8% to 28.3% in exotic soybean cultivars under water deficit conditions. For 1000-grain weight, a vast genotypic sensitivity to water deficit regime manifested in the local variety Sochilmas and genotype Sparta belonging to the Russian selection and cultivar Nena from Kazakhstan. The least genotypic susceptibility to water deficit emerged in the local soybean cultivar Baraka, Russian cultivar Selecta-302 and Chara, and genotype Eureka-357 from Kazakhstan selection. Other soybean cultivars provided an average genotypic sensitivity to water deficit conditions for the trait.

Studying the correlation between economic characteristics and physiological and biochemical attributes in crop plants is imperative. In optimal water supply, there was a sturdy positive correlation ($r$ = 0.85) between the chlorophyll "a" and chlorophyll "b," the chlorophyll "a" and total chlorophyll ($r$ = 0.95), and the chlorophyll "b" and total chlorophyll ($r$ = 0.83) (Table 4). In water deficit conditions, strong positive correlations were remarkable among the traits, i.e., chlorophyll "a" and chlorophyll "b" ($r$ = 0.93), total chlorophyll content and chlorophyll "b" ($r$ = 0.89), catalase enzyme and superoxide dismutase enzyme activity ($r$ = 0.69), and 1000-grain weight and the number of pods per plant ($r$ = 0.66) (Table 5).

**Table 4.** Correlation between economic and physiological-biochemical characteristics of soybean cultivars under optimal water supply.

| Traits | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | 0.63 ±0.15 | | | | | | |
| 3 | 0.07 ±0.24 | -0.31 ±0.29 | | | | | |
| 4 | 0.24 ±0.22 | -0.16 ±0.27 | 0.85 ±0.10 | | | | |
| 5 | -0.07 ±0.26 | -0.07 ±0.26 | -0.21 ±0.27 | -0.15 ±0.27 | | | |
| 6 | 0.31 ±0.21 | -0.08 ±0.26 | 0.36 ±0.20 | 0.53 ±0.17 | -0.08 ±0.26 | | |
| 7 | -0.06 ±0.26 | -0.28 ±0.28 | 0.11 ±0.24 | 0.01 ±0.25 | -0.08 ±0.26 | 0.51 ±0.17 | |
| 8 | 0.39 ±0.20 | 0.02 ±0.25 | 0.14 ±0.23 | 0.42 ±0.19 | -0.56 ±0.31 | 0.37 ±0.20 | -0.08 ±0.26 |

Note: 1- 1000-grain weight, 2- Number of pods per plant, 3- Chlorophyll "a" amount, 4- Chlorophyll "b" amount, 6- Peroxidase enzyme activity, 7- Catalase enzyme activity, 8- Superoxide dismutase enzyme activity

**Table 5.** Correlation between economic and physiological-biochemical characteristics of soybean cultivars under water deficit conditions.

| Traits | 1 | 2 | 3 | 4 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | 0.66 ±0.21 | | | | | | |
| 3 | -0.09 ±0.26 | 0.20 ±0.22 | | | | | |
| 4 | 0.01 ±0.25 | 0.07 ±0.24 | 0.93 ±0.07 | | | | |
| 6 | -0.30 ±0.29 | 0.08 ±0.04 | -0.42 ±0.30 | -0.40 ±0.30 | | | |
| 7 | 0.03 ±0.25 | -0.40 ±0.30 | -0.22 ±0.28 | -0.09 ±0.26 | 0.32 0.21 | | |
| 8 | 0.35 ±0.20 | -0.62 ±0.32 | -0.05 ±0.26 | 0.15 ±0.23 | 0.10 ±0.24 | 0.69 ±0.14 | |
| 9 | -0.17 ±0.27 | -0.20 ±0.27 | 0.20 ±0.22 | 0.22 ±0.22 | -0.19 ±0.27 | -0.27 ±0.28 | -0.09 ±0.26 |

Note: 1- 1000-grain weight, 2- Number of pods per plant, 3- Chlorophyll "a" amount, 4- Chlorophyll "b" amount, 6- Peroxidase enzyme activity, 7- Catalase enzyme activity, 8- Superoxide dismutase enzyme activity.

## DISCUSSION

Photosynthesis is the process by which plants convert light energy into chemical energy to produce organic products from inorganic substances, which serve as nutrients for plant growth and development (Simkin *et al.,* 2020). Thus, during water scarcity, plants' exposure to some degree of water stress ensues (Singh *et al*., 2016; Parkash and Singh, 2020; Ramazonov *et al.,* 2020). However, dehydration adversely affects crop plants' biochemical and physiological processes (Yuan *et al.,* 2015). These changes in biochemical and physiological processes affect the plant's photosynthetic activities and growth, resulting in reduced yield (Sharma *et al.,* 2012; Fayziev *et al.,* 2020).

Noteworthy were the varying plastid pigments in soybean cultivars' leaves, depending upon the biological characteristics of the cultivars and moisture availability. In the soybean cultivar leaves, chlorophyll "a" was higher than chlorophyll "b," indicating that the soybean plant is light-loving. In the experiments of Parida *et al*. (2007), the observed chlorophyll and carotenoid content in cotton genotypes decreased with low water supply, and the chlorophyll and carotenoid content again enhanced with re-irrigation.

The chlorophyll "b" in chloroplasts can be up to three times less than chlorophyll "a." Chlorophyll "b," like chlorophyll "a," absorbs rays from the sun and participates in photosynthesis (Meliev *et al.,* 2021; Kurbanbaev *et al.,* 2023). In addition to participating in the process of photosynthesis, chlorophylls "b" and "a" have a protective function against high temperatures and in receiving signals that regulate plant growth and development in the chloroplasts (Tyutereva *et al.,* 2017). It can be visible that the greater the amount of chlorophyll "b," the faster the growth and development in crop plants.

The presented research evaluated the activity of certain enzymes in the leaves during the blooming period of soybean cultivars under different water regime conditions. Enzymes that act as catalysts in chemical reactions also reduce a chemical reaction to activate energy and transfer it through a circuitous pathway with a low energy barrier. With abiotic stress conditions, the dynamic balance between the active forms of oxygen and the detoxifying enzymes broke. Peroxidase enzyme is also one of the constant stabilizers of equilibrium (Mohammadi and Kazemi, 2002).

The plants' growth under unfavorable environmental conditions primarily affects their biochemical state, which is reflected in changes in vital activity (Titov *et al.,* 2014). One of the most critical processes of cell damage at the biochemical level is lipid peroxidation (LPO) (Skorzynska-Polit, 2007). Catalase and peroxidase enzymes also take part in the breakdown of hydrogen peroxide and protect them against its toxic effects. The concentration of superoxide anion and hydrogen peroxide's reduction in the cell to a minimum level prevents them from reacting with the formation of hydroxyl anion (Hosseini *et al.,* 2007). Catalase enzyme is a chromoprotein, and its one molecule can break down 6 × 106 molecules of $H_2O_2$ in one second. The higher the amount of catalase enzyme in the cell, the less affinity it has for hydrogen peroxide.

It is a fact that superoxide dismutase belongs to the group of antioxidant enzymes. With catalase and other antioxidant enzymes, the plant protects the body from highly toxic oxygen radicals generated constantly. Superoxide dismutase catalyzes the splitting of superoxide into oxygen and hydrogen peroxide. Thus, it is vital in the antioxidant protection of almost all cells in contact with oxygen. Superoxide dismutase has the highest catalytic reaction rate; however, this reaction has limitations from the frequent collision of superoxide with the enzyme, causing superoxide dismutase to protect the cell from the harmful effects of superoxide (Hosseini *et al.,* 2007).

Past research has also emphasized that the amount of protein and fat in soybean seeds has influences from environmental and genetic variations (Choi *et al.,* 2021). The starch analysis results and the required amount of protein in soybeans depend upon different ecological factors (Jaynaqov *et al.,* 2022). The correlation between physiological-biochemical and economic traits revealed significant positive associations between them. Likewise, a strong positive correlation between economic indicators appeared under water deficit conditions.

## CONCLUSIONS

Under water deficit conditions, chlorophyll "a" and "b" in the leaves of soybean plants decreased from 0.3% to 29.6% and 5.5% to 30.7% during the blooming period. According to the analysis of chloroplast pigments in the leaves under water deficit conditions, cultivars Ustoz MM-60 and Tomaris recorded the highest values and showed less color change. Based on the magnitude of chloroplast pigments in plant leaves and the activities of peroxidase, catalase, and superoxide dismutase enzymes, local soybean cultivars Baraka and Tomaris and exotic cultivars Selecta-301 and Eureka-357 provided a less genotypic sensitivity to water deficit, recording as drought-resistant cultivars. Local cultivar Baraka and exotic cultivars Selecta-302, Evrika-357, and Chara revealed a less genotypic sensitivity to water deficit conditions based on 1000-grain weight.

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